Noosa Estuary Trial Oyster Reef Restoration

Final Monitoring Report

Prepared for: Noosa Council

Prepared by Ecological Service Professionals Pty Ltd on behalf of Noosa Biosphere Reserve Foundation

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Executive Summary

This report provides the final assessment of the trial oyster reef restoration program in Noosa Estuary, which ran from October 2017 to October 2020. The work was completed under Resource Allocation Authority (RAA) 2016CA0575 and Prescribed Tidal Works Approval number OPW17/0016 issued to Noosa Council on behalf of the project proponents.

- Permissions obtained included a Beneficial Reuse Permit, Resource Allocation Authority and Prescribed Tidal Works Approvals through the State and Local Government.
- Restoration structures were designed and deployed at a total of 14 sites around the estuary in November 2017 by the University of the Sunshine Coast (USC) generally in accordance with the approval.
- Restoration areas within the main river channel were deemed successful at providing suitable habitat for a variety of rock oysters to settle, with the greatest settlement occurring at reefs close to the mouth of the estuary and at sites along Weyba Creek.
- The restoration structures provided habitat for a variety of fish species as assessed by USC (Gilby et al. 2018; Gilby et al. 2019).
- Incidental damage from boat anchoring resulted in excessive damage and subsequent removal of 10 reefs from sites along the main river channel in early 2019, before the completion of the trials (Gilby et al. 2019).
- Reefs at the remaining 4 sites in Weyba Creek and Lake Weyba were monitored twice a year to the completion of the trial in September 2020 in accordance with approval requirements (ESP 2020 and this report).

Following the completion of the trial, the restoration units at sites 12, 13 and 16 were removed by hand because they did not meet the target of self-sustaining fish habitats as required by Condition 11 of the RAA. The restoration units at these sites had become buried and subsided in the unconsolidated sediment (sand and mud) as the coir mesh used to contain cultch had failed. All restoration units and signage have now been removed from the estuary and disposed of or recycled appropriately, except for the reef at Site 14, which we recommend should remain as part of the Fish Habitat Area because it satisfies Condition 11 of the RAA.

Due to the trial nature of this restoration initiative, we have identified several key learnings from the trial reef restoration and associated research, including information on the suitability of construction methods used for restoration, speed and amount of sediment smothering surfaces, successful placement of oyster cultch on the shore, natural recruitment rates, settlement and growth of oysters and other benthic organisms, and considerations for additional community engagement activities. Key learnings from the trial include:

- The need for improved design and construction of restoration units. The structures were constructed in accordance with the approved plans but could be improved using more robust construction methods as coir mesh only held the shell at a suitable vertical height for approximately 18 months. Locating the reefs over a consolidated sediment or bedrock would likely result in improved outcomes. Building up structures

gradually with sufficient material to allow for subsidence and reach consolidated channel material (i.e. historical shell and gravel beds) smothered by sand and mud may also result in improved outcomes. The trial structures were too small in vertical relief (<60 cm) when deployed to allow for subsidence and burial, except at Site 14 where they were shell was placed close to the bank and remains above the sediment surface.

- Shell cultch was not displaced outside of the RAA and generally moved less than 0.5 m from the original deployment point, even after degradation of the coir mesh. The bulk of the shell did not move from the deployment point as identified when removing the buried reefs.
- There are historical records of the removal of live oysters and cultch from the estuary and there is now limited availability of quality low relieve hard structure in the intertidal zone. The estuary is substrate limited with suitable recruitment to the restoration structures in each year of the trial throughout the lower estuary, particularly when the reefs remained within optimal recruitment zone (i.e. low to mid tidal height). Based on this result of the trial, the use of smaller reefs distributed throughout the estuary was not necessary to maximise recruitment of oysters, instead contributing to recruitment of fish and other mobile organisms.
- Installing and maintaining reefs at an appropriate height shore is key to maximising recruitment of rock oysters as identified through supplemental settlement plate experiments and the reduction in settlement density as trial reefs subsided over time.
- Smothering from mobile unconsolidated sediments was also major source of disturbance and decreased settlement of spat on horizontal surfaces of settlement plates and on shell cultch at several sites.
- While there was signage provided at each restoration site, sustained engagement with visitors during the restoration program is necessary to reduce the potential for incidental damage from boat strike. There may also be a place for suitable additional administrative controls including reducing boat speeds through additional administrative signage around the reef structures, as occurred in Weyba Creek. This would need to be balanced with community enjoyment and use of the Fish Habitat Area.

Based on the outcome of this trial, oyster reef restoration in Noosa Estuary has the potential to be an effective tool for restoring a mosaic of habitats in the estuarine seascape by creating conditions suitable for a range of habitat forming species to recover naturally (i.e. oyster reefs, seagrass) and potentially baffling wave action to prevent bank erosion, protecting mangroves and saltmarsh.

1 Introduction

This report has been prepared by Ecological Service Professionals (ESP) and Noosa Parks Association to address the requirements of a Prescribed Tidal Works Approval (number OPW17/0016) and Condition 9 of the Resource Allocation Authority (RAA) 2016CA0575 issued to Noosa Council to install 14 trial oyster reefs in the Noosa Estuary (the Project). The report was completed in accordance with the approved Noosa River Reef Restoration Plan prepared by Gilby et al. (2017), as required by condition 10 of the OPW concurrence agency response, and to demonstrate compliance with reef removal requirements.

Initial deployment of the trial oyster reefs occurred in 2017 and subsequent early monitoring, was completed by the University of the Sunshine Coast (USC) in accordance with the approved restoration plan (Gilby et al. 2017). ESP completed the final two years of monitoring events in accordance with the restoration plan where this was possible.

This report presents a summary of the results of the first two years of monitoring and the results of the final two monitoring events in May and September 2021, as well as an overall assessment of the success of the restoration program.

1.1 Overview of the Project

1.1.1 Project Aims

The aim of this restoration project was to restore the complexity of habitat in the estuarine seascape by bringing back the once prolific oyster reef habitat to the lower estuary. This trial deployment was completed to assess the feasibility of a larger-scale restoration programs in the estuary and to inform suitable deployment methods and assisted restoration techniques within the shallow estuary.

The intent of the restoration units was to provide a natural substrate that would hold oyster cultch together long enough for it to become consolidated into a reef habitat, and to allow removal of shell material if the restoration effort was deemed unsuccessful. The success of the restoration trial was based on a number of key performance indicators determined through the development application process and in general accordance with global best practice.

This report provides an overview of the results of monitoring completed in accordance with the Noosa River Oyster Reef Restoration Plan (Gilby et al. 2017) as approved by DAF 06 January 2017) and Condition 9 of the RAA (2016CA0575). The report also addresses Conditions 4 and 10 of the Concurrence Agency Response (SARA reference SDA-0117-036529) including suitable removal of the restoration units where they do not meet the performance objectives. Attachment 2 RAA required monitoring of four main components to be assessed over the 3 year deployment period, including:

- Measuring reef stability,
- Assessing natural recruitment processes,
- Assessing the impact of the reefs on community use and enjoyment of the fish habitat area, and

- Assessing the impact of the reefs on marine plants and coastal processes.

Condition 11 of the RAA states "Where a particular oyster reef restoration unit does not meet the performance objectives listed in Attachment 2 [of the RAA] and is not a viable self-sustaining oyster reef fish habitat at the completion of the 3 year trial period, the particular oyster reef restoration unit must be removed and disposed of appropriately outside of the declared Fish Habitat Area". This report outlines the outcome of monitoring assessments completed on the remaining 4 restoration areas, including removal of reef restoration units where these did not meet with Condition 11 of the RAA at the completion of the trial. Notification of the removal of 10 of the 14 restoration areas by USC was provided in an earlier report (Gilby et al. 2018).

1.1.2 Initial Reef Deployment

Sixteen sites were initially identified by USC as potential areas for oyster reef restoration throughout the lower Noosa River Estuary (which were approved through a Resource Allocation Authority issued by the Queensland Government and Prescribed Tidal Works Approval issued by Local Government); although restoration units were deployed at only 14 sites due to external constraints at two of the initial sites.

USC constructed reefs at 14 sites throughout the Noosa Estuary in November 2017 (Gilby et al. 2018). The location of all the initial trial sites is provided in Appendix B. Each reef area consisted of three stacks of three coir bags filled with oyster shell. The bags were stacked in a pyramid in accordance with approved plans. The reefs were monitored in accordance with the monitoring program key performance indicators (Gilby et al. 2017) as approved in Attachment 2 of the RAA.

2 Overview of Previous Monitoring Results

2.1 Monitoring Year 1 – Completed by USC

The first annual monitoring report covered the period November 2017 to November 2018 (Gilby et al. 2018). Ten of the 14 restoration areas in the main channel of the Noosa River were deemed to have met the Key Performance Indicators (KPIs) for natural recruitment processes as detailed in the approved oyster reef restoration plan by the USC team (Gilby et al 2018). The reef units allowed for substantial recruitment of oysters onto the bare shell, with up to 1101 ind.m^{-2} spat settling at some sites in the main river channel (spat settlement density ranged from 37 – 1101 ind.m^{-2}). However, the restoration units were damaged by boats over the summer of 2018–19 resulting in significant damage to reef restoration units that were beyond repair (Gilby et al. 2019) and removed by USC in accordance with the conditions in the approval.

In February 2019, it was decided that 10 of the 14 reefs initially deployed should be removed, due to substantial incidental damage from boat strike and other damage (all reefs removed were from within the main Noosa River channel) (Gilby et al. 2019). An example of the damage caused to reefs at Site 10 is provided in Figure 1. As identified in the report, the restoration units were removed, and all shell and coir mesh disposed of at the Noosa Council waste disposal site in accordance with State Permitting and Approval requirements (refer to Section 4). Pre- and post-deployment photos, as well as pre- and post-removal photos are provided in Appendix A.

Figure 1 Example of damage caused by a boat at Site 10 in January 2019 (reef now removed)

Restoration areas remained at Sites 12, 13, 14 and 16 in Weyba Creek and Lake Weyba, which were monitored through to the completion of the trial in October 2020.

2.2 Monitoring Year 2 – Completed by ESP

Based on assessments completed at the end of the second spat settlement season in May 2019 and start of the third spat settlement season in October 2019 (ESP 2020a), the performance objectives of the RAA were being met for the four oyster reef restoration sites that remained (i.e. sites 12, 13, 14 and 16 in Weyba Creek and Lake Weyba). All signage at sites (sites 2 to 11) that had been decommissioned earlier by USC along the Noosa River was removed using the licensed contractor (ESP 2020b; Appendix A).

Each of the reefs remained within the RAA and did not move substantially, except for some scattered shell that expanded the footprint of each patch. The coir mesh used for holding shell within the restoration units had degraded within 1.5 to 2 years of deployment, to the point it was no longer possible to repair the bags by hand. The shell on the surface has remained largely in the same location despite the bags spilling shell (i.e. moved less than 1m from the original deployment location), although the degradation of the coir mesh results in a loss of the vertical height gained by stacking shell filled bags, with insufficient time for the shell to bind together prior to the bags degrading. Excess coir mesh was removed from sites where necessary at the time of monitoring. The restoration units met Performance Objective 1 in the approved monitoring schedule in the RAA.

Despite the collapse of the restoration bags, there was still good recruitment of oysters to the restoration units, demonstrating that the Noosa River Estuary is a suitable location for oyster reef restoration and that the estuary is substrate limited. In May 2019, the average density of oysters ranged from 192 to 367 ind.m^{-2}, and was relatively consistent among the 4 sites, with the lowest settlement at Site 16 in Lake Weyba. In October 2019, the average density of oysters ranged from 197 to 443 ind.m^{-2}, with the highest settlement occurring at Site 13 in Weyba Creek. The consistently high settlement rates demonstrates that the estuary is currently substrate limited and there is good potential for oysters to recruit to shell culch where it can be stabilised, remain at a suitable height on the shore, and not become covered by unconsolidated sand and mud. These results met the Performance Objective 2.1 and 2.2 for settlement of oysters. There was insufficient time for a biogenic matrix to form; however, there were several clumps of shell held together by recently settled oysters, sponges and macroalgae indicating a general positive trend towards a suitable biogenic matrix (Performance Objective 2.3).

The presence of the oyster reef structures, and potentially administrative signage (i.e. yellow and black “Underwater Obstruction”) may have indirect consequences including reducing potential impacts of boats on seagrass, and stabilising sediments that would otherwise not be suitable to seagrass recruitment in Weyba Creek allowing seagrass to recruit and grow in areas where it previously was not. The subtidal sections of restoration units also had a high coverage of macroalgae, including *Padina*, *Laurencia* and *Acetabularia* species. This unintended positive consequence of the reef deployment highlights the potential for oyster reef restoration to provide a mosaic of important fish habitat types. There was no negative impact on marine plants meeting Performance Objective 4.

We note also during the trial that several “6 knot” speed signs were installed throughout the Weyba Creek reach, including opposite the restoration areas at Sites 12, 13 and 14, which likely further reduced potential for boat strike in this area that caused damage to reefs in the main river channel.

3 Description of the Final Year of Monitoring

3.1 Methodology

The final two years of monitoring of the remaining four oyster restoration areas was completed in May and October 2019 (ESP 2020a), and on 8 May and 8 and 18 September 2020, by ESP scientists, to comply with the requirements of Condition 9 of the RAA approval and Condition 10 of the OPW and generally in accordance with Section 12 of the approved Oyster Reef Restoration Plan (Gilby et al. 2017; Attachment 2 of the RAA).

Table 1 Centre position of the four remaining restoration sites monitored in 2019 and 2020

Site	Easting*	Northing
Site 12	507681.973	7079962.501
Site 13	507106.028	7078792.976
Site 14	507093.310	7078704.485
Site 16	506201.831	7075593.654

*Datum: GDA 94 Zone 56

Figure 2 Trial oyster restoration sites assessed in 2019 and 2020

Monitoring was completed generally in accordance with monitoring outlined in the oyster reef restoration plan (Gilby et al. 2017) as approved by the Queensland Department of Agriculture and Fisheries (DAF) Condition 9 and Attachment 2 of the RAA approval and endorsed by Condition 10 of the OPW approval, with the following exceptions:

1) To achieve the same outcome intended by the monitoring method specified in RAA Attachment A item 1 of plan, the location of each patch reef was measured relative to a fixed known point (signpost) using a direction and distance along a tape measure on each occasion (with centimetre accuracy) and with handheld GPS unit, to determine if the reef patches had moved.
2) To achieve the same outcome intended by the monitoring method specified in RAA Attachment A item 2(3), an additional 5 replicate oyster shells were assessed for settlement in each patch reef (i.e. 10 replicate shells per patch – 30 shells per restoration area) to increase the accuracy of the measure of oyster settlement density. The average density was corrected to individuals per m^2 based on the surface area of each shell assessed.
3) To achieve the same outcome intended by the monitoring method specified in RAA Attachment A item 2(2), the presence of additional sessile invertebrates was assessed on each shell rather than specifically on the outside of coir mesh bags as it was not possible to get suitable underwater photo-quadrats due to the reduced height of shell and shallow depth of water. Foliose macroalgae was recorded growing on coir mesh and oyster shell at most sites.
4) To complement the outcome intended by the monitoring method specified in RAA Attachment A item 2(1): Settlement plates were deployed in December 2019 and removed in May 2020 as part of a complementary study to assess oyster settlement and genetic identification at two of the four restoration sites (sites 12 and 13) (McDougall & Walker 2020).

3.2 Overview of Results

The trial restoration units generally met the key performance indicators for several monitoring periods post deployment; however, during the last monitoring period, the restoration units at 3 of the 4 sites (sites 12, 13 and 16) had settled into the sediment and were largely below the sediment surface (Figure 3). Only a scattering of shell was present on the surface at those sites.

Figure 3 Oyster reef and wooden stakes at Site 12 in September 2020

The reef areas remained within the RAA and moved less than 1 m within the 3 year trial period. Without the coir mesh the reefs collapsed; however, there were insufficient tidal currents or freshwater flow to shift the shell outside the RAA.

The restoration area at Site 14 was nestled between existing seagrass beds, which had grown up next to the restoration units. The reefs at this site remained elevated above the sediment surface, although no longer intertidal (within the optimal zone of highest spatfall). They represented a good aggregation of shell cultch with oyster spat and macroalgae growing on it. With additional time, these shell aggregations are expected to consolidate further and become a functional habitat type within the existing seagrass beds, contributing to the mosaic of habitats found there (Figure 4). The growth of marine plants around the oyster reefs further reduced accumulation of fine sediment on the shell cultch, but did not prevent it from sinking into the sand until it reached an underlying gravel layer below.

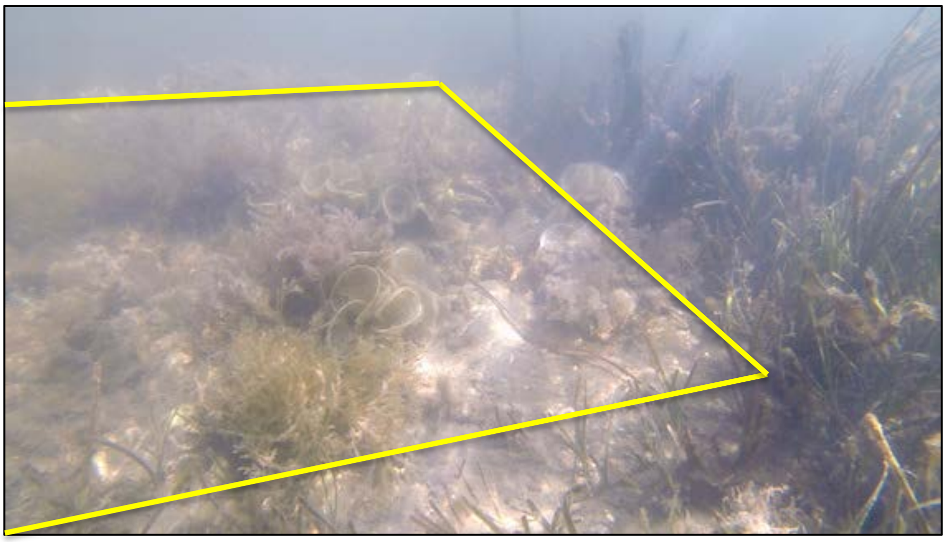


Figure 4 Oyster shell patches covered by macroalgae (*Padina* and *Laurencia*) at Site 14 showing proximity to seagrass in 2020*

* yellow lines indicate the outline of one of the three patches of oyster reef restoration units

3.3 Assessment Against Approved Monitoring Performance Objectives

A summary of the results of the final monitoring event, and the Project as a whole, against the performance objectives is provided in Table 2, with detailed responses in the subsequent sections.

Due to the trial nature of this program, we have added additional responses including design considerations and additional knowledge gained where reefs failed to meet the specific targets for each of the performance objectives to inform future restoration initiatives.

Table 2 Summary of assessment against restoration Performance Objectives

Performance Objective	Monitoring Outcome	Emerging Issues / Design Considerations	Knowledge Gained
1. Oyster Restoration Unit Location Stability (Refer to Section 3.4 below for further details)			
Oyster Restoration Units Remain within the Resource Allocation Area	**Achieved at all sites -** All oyster reef patches remained within their respective RAA, although some shell has moved up to 0.5 m from the original location following degradation of the Coir Mesh bags. In September 2020, the remaining four restoration areas were assessed. The restoration units (coir bags) had lost rigidity and coir mesh had degraded over the surface allowing shell to spill from bags at several sites. All shell remains within the RAA; however, the shell piles had settled almost entirely below the surrounding unconsolidated sediment or had been covered by fine silt and sand.	Boat damage resulting in removal of restoration structures at 10 sites after second spawning season. Boat damage was not observed at the remaining reefs, which were outside of the main hire boat navigation area. Considerations: • location relative to boat traffic requirements • how the community and visitors are informed of the project including signage requirements • scale of the restored areas - larger scale restoration areas are less likely to be impacted due to visibility and edge effects	Additional and ongoing community engagement and education required to reduce the frequency of boat damage. Including flyer for tourists, provision of additional information signage at key boat ramps and other communications through local media. Consideration of the wording on signage may reduce incidental damage. In our opinion the use of the term "fishing permitted" was not necessary, as it may have indicated to tourists that the restoration areas were suitable for fishing and contributed to increased incidental anchoring and vessel damage. Consideration of future signage to simply state that the area is a restoration area completed under suitable approvals and to provide contact details for questions/complaints would be sufficient.

Performance Objective	Monitoring Outcome	Emerging Issues / Design Considerations	Knowledge Gained
2. Natural Recruitment Processes (Refer to Section 3.5 below for further details)			
Oysters and other sessile benthic invertebrates recruit to reef restoration units to establish a biogenic matrix, which binds oyster shells in place prior to degradation of coir material	**Achieved at all sites:** Average density of oysters (oysters/m^2) across all sites remained consistent over monitoring period due to naturally low settlement in winter months, increasing in spring and summer months. In September 2020, several small rock oysters were present at Site 14 indicating a recent recruitment event; however, no settlement was recorded where restoration structures and shell cultch had become buried in the sand. The coir mesh used to create deployable restoration units degraded within 18 months of deployment to the point where it was no longer possible to repair by hand. This prolonged the period to create a biogenic matrix.	The restoration units at most sites had either been completely buried in sand or damaged so much that they could not be re-established without a complete redeployment. Seek alternatives for deployment including whether there is a need for structures to be built out of mesh, given that none of the shell moved outside of the RAA within the trial period even after the mesh had degraded. Alternatively seek to build up a firm base below the reefs using a suitable material such as gravel or shell cultch until a sufficient height on the shore is achieved.	Settlement and growth continued on oyster shell that were not buried by sand – clear evidence that the estuary is substrate limited and where a suitable reef base can be deployed, there would be natural settlement of oysters. Some consolidation of shell and clumping largely due to other sessile invertebrates such as sponges and ascidians (sea squirts). This was particularly evident at sites 13 and 14 in Weyba Creek. The trial reef at Site 14 remains above the sediment surface (although had collapsed into a shell pile on the sediment surface) assisted by the growth of seagrass surrounding the shell piles reducing excess fine sediment. Settlement of juvenile oysters continued at this site due shell remaining unburied and at a suitable height on the shore.
2.1. Oyster recruitment: Successful recruitment of oyster spat in at least 1	**Achieved at all sites:** The density of oysters recruiting to the restoration structures varied	Reduction in the vertical height of restoration units (reefs remain submerged at low tide) due to	Reef structures to be deployed at a suitable height on the shore to maximise oyster recruitment with potential to

Performance Objective		Monitoring Outcome	Emerging Issues / Design Considerations	Knowledge Gained
	out of 3 years (i.e. 33% of the time) post deployment (following international best practice of 40% Baggett et al 2015)	spatially depending on the degree of burial by surrounding sand, although has increased over time. The maximum average density of rock oyster recruits across all sites was 187 oysters/m^2 in May 2020, and 246 oysters/m^2 in September 2020. The maximum density of oysters recorded in the first year of deployment was 1101 oysters/m^2 at site 8 in the main Noosa River Channel (Gilby et al. 2018).	settling into the underlying sediment may have reduce the density of oysters recruiting to the reefs, due to smothering from surrounding sediment and potentially increased predation.	supplement cultch to keep reefs at a suitable vertical height (i.e. mid to lower intertidal). Where possible, use natural cues from the surrounding environment or surveyed heights to determine suitable height on the shore prior to and during deployment.
2.2.	Cover of oysters and other sessile benthic invertebrates: an upward trend in the coverage of sessile benthic invertebrates growing on the restoration units; and	**Partially Achieved:** There was recruitment of encrusting sponges on many of the shells, which in some cases had consolidated shell into larger clumps (refer to Figure 17). Macroalgae dominated several of the oyster restoration units, particularly once the units had settled in to the sediment and lost vertical height (i.e. were below the optimal height for oyster spat settlement as identified using settlement plates).	A more substantial engineered structure is needed to elevate oysters above the existing unconsolidated sediment for an extended time (>3 years) and prevent becoming buried in sediment. The coir mesh bags holding the oyster cultch together failed within 18 months, resulting in mounds of shell that more easily settled into the sediment below. To improve reef establishment we suggest avoiding unconsolidated sediment or deploying shell culch in	The length of time for reef consolidation in Noosa Estuary is prolonged (greater than 3 years), and beyond the length of this trial phase for reefs to reach their full potential. Our understanding of remnant reef structure and function is increasing however, it may take more than 10 years to develop a suitable shell aggregation that covers the restoration structures (Fitzsimons et al. 2019). Deployment in or adjacent to seagrass beds may improve the success of oyster reefs, due to baffling of fine sediment, which may improve suitability for oyster

Performance Objective	Monitoring Outcome	Emerging Issues / Design Considerations	Knowledge Gained
	There was an upward trend in coverage of oysters and other sessile invertebrates within the first two years of deployment	an area such as a gravel or rock base or deploying a more suitable based substrate (gravel/rock) on unconsolidated sediment and topping with shell cultch.	settlement by reducing smothering by fine sediment.
2.3. Establishment of stable biogenic matrix – i.e. structural rigidity of oyster restoration units, denoting a stable biogenic matrix after 3 years post deployment, which is sufficient to hold oyster shells in place	**Partially Achieved:** Oyster restoration units did not move outside the RAA area within the trial period. Some smaller shell cultch clumps had become consolidated with shells being bound together by settled rock oysters and sponges, although in September 2020 the majority of shell remained unconsolidated approximately 3 years post-deployment particularly where it had been buried in fine sand. This points to a failure of the coir mesh to sufficiently hold shell until natural processes can consolidate the reefs Deposition of fine sediment on reefs accelerates the burial of the restoration units and prevents settlement of oysters. There is a need to deploy over consolidated sediment, supplement	The type of coir mesh bags used in this trial are unlikely to provide a suitable or stable way of holding shell together for a long enough period to become a stable biogenic matrix. The breakdown of the reef height following the rapid degradation of coir mesh bags likely delayed the development of a biogenic matrix that was dominated by oysters. To maximise oyster recruitment and densities (i.e. remain within the lower intertidal zone), design improvements are required that would allow shell cultch (suitable settlement surface) to remain at a suitable height on the shore. At site 14 the shell had been partially buried, although had reached a firm base (gravel and shell) below muddy sand prior to becoming completely buried.	Degradation of coir mesh results in collapse of the unconsolidated shell and a reduction in the relative height above the sediment surface. Height should be suitable to maximise natural recruitment of intertidal rock oysters. While additional shell cultch was not added, supplementing shell cultch until a stable height on the shore is reached could be one way of maintaining a suitable shore height. Assess potential for alternative deployment method to elevate shell above the existing substrate and prevent slumping, including selection of sites based on underlying substrate where possible to do so (noting that in many cases suitable substrate has been physically removed from the estuary) Notably, the reefs at Site 14 remain above the sediment surface. Reefs at this site were deployed adjacent to seagrass,

Performance Objective	Monitoring Outcome	Emerging Issues / Design Considerations	Knowledge Gained
	shell over a prolonged period or build up a sufficient firm base prior to deployment where this has been removed historically. There was a high coverage of macroalgae on the remaining reefs at Sites 13, 14 and 16 until the reef restoration units at sites 13 and 16 had become buried in the sand. All shell was easily removable once it had become buried under the sand, while approximately 30 to 50% of shell had been bound together at site 14 (refer to Figure 17). The reefs present at site 14 represent a stable substrate of shell cultch upon which a variety of sessile invertebrates and macroalgae growing on the surface (Figure 4). There was little movement of the location of shell relative to the original deployment location.		and have resulted in consolidation of the soft mud below the shell matrix.

Performance Objective	Monitoring Outcome	Emerging Issues / Design Considerations	Knowledge Gained
3. Community use and enjoyment of the declared Fish Habitat Area (Refer to Section 3.6 below for further details)			
Oyster restoration units do not significantly impair the community use and enjoyment of the declared Fish Habitat Area, particularly fishing activity.	Further detail to be provided by Council. No observed detrimental impact on fisheries or enjoyment of Fish Habitat Area. We are not aware of any complaints to that effect in 2019 or 2020. Complaints of boat strike received from the community due to hire boats anchoring and fishing on reefs in 2018 and early 2019. Ten out of the 14 reefs were damaged by boat strike beyond repair. These sites were all along the edge of the main Noosa River channel. An investigation was completed into the damage of restoration units. Due to substantial damage, it was decided to remove reefs at 10 sites throughout the main boating channel of the Noosa River in 2019. To our knowledge no complaints about the installation or removal of the reefs were received.	To meet corrective action, restoration units damaged due to boat strikes were removed by USC and habitat remediated back to pre-deployment condition (Figure 1). All signage was removed from the sites (ESP 2020b). There was no impact to the receiving environment during removal of buried reefs or signage. All removal of restoration units at sites 12, 13 and 16 was done by hand and the shell has been placed at a suitable shell recycling facility. Sediment profiles were restored by sieving the sand off shell and raking carefully through the sediment once shell had been removed (refer to Section 4 below) Increasing the size of reefs would increase visibility to skippers.	Suitable dissemination of information to non-locals including ongoing campaign to educate public on the outcomes of the project and engage them in looking after the Noosa River beyond signage at the site. Reefs outside of the area of operation for hire vessels have remained intact without impact from boat strike. Providing administrative mechanisms of protection of restoration structures may yield optimal restoration outcomes; however, these need to be balanced with other ecological considerations such as suitable accommodation space, presence of remnant reefs and evidence of historical reefs in the area and the need to provide public access to restoration sites. Reducing vessel speed limits may be a viable and effective way to prevent or reduce damage from vessel strike as all reefs in Weyba Creek are within an area with a 6-knot speed limit.

Performance Objective	Monitoring Outcome	Emerging Issues / Design Considerations	Knowledge Gained
4. Other Potential Effects (Refer to Section 3.7)			
Oyster reefs do not have a detrimental impact on the extent of marine plants within 50m radius of the restoration units and are not attributed to erosion of the shoreline or other ambient impacts	There is no evidence of a detrimental impact on the shoreline as a result of the placement of units. Some minor build-up of sediment has occurred around the reefs as they have settled due to the unconsolidated sediments at most sites. There has been recruitment and growth of seagrass observed, particularly around the reefs at Site 13 with recent recruitment of *Halophila ovalis*, a pioneer seagrass species, around each of the restoration units. Existing seagrass beds (*Zostera muelleri subsp. capricorni*) have grown around the restoration units at Site 14.	Oyster reefs may have a positive impact on the extent of marine plants within proximity. Further assessment of the synergies between oyster reef restoration and improvements in other biogenic habitat needs further assessment	Oyster reefs are known to provide good shoreline protection which may enhance the incidental restoration of marine plants. The coverage of seagrass increased on bare sediment between restoration units (as was observed at sites 13 & 14 while reefs were above the sediment surface). Oyster reef restoration units may therefore be an effective tool for restoring a mosaic of habitats in estuarine seascape by creating ambient conditions suitable for a range of habitat forming species to recover naturally (i.e. oysters and seagrass), as well as potential to support coastlines for mangroves and saltmarsh.

3.4 Performance Objective 1: Oyster Reef Stability

The position of each of the four corners of the reef were measured relative to the known position of the signpost using a measuring tape, to provide centimetre accuracy. The position of each corner was then mapped in ESRI ArcGIS and any change in the location relative to the original survey was assessed.

3.4.1 Site 12

In September 2020, the restoration units had largely settled into the unconsolidated sandy substrate below. The reefs did not move substantially from their original deployment position as indicated by the position of wooden stakes and distance from the signpost. In September 2020 the oyster shell had moved less than a 0.5 m radius from the original position and remained within the RAA which was identified by probing the sediment with a Kevlar probe. Fine sediment buried much of the remaining shell at this site, and they have lost vertical height due to the collapse of the top bag, lack of consolidation among the shell and settling into the unconsolidated sediment below. Due to the almost complete burial of reefs (Figure 5), they were removed by hand and the site was remediated back to the pre-deployment condition. Subsequent monitoring of the area after reef removal has demonstrated no ongoing influence of the reefs or removal. All signage was removed by hand (Refer to Section 4).

OUTCOME: Restoration units have been removed from Site 12 and the area rehabilitated – refer to photos pre- and post-removal provided in Appendix A.

Figure 5 Restoration patch subsided under sediment at Site 12 in September 2020

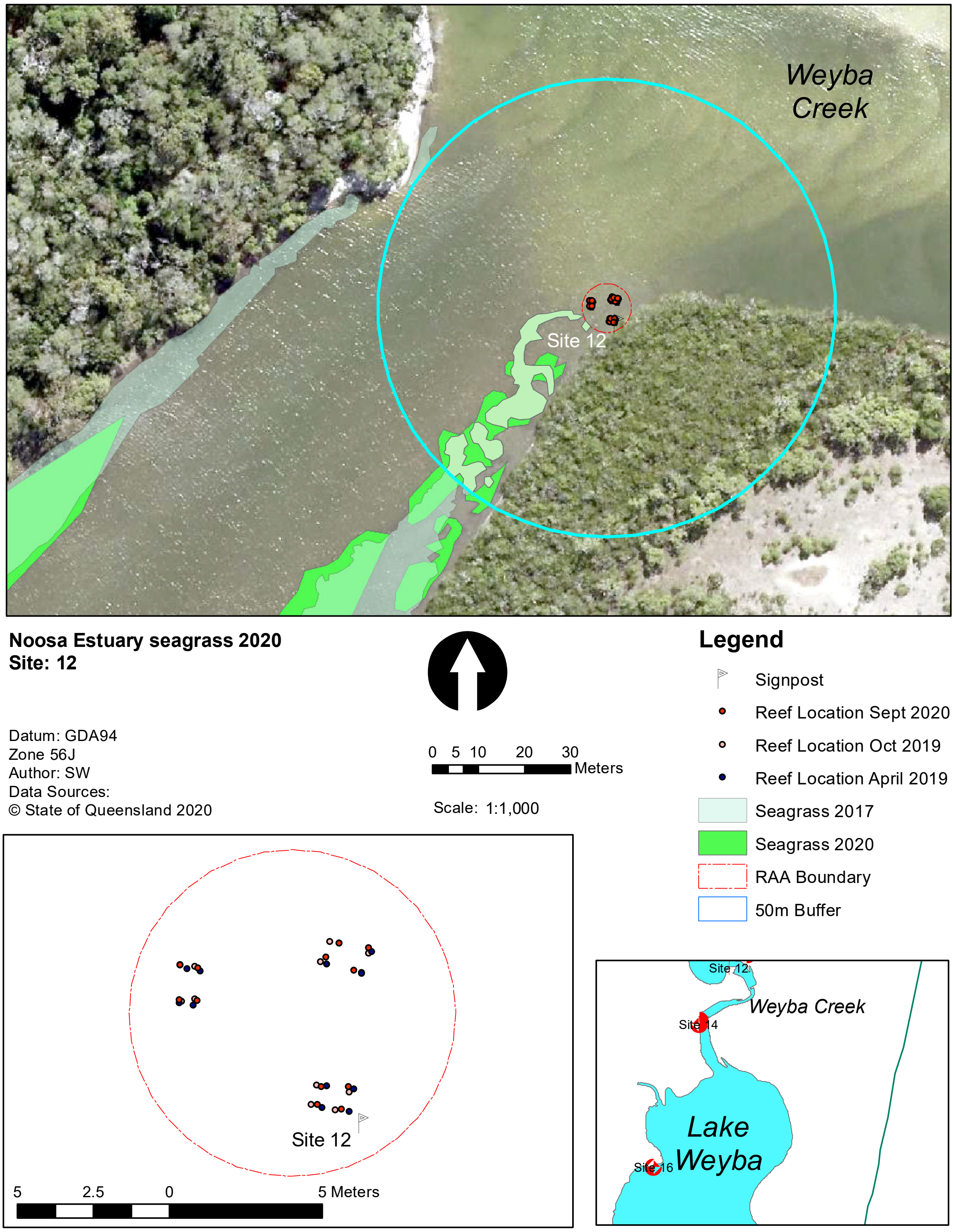


Figure 6 Location of restoration structures at Site 12 in relation to the RAA boundary and seagrass mapped in the area in November 2020

3.4.2 Site 13

Despite the breakdown of the coir mesh, shell at this site did not move more than 0.5 m from the original deployment position and all shell remained within the RAA area. Restoration units had lost substantial vertical relief over the deployment period from approximately 40 cm above the sediment surface in 2018, following deployment to approximately 10 to 15 cm above the surrounding substrate surface in October 2019 and almost complete burial of all shell patches in September 2020. In September 2020, the scattered oyster shell had moved less than 0.5 m from the original position to the north west, due to predominant surface wave motion (Figure 3). There were scattered shell over the surface of the sediment, but these were generally no longer at a suitable height on the shore to allow for substantial spatfall (i.e. shell remained subtidal with a high coverage of macroalgae).

Relative to previous periods of spatfall, when sufficient vertical relief remained, in May 2020 there was only 129 oysters.m^{-2}, and in September the density had dropped to only 9 oysters.m^{-2}, with most shell buried or scoured by unconsolidated sand. The extent of vertical burial was determined when removing oysters from the site, with most of the coir bags and shell buried 20-30 cm below the surface. In October 2020, there was some sparse seagrass (*Halophila ovalis*) present at the site between the three restoration units, however the coverage was sparser than in 2019 (Refer to Section 3.7; Figure 20).

As the reefs had been almost completely buried in September 2020, the shell patches were removed by hand and the area remediated back to the pre-deployment condition (Figure 22). Subsequent visual assessment of the area after reef removal has demonstrated no ongoing influence of the reefs or removal of the restoration units or signage (Refer to Section 4).

Figure 7 Oyster reef restoration area at Site 13

Figure 8 Oyster reef covered with macroalgae at Site 13 in September 2020

OUTCOME: Restoration units have been removed from Site 13 and the area rehabilitated – refer to photos pre- and post-removal provided in Appendix A.

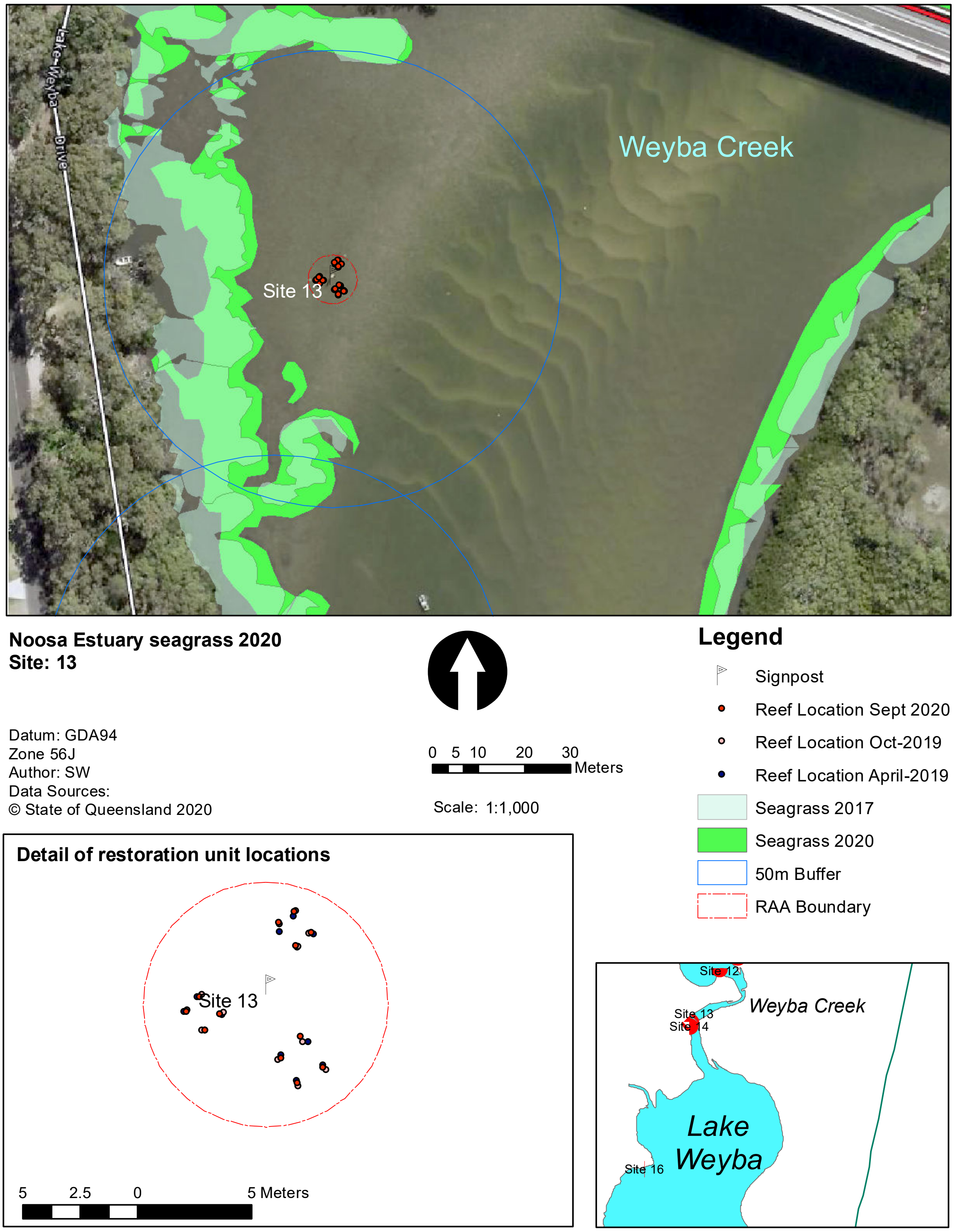


Figure 9 Location of restoration structures at Site 13 in relation to the RAA boundary and seagrass mapped in the area in November 2020

3.4.3 Site 14

The remaining shell from the restoration units had largely been consolidated by foliose macroalgae and sponges (Figure 4). In October 2020, the restoration units at this site were surrounded by established seagrass beds (dense beds of long blade *Zostera muelleri subsp. capricorni*) (Figure 4), which had increased in extent since deployment, particularly infilling over bare sediment up to the edge of each restoration unit (Figure 11; refer to Section 3.7 Table 3). Numerous juvenile fish were observed using the reef restoration units and moving between them and the surrounding seagrass in both May and September 2020.

The reefs at this site remain relatively intact although have lost approximately 20 cm of vertical relief. In our opinion they currently represent the beginnings of small oyster reef patch. The reef is similar in morphology to remnant reefs found elsewhere in Southeast Queensland, including the leaf oyster reef downstream of this area, where there is an aggregation of small oysters, other invertebrates and macroalgae growing on layer of shell cultch over the sediment surface (Figure 4). These restoration areas have met several of the objectives of the trial and therefore we believe they should remain as part of the natural fish habitat available in the estuary and all associated signage removed.

There has been considerable consolidation of the underlying sediment within the restoration area at Site 14 relative to other sites deployed over bare sediment. The seagrass surrounding the restoration area may have baffled wind borne wave action sufficiently to baffle the build-up of fine sediment. The sediment below these reef structures was also substantially more compact than at the other sites, which may be due to reduced wave action or shallow depth of sediment to underlying gravel and bedrock which is exposed further upstream. It appears that there were unexpected positive outcomes for both oyster reef and seagrass habitat, which have remained intact or increased in extent during the trial period.

OUTCOME: Reefs remain at this site. Signage still to be removed.

Figure 10 Oyster restoration Site 14 in September 2020

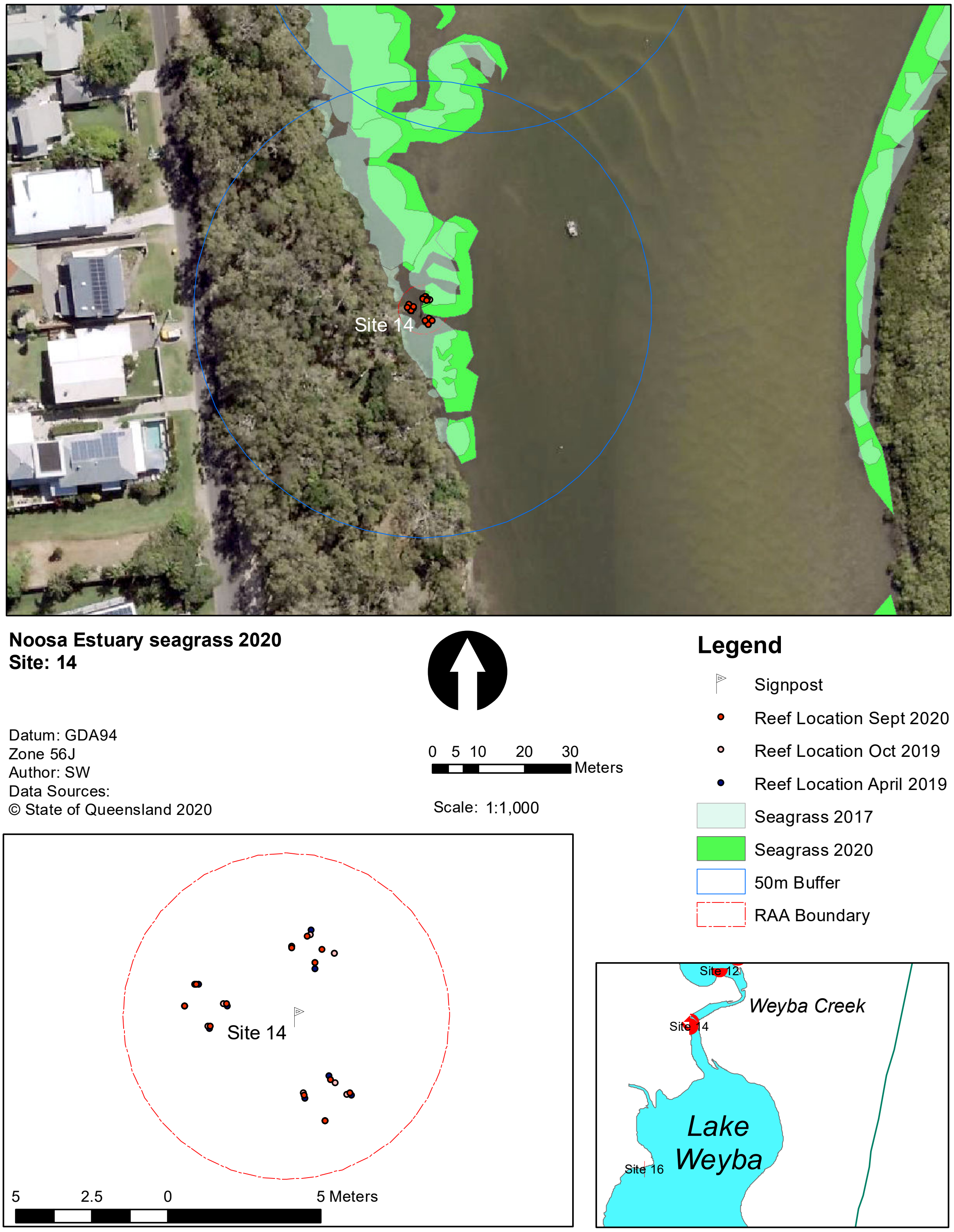


Figure 11 Location of restoration structures at Site 14 in relation to the RAA boundary and seagrass mapped in the area in October and November 2020

3.4.4 Site 16

In September 2020, the reef units at Site 16 had not moved substantially from their original position (<0.5m), although due to breakdown of coir mesh observed in October 2019, the oysters contained in the bags had spread to the northwest due to wind driven wave action and become buried under the fine sand. There was a high cover of macroalgae observed on bags at this site in October 2019 and again in September 2020 (Figure 12); although, following burial by sand in September 2020, the shell and much of the macroalgae was largely absent and just covered the surface in some sections.

Due to the almost complete burial of reefs, they were removed by hand and the sediment in the area remediated back to the pre-deployment condition (Refer to Section 4). Subsequent monitoring of the area after reef removal has demonstrated no ongoing influence of the reefs or from shell removal (Appendix A).

OUTCOME: Restoration units have been removed from Site 16 and the area rehabilitated – refer to photos pre- and post-removal provided in Appendix A.

Figure 12 Oyster reef covered with macroalgae at Site 16 in September 2020

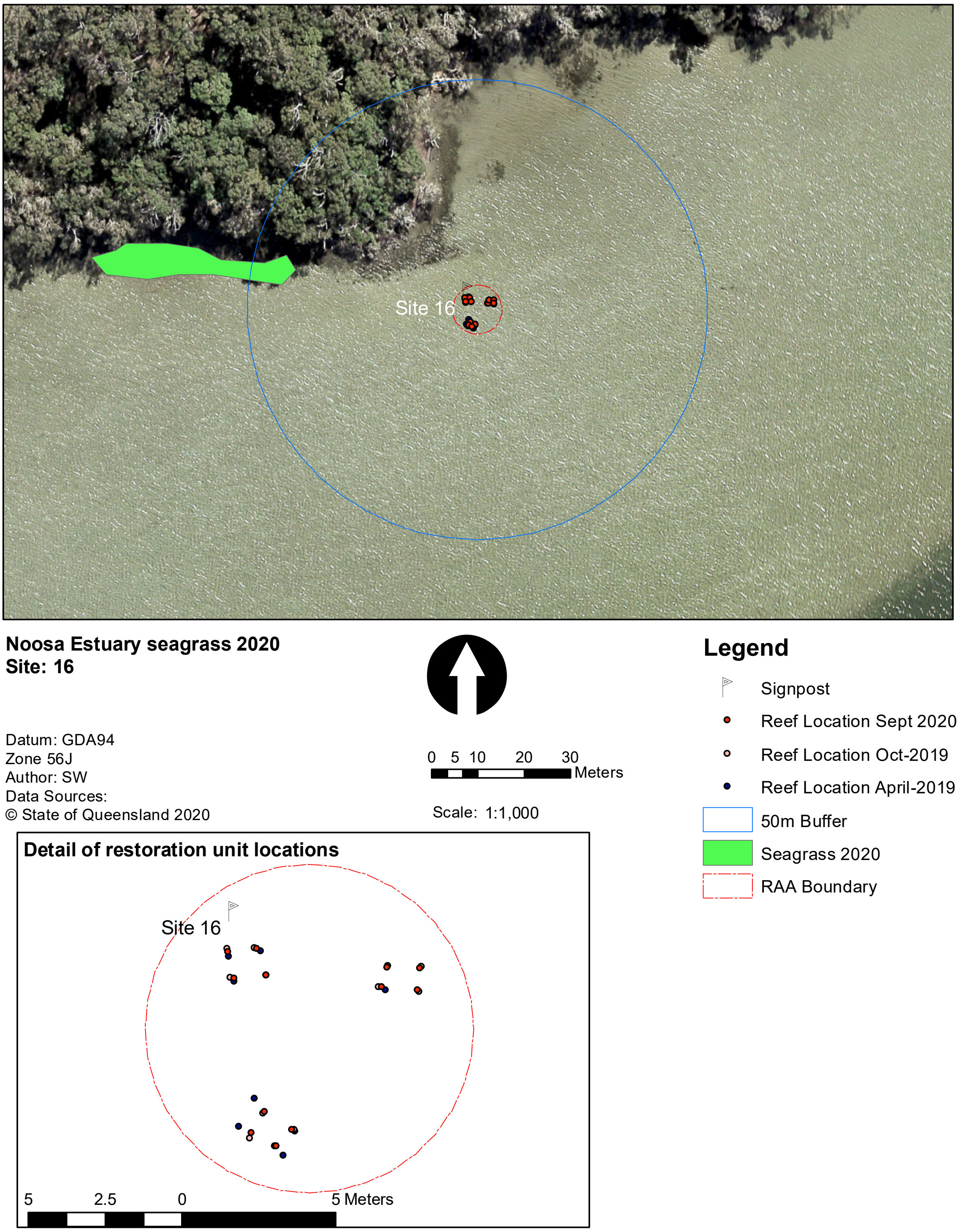


Figure 13 Location of restoration structures at Site 16 in relation to the RAA boundary and seagrass mapped in the area in November 2020

3.4.5 Knowledge Gained

The coir mesh provided a mechanism to deploy shell and support construction of restoration units using shell cultch only. The bags also allowed the reefs to be removed following the completion of the trial, as much of the coir mesh below the sediment surface remained intact. The coir mesh used for restoration units exposed above ground degraded within 2 years of deployment, to the point it was no longer possible to repair the bags by hand and shell spilled out the bags.

Over the trial period there was considerable settling that occurred, particularly where restoration units were placed over unconsolidated sediment, resulting in the considerable loss of vertical height in the restoration units. The length of time for the trial (3 years) was insufficient time for the shell to bind together prior to the coir bags degrading which allowed the shell to spill out and become buried in the underlying unconsolidated sand substrate.

Existing shell remained within the RAA area; however, the reefs lost vertical height due to subsidence of the aggregation of shell prior to becoming consolidated into a single unit. This demonstrates the potential to create a firm base of shell or rock and then supplement, without the need for substantial engineered structures. This approach is currently being employed in Port Stephens by NSW Fisheries (NSW DPI 2020). The rugosity provided by rock and gravel provides a place for shell to be held in place before becoming consolidated.

3.5 Performance Objective 2: Natural Recruitment Processes

3.5.1 Oyster Settlement & Recruitment

In May 2020, the mean oyster density was relatively consistent amongst the sites, ranging from 109 to 187 oysters.m^{-2} (Figure 15). Settlement was a lot lower in 2020 at Sites 13, 14 and 16 than in October 2019, which was a particularly good year for settlement, particularly at Site 13.

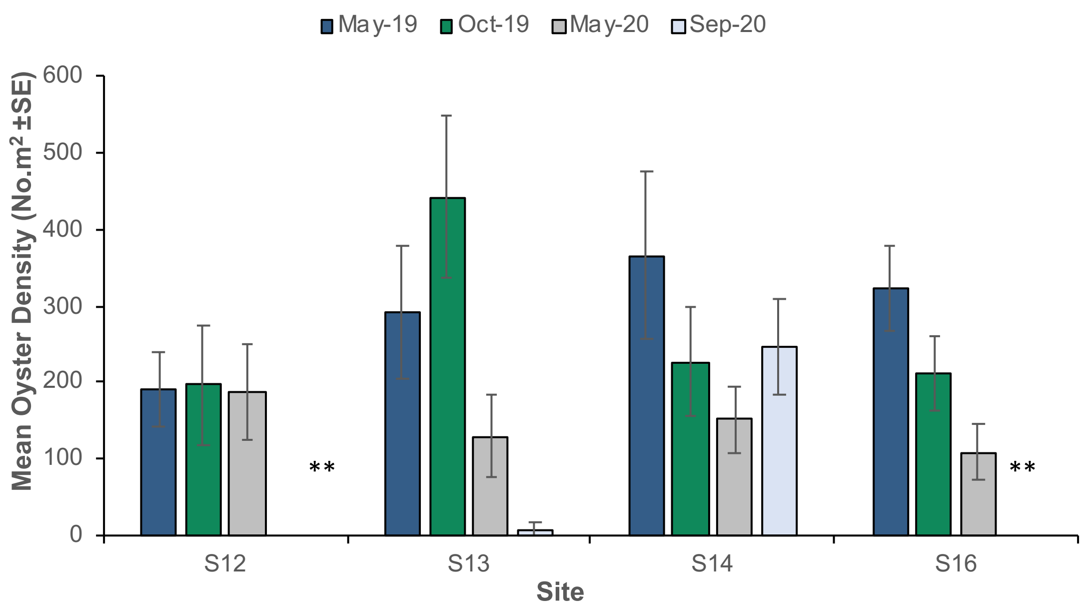
The survival of oysters that settled in the 2019–2020 settlement period, as measured in September 2020, was moderate at Site 14 with a similar average density of oysters found between the two monitoring periods although an increase in recently settled spat had reduced the average oyster height. Survival was poor at Site 13, with an 93% reduction in the density of oysters between May and September 2020. The reduction in oyster density and absence of recent settlement recorded at sites 12 and 16 in September 2020, was due to the almost complete burial of shell below the sediment surface, resulting in death of existing oysters and a lack of suitable substrate for spat to settle (Figure 15).

The settlement of oysters at some sites was highly variable during the 2019-2020 spat fall period as measured by recruitment onto settlement plates at sites 12 and 13, which differed in the density of rock oysters on different substrates and surface orientations deployed intertidally, with average density ranging from 25 to 4000 oysters.m^{-2} (McDougall & Walker 2020). In particular, there was a high covering of fine sediment on the upper surface of settlement plates, which prevented settlement or smothered recently settled oysters (Figure 14).

Figure 14 Sediment covering intertidal settlement plates at Site 12 in April 2020

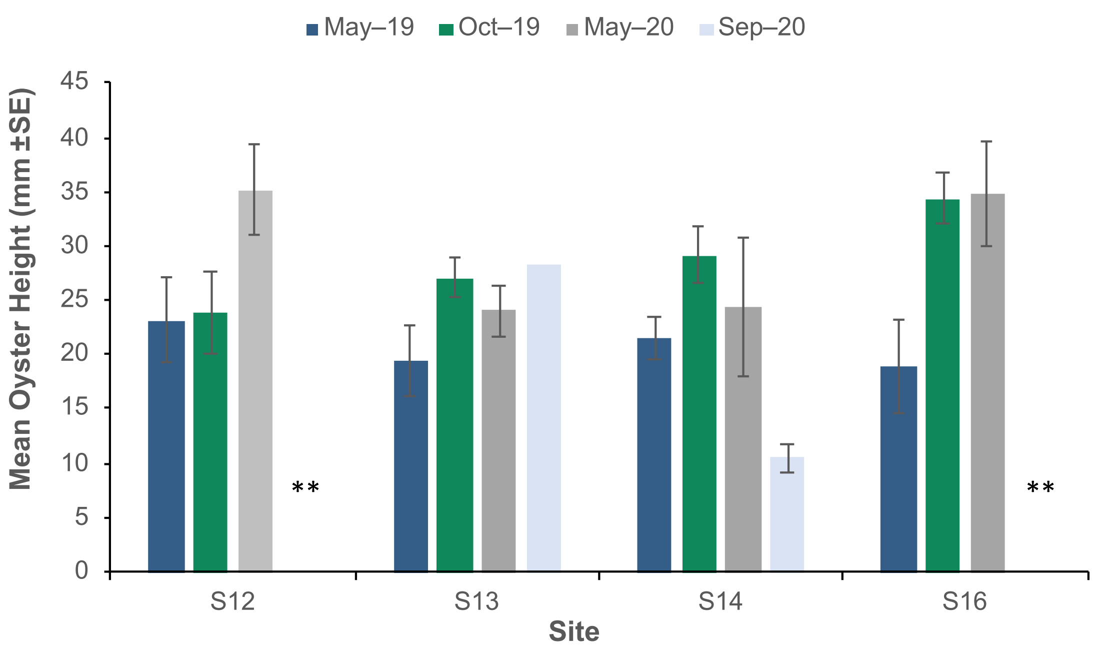
The average height of oysters from May 2019 to September 2020 was relatively consistent among the sites ranging from 11 to 35 mm and tended to increase in average size over time allowing for both growth and new spat recruits (Figure 16). The largest oyster (shell height of

88.5 mm), was recorded at Site 12 in October 2019, with several oysters exceeding 60mm recorded in the subsequent monitoring period in May 2020. In September 2020, there was no successful recruitment oysters of at Site 12 and Site 16 due to burial of the oyster shell at those sites and the maximum size recorded at the other sites was only 29 mm.



** denotes no oysters present

Figure 15 Average (± SE) density of oysters/m^2 among sites in May 2019, October 2019, May 2020 and September 2020



** denotes no oysters present

Figure 16 Average (± SE) height (cm) of oyster recruits among sites in May 2019, October 2019, May 2020 and September 2020

3.5.2 Presence of other Sessile Invertebrates and Macroalgae

A variety of other sessile invertebrates had recruited to several of the restoration units including other shellfish (hairy mussels, pearl and leaf oysters), sponges and ascidians. These sessile invertebrates are critical for consolidating the oyster shells into clumps (Figure 17) they also perform important ecological functions similar to oysters including filtering water and contributing to diversity. In October 2019, three sea hares (*Aplysia* sp.) approximately 15 to 20 cm long were also observed grazing on macroalgae growing on the reefs at Site 13 (Figure 18).

Figure 17 Oyster shell consolidated by encrusting sponges, algae and oysters at Site 14

Figure 18 One of three large sea hares (*Aplysia dactylomela*) consuming algae on oyster reefs at Site 13 in October 2019

3.5.3 Knowledge Gained

While there were occasional large oysters (>50mm shell height), the size of oysters sampled on restoration units declined as the reefs subsided; presumably due to a combination of ecological factors including increased physical disturbance (scouring and smothering from sediment), increased predation pressure and increased competition for settlement space with macroalgae and other sessile invertebrates.

There is sufficient natural spatfall in the estuary where restoration units and shell cultch can be maintained at a suitable height above the sediment surface.

The length of time required for restored areas to become self-sustaining is likely to be far longer than the trial period of 3 years. There were several oysters recorded growing on the restoration structures that were mature and at a size that they could reproduce; however due to the completion of the trial, a test of self-recruitment was not undertaken.

3.6 Performance Objective 3: Community Use

Community use and complaints are monitored through Noosa Council. A community member raised a concern to the restoration steering committee about the state of several reefs along the main Noosa River channel in February 2019. An investigation into the status of the reefs revealed that there had been substantial damage, most likely from repeated boat strikes during the Christmas holiday period (Figure 1), which was supported by anecdotal evidence provided by several local community members during the investigation. Wording on the project signage may have made the restoration areas highly attractive for tourists operating hire boats, who are unfamiliar with local fishing laws and were observed anchoring directly on the reefs in some areas of the main river channel. Despite these areas showing good signs of oyster settlement (Gilby et al. 2018), it was decided to remove remaining reef structures from 10 restoration sites, due to the substantial damage to reefs at those areas.

3.6.1 Knowledge Gained

While many of the reef areas in the main river channel had good to very good recruitment of oysters, a key learning from the trial is to provide additional communication and education to river users to reduce potential accidental damage. This could be achieved through dedicated signage at boat ramps and accessible information handouts for tourists hiring vessels who may have limited boating experience and be unfamiliar with the objective of the study.

Targeted communication with tourists via tour operators, may have reduced damage caused by boats within the main river channel. The small-scale of the trial reefs may have also made them susceptible to incidental disturbance from boats.

Figure 19 Signage at Site 13 to mark location of the reef and inform public – note that this sign has now been removed

3.7 Performance Objective 4: Other Potential Effects

The presence, type, and location of marine plants within a 50 m radius of the restoration unit was recorded in May and September 2020. The coverage of seagrass was assessed visually from the surface and from georeferenced imagery collected using an underwater camera. The extent was mapped using a handheld GPS unit. Due to the shallow nature of the sites, it was not possible to obtain vertical pictures for quantitative assessment of seagrass cover, so this was done based on visual assessment.

There was no evidence of any negative impact to the existing location of marine plants or impact on the coastline as a result of the reef units (Table 4). In September 2020, there was a small reduction in the extent of seagrass adjacent to the site, but this was well within the extent of change previously assessed.

In May 2019, the pioneer seagrass species *Halophila ovalis* was observed growing within the RAA area at site 13 (Figure 20). Prior to reef deployment, this area was an unconsolidated mobile sand bank with no seagrass present. There was a reduction in the cover of the *Zostera* bed along the shoreline between July 2017 and May 2018, followed by a large increase, which has remained relatively stable between 2019 and 2020 (Figure 21; Table 3 & Table 4). The causal mechanism for this broader change is unclear; however, this area is adjacent to a stormwater outlet and the reduction in seagrass cover is likely due to external environmental factors, not the placement of restoration structures at site 13 or 14. We completed an additional historical assessment to examine the change in seagrass coverage within 50 metres of the restoration area using imagery sourced from Queensland Globe between 2015 and 2019, and found that the coverage of seagrass adjacent to Site 13 peaked in 2017, then declined by approximately half the area between 2017 and 2018 (Table 3). In 2019, the area covered was similar to that assessed in 2016 (Table 3). In contrast, at site 14 there has been an increase in coverage of seagrass (and seagrass wrack) adjacent to the restoration structures (Table 3 & Table 4).

The presence of reef structures and potential administrative yellow and black “Underwater Obstruction” on a signpost at both sites 13 and 14, and the consolidation of mobile sand provided by the restoration units as they embedded, may have allowed increased recruitment of pioneer seagrass species in an area they otherwise would not survive. Furthermore, many of the reefs became covered in macroalgae on cultch that remained subtidal. The coverage of macroalgae increased over time to a peak in 2019, then reduced once shell had become buried below the sand. Macroalgae cover was dense on the cultch remaining at Site 14. This unexpected positive consequence for seagrass (and macroalgae) highlights the potential for oyster reef restoration to provide a mosaic of important fish habitat types. During the trial “6 knot” speed limit signage was placed by MSQ at points adjacent to the sites, which may have reduced potential boat strike.

Table 3 Area (m^2) of seagrass within 50 m of each restoration site pre- and post-deployment.

Site	Seagrass Area (m^2) within 50 m radius					
	Post-deployment			Pre-deployment		
	Oct/Nov '20	Oct '19	May '18	Jun '17	Jul '16	Apr '15
Site 12	254	341	–	238		
Site 13	1323	1369	733	1490	1350	947
Site 14	923	1103	941	861	702	421
Site 16	43	Sparse *H. ovalis* recorded	–			

– Not recorded by ESP

3.7.1 Knowledge Gained

There has been a positive influence from the remaining oyster reefs on the distribution of marine plants, particularly pioneer seagrass species where there is suitable seedbank or source of recruits nearby without the need for direct planting intervention. There is no evidence of any adverse impact on seagrass or coastal erosion due to the placement of the restoration units, or impacts to fringing mangroves.

Unfortunately, once the oyster restoration structures had become buried in the underlying sediment in 2020, the coverage of the sparse pioneer seagrass (*H. ovalis*) and macroalgae also declined around the restoration area but was still present once restoration units had been removed (Figure 20). This was likely due to resuspension of fine sediment and shifting sand at the site, but may have also been a response to flooding and sedimentation impacts as there was a surface layer of darker fine sediment present. In September 2020, only a very sparse covering of seagrass was recorded at Site 13 adjacent to the remaining patch of macroalgae attached to surface shell.

Optimal reef design should maximise space in the intertidal zone to allow increased opportunity for oyster spat settlement (as identified with settlement plates TNC & ESP 2015; McDougall & Walker 2020) and reduced competition with macroalgae and other subtidal organisms which likely recruited on the surface of reefs in winter, once the height of the cultch had dropped below the mean low tide mark.

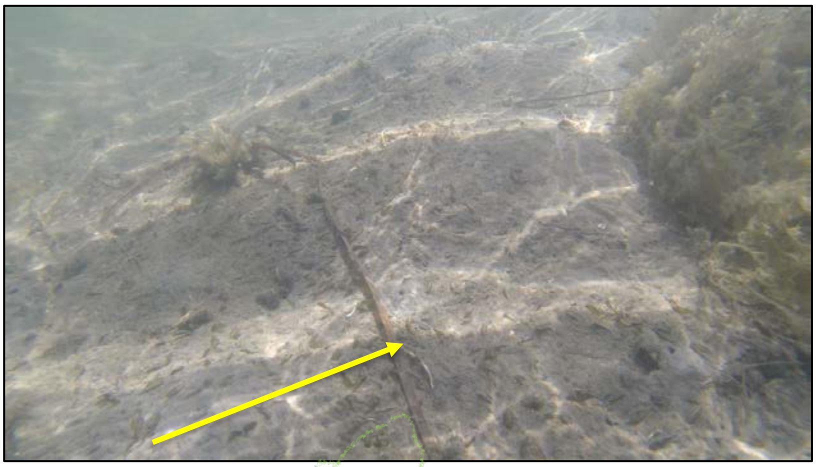


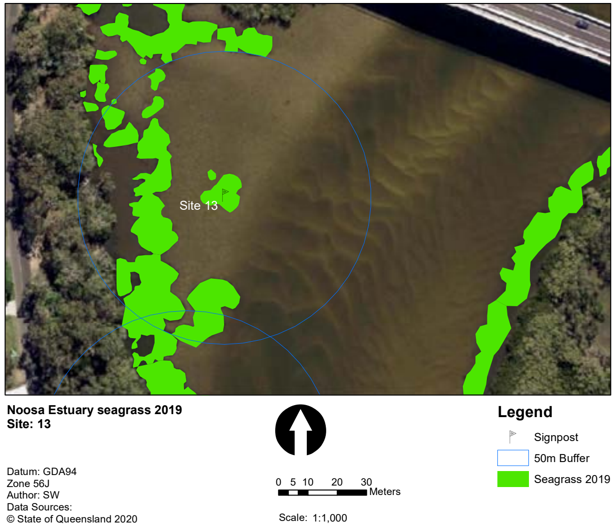
Figure 20 Sparse *H. ovalis* growing adjacent to the oyster reefs at Site 13 in September 2020

Table 4 Queensland Globe imagery of remaining restoration sites pre- (July 2017) and post- reef deployment (May 2018, 2019 & 2020)

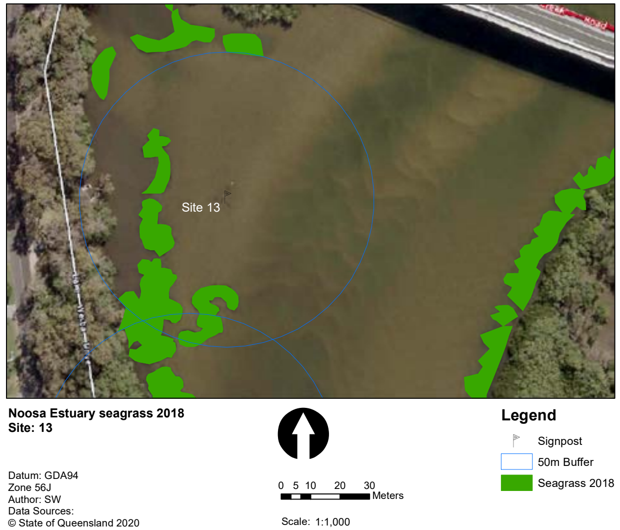
July 2017 Pre-deployment	May 2018 Post-deployment	May 2019	May 2020
Site 12			
			
Site 13			
			

July 2017 Pre-deployment	May 2018 Post-deployment	May 2019	May 2020
Site 14			
			
Site 16			
			

a) Post-deployment
October 2019



b) Post-deployment
May 2018



c) Pre-deployment
June 2017

d) Pre-deployment
July 2016

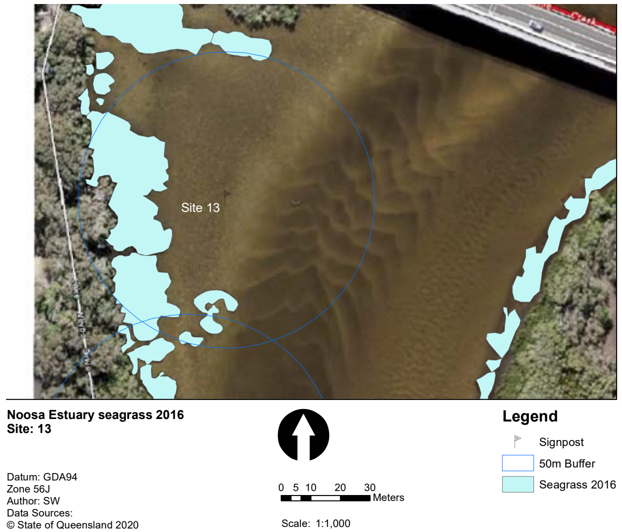


Figure 21 Seagrass area in proximity to Site 13, pre- and post-deployment of oyster reefs

4 Removal of Restoration Units

Oyster restoration units were removed at 10 of the 14 initial restoration sites by USC following the discovery of considerable incidental boat damage to the structures (Gilby et al 2019). Signage from each of these sites was removed in April 2020 by Noosa Jetty Builders, under observed by ESP scientists (refer to ESP 2020b; Appendix A).

Oyster shell and restoration units were removed from sites 12, 13 and 16 following fish assessments in September 2020 which identified the reefs had become subsided into the sand below (Refer to Appendix A). On the 18, 30 September and 1 October 2020 all reef structures were removed from sites 12, 13 and 16 by hand. The shell and coir mesh remaining under the sediment surface was dug out by hand and sieved to separate sand from the shell. The sand was then used to reprofile the bottom at each site and then checked for no adverse effects a month later on 4 November 2020. A total of approximately 500 kg of shell cultch was removed from the sites and deposited at the oyster shell recycling facility at Noosa Council Waste Depot. The only restoration area remaining is at Site 14 in Weyba Creek.

All signage was removed by hand using a waterjet and the signs recycled for other project purposes. Due to issues with vessel access into Lake Weyba, the sign at Site 16 was removed on 12 March 2021. The only remaining sign is at Site 14 in Weyba Creek, which should be removed pending a decision about where the reefs are to remain as natural habitat.

Figure 22 Removal and sieving of oyster shell by hand at Site 13 (18 September 2020)

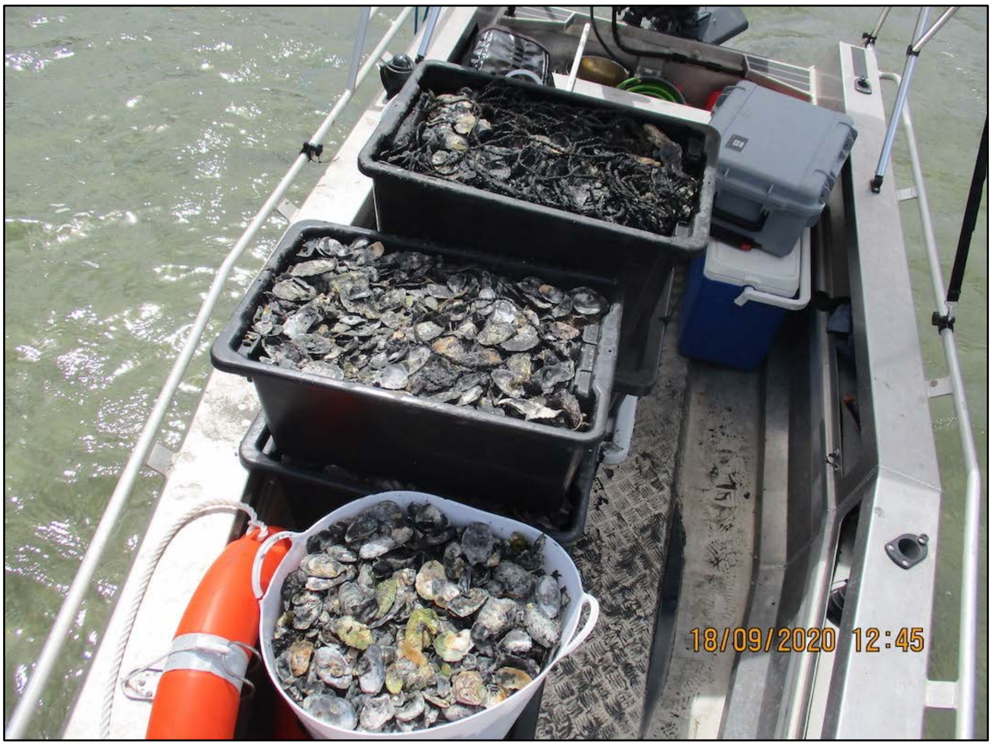


Figure 23 Oyster cultch removed and stored in tubs for disposal at the oyster shell recycling facility at Noosa Council Waste Depot

5 Conclusions and Recommendations

The small-scale trial restoration of oyster reef habitat, generated significant new knowledge for the restoration of oyster reefs within the Noosa Estuary including information on the placement of restoration structures, construction methods and possible structures required to support oyster growth, and the need for ongoing engagement with the community and information flow.

Several performance objectives of the RAA were met for all reef restoration areas; however, only one of the trial oyster reef remains due to a combination of factors including incidental damage resulting in removal of restoration units at 10 sites, and failure in the restoration structures resulting in burial by unconsolidated sediments at three of the remaining sites. The restoration structures remaining at Site 14 provide a shell aggregation that is consolidating due to sponges and macroalgae with some unconsolidated shell remaining. The dense seagrass in this area has also grown up to and around the reef patches, and the reefs have consolidated the underlying sediment resulting in positive benefits for both oysters and seagrass in the local area.

From the trial, it was evident that:

- Oyster spat settled on the oyster cultch in each of the restoration areas, but were particularly abundant in some areas of the lower estuary with reduced turbidity and salinity was more stable.
- Shell remained within the allocated area despite the coir mesh bags failing to remain intact for the full 3 year trial period. This was particularly evident in sites within Weyba Creek where wave action was reduced.
- Unconsolidated sand banks are highly mobile within the estuary, which can result in burial of restoration structures within 3 years of deployment.
- Unexpected positive consequences of the restoration effort included increased establishment and growth of seagrass, macroalgae, abundance of fish around the oyster reefs and presence of other invertebrates around and on the restoration structures that would otherwise not occur on bare sand.
- Interactions between the restoration areas and river users are unavoidable. Having positive outcomes for the restoration efforts requires additional and ongoing community engagement efforts to prevent incidental damage from other river users.
- Noosa Council Complaints Hotline received no formal requests to remove the installed oyster reef restoration units due to interference with community activities particularly fishing.

Following the completion of the trial, the restoration units at Sites 12, 13 and 16 were removed by hand as they had become buried in the unconsolidated sediment (sand and mud) in accordance with the approval requirements. All restoration units and signage have now been removed from the estuary and disposed of or recycled appropriately, with the exception of the reef at Site 14 (), which in our opinion is providing fish habitat and is also supporting seagrass and macroalgal growth, and therefore should remain as a natural part of the fish habitat area.

5.1 Recommendations

Several key learnings and recommendations for future restoration initiatives were determined from the trial deployment including information on the suitable construction of restoration units, successful placement of oysters on the shore, natural recruitment, settlement and growth of oysters and other benthic organisms, legislative requirements for restoration, and considerations for additional community engagement activities.

1) **Design and construction of restoration units suitable to attract oyster spat, but could be improved**

Future restoration should avoid placement in an area of accretion of sand and fine sediment and/or seek to use sufficiently firm base to elevate any oyster shell cultch layer or live oyster clumps above the underlying sediment layer. Selection of areas with historical shell beds or placing reefs over consolidated substrates (existing gravel, rock and bedrock) would reduce the potential for subsidence. Monitoring any subsidence and having provisions to supplement additional live shell attached to cultch or just shell cultch over time may assist natural reef accretion and restoration processes and ensure that a suitable height on the shore to maximise oyster recruitment is maintained.

Most of the restoration units used in the trial subsided into the soft substrate below by more than 40 cm, so at the completion of the trial the tops of the shell were either at or below the sediment surface. The exception was at Site 14, these restoration units close to the edge of Weyba Creek and while there was some slumping, shell remained above the sediment surface due to the underlying natural geology (gravel underlying the soft sand and mud).

2) **Estuary is substrate limited due to historical removal of cultch**

Oysters still exist in the estuary growing on artificial and natural structures such as mangrove roots at low densities. There was good settlement achieved on both settlement plates (TNC & ESP 2015) and natural oyster cultch placed at all trial restoration areas. The height on the shore at which oysters are currently growing (i.e. on existing rock walls, bridge pylons and some mangrove roots), provides an appropriate height at which settlement can be maximised under the current set of environmental conditions. This is a necessary consideration to maximise the potential for the initial phase of restoration in the modern era. In the subtidal zone, there was high coverage of macroalgae on shell cultch, which combined with a lack of vertical height in the intertidal zone created less suitable conditions for maximising recruitment of spat relative to that measured on intertidal settlement plates placed at the same sites. This translated to a reduction in the density of oyster settlement over time.

Due to the historical removal of cultch, successful restoration of oyster reef structures are likely to require additional corrective actions including supplementing shell cultch or live oyster clumps through time to assist successful restoration (i.e. particularly where there has been subsidence of the reefs into underlying sediment). Provision should be made for this in future approved restoration plans.

3) **Appropriate shore height is key for abundant recruitment**

Recruitment and survival of oysters declined where a suitable height above the underlying sandy substrate was not maintained or where deployment of reef units was over unconsolidated sand, resulting in burial and subsidence over the trial period. Suitable height of the restoration structures needs to be maintained or mechanisms for supplemental oyster shell included in the approval requirements to maximise natural oyster settlement and recruitment. Where there are no existing oyster at the restoration site to provide an indication, the reefs should be deployed between mean and lowest astronomical tide to maximise opportunities for rock oyster recruitment, survival and growth and therefore the potential success of the restoration structures.

Careful consideration of the placement of reef structures in relation to the tidal height on the shore are required throughout the estuary. Due to differences in the tidal prism with increasing distance from the mouth of the Noosa Estuary, there can be significant differences in the relative tidal heights at different locations. When placing oyster reefs in the estuary. While oysters can and do survive in the subtidal zone, it potentially increases a range of disturbance vectors including exposure to increase predation pressure and salinity stress and therefore prolongs the potential timeframe for restoration.

4) **Sustained community engagement during the restoration program**

Consideration of management mechanisms to protect the restoration areas from incidental damage while they are being restored. This should include community engagement and education campaigns and if possible, exclusion or reduction of vessel traffic, either through physical placement of implementation which would limit direct disturbance or the implementation of no anchor, exclusion or go-slow areas (i.e. 6 knot limits around restoration areas).

5) **Consideration of permitting, approvals and insurance required for the life of the program**

Community groups wanting to complete restoration need to consider the cost of public liability insurances, permitting and approvals, including suitable engineering plans and design costs into budgets for restoration programs.

In Noosa, the pathway to approval for this project included the designation of a Beneficial Reuse permit, Resource Allocation Approval (QLD Fisheries) and Prescribed Tidal Works Approval (Local & State Government). This required the production of suitable engineering plans, engineering signoff and suitable engagement with Local Council and State agencies.

The location of restoration activity may be constrained by existing management areas and the requirements under Local, State and Commonwealth legislation. While the key goal of the restoration project should be to restore reefs in areas where remnant reefs once occurred, the final positions may be constrained by other external factors.

Permitting approvals and resulting public liability considerations were identified through this project, which reduced the potential for engaging volunteers during the construction phase of the reefs. Where possible, a mechanism for increasing community involvement in the deployment and monitoring of reef structures should be sought although often due to the need for suitable contractors to construct the structures and engineering signoff, as well as risk of litigation, community involvement for the construction element may be reduced. Successful engagement in restoration has occurred in other projects through oyster gardening and shell recycling facilities, but there needs to be a mechanism in the permitting of reef deployment that allows for additional deployment phases of shell collected or live oysters grown under jetties from within the estuary that can be translocated onto the restoration areas.

Since the inception of this program, several other subtidal and intertidal oyster reef restoration programs have begun throughout Australia (e.g. NSW DPI 2020), including the publishing of an updated practitioners handbook (Fitzsimons et al. 2019), each providing a wealth of new information and experience needed to successfully undertake a restoration at a scale required to bring an functionally extinct habitat back from the brink of extinction. The knowledge gained through this and other trials in Australia (including best practice restoration manuals from international programs) could be incorporated in a Code of Practice for restoring oyster reefs in areas deemed beneficial to the environment and in particular where they have been historically present and are in decline or have become functionally extinct.

Smothering from mobile unconsolidated sediments (sand and mud) was a major source of disturbance and decreased survival in spat on shell cultch and on settlement plates. Further targeted assessment of the sedimentation rate using sediment accumulation within the estuary is warranted as this would inform a range of suitable estuarine restoration approaches and management (including oyster reef restoration); in the water, along the riparian edge and on land to restore whole of catchment functions and protect investments in scaled restoration initiatives within the estuary into the future.

6 References

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Fitzsimons J, Branigan S, Brumbaugh RD, McDonald T. & zu Ermgassen PSE. (eds) 2019. *Restoration Guidelines for Shellfish Reefs*. The Nature Conservancy, Arlington VA, USA

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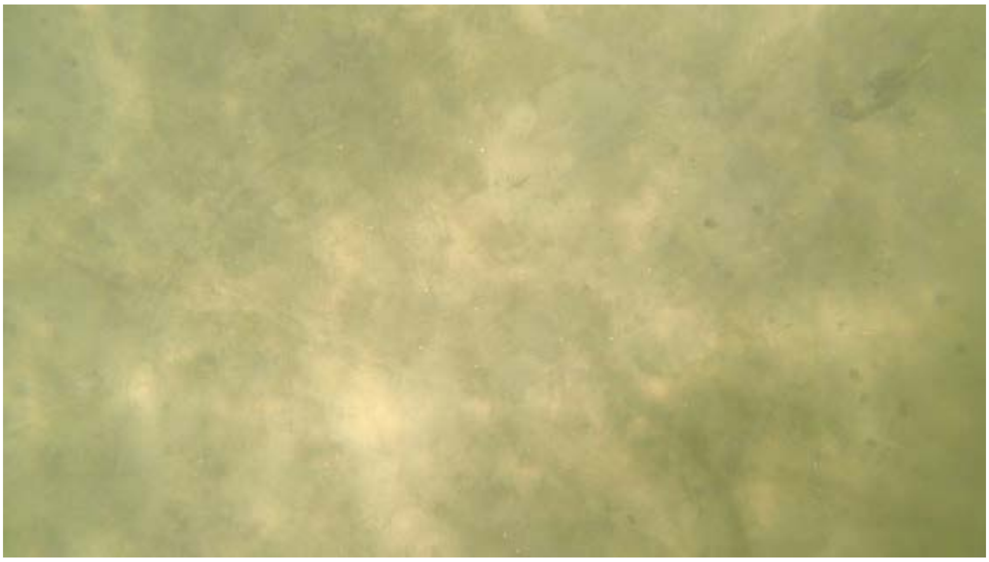
Appendix A Restoration Site Photos

Photos of restoration sites after trial reefs were removed (note that signs were removed by hand following the removal of trial reef structures in October 2020. The signposts provided a point of reference to confirm satisfactory removal of restoration unit and reprofiling of sediment). The signpost at site 16 was removed by hand using a small water jet in March 2021 due to access constraints.

Site 12 – Pre removal

September 2020

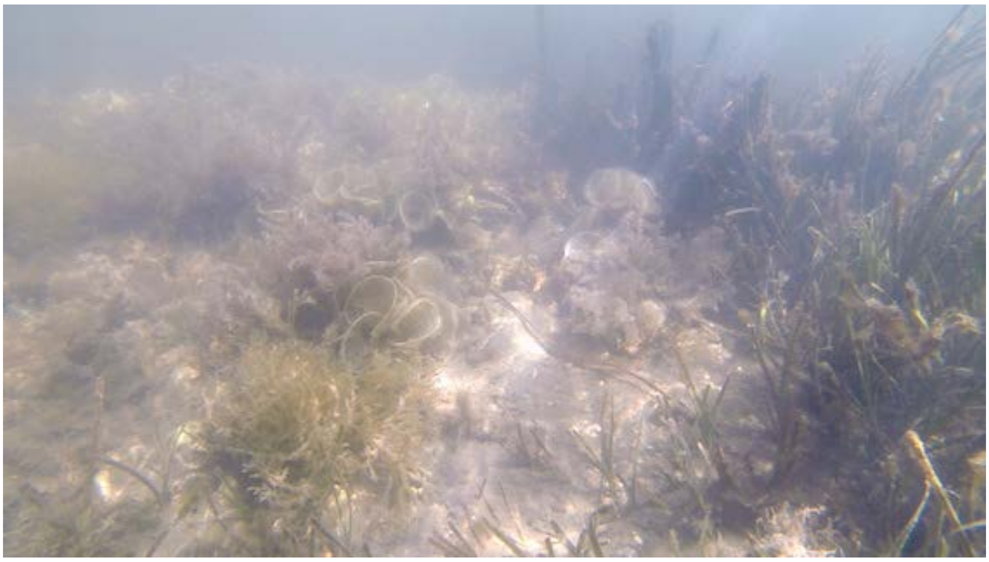
Site 12 – Post removal October 2020



Site 13 – Pre removal September 2020

Site 13 – Post removal September 2020

Site 14 – September 2020



Site 14 – Post removal	Reefs and signage has not been removed at this site
Site 16 – Pre removal September 2020	
Site 16 – Post reef removal October 2020	

Post signage removal March 2021

Refer to ESP 2020b *Removal of Signage from Noosa River.* Letter prepared for Noosa Council. 31 May 2020

Ecological Service Professionals
Sustainable Science Solutions

Alannah Duffy
Environmental Officer
Noosa Council
PO BOX 141
TEWANTIN QLD 4565

Our Reference: 1533.005L1

31 May 2020

RE: Removal of signage from Noosa River

Dear Alannah,

A total of 10 signs that were used to designate oyster habitat restoration areas were removed from the Noosa River by the Noosa Jetty Builders. We supervised and measured environmental parameters during the sign extraction as well as taking before and after photos. We will complete an additional assessment of habitat when next we are in Noosa in June 2020.

Signs were removed using a commercial contractor under an approved Accepted Development notification to DAF received on 29 April 2020 (Appendix B, approval number 2004-5781 ADR-FHA). All posts were removed on 30 April 2020 using a suitably qualified commercial contractor and vessel (Noosa Jetty Builders). Sign posts were either extracted vertically using a winch or with the aid of a water jet using ambient water with the post then removed by hand. Where possible and water clarity allowed, a photograph was taken of the sign, general area, and substrate prior to and after extraction of the post.

Ambient water quality was measured at each site before and during the sign removal to assess whether there was any change due to the use of the water jet. Water quality was measured at the surface with a suitably calibrated YSI ProDSS handheld water quality meter (Serial number 16G101636 – Refer to calibration record Appendix B). While there was some localised disturbance (increased turbidity) of the water within 1-2m of the sign post, this quickly returned to ambient conditions once the water jet was removed (usually within 5 minutes). In all cases, water quality remained at ambient conditions within 2m of the sign removal area.

Figure 1 Noosa Jetty Builders purpose commercial vessel used for sign removal

Figure 2 Removal of signpost by hand using waterjet over bare sand at site 2

Figure 3 Manual extraction of signpost adjacent to Rhizophora mangrove at Site 11.

All signs were positioned over bare sediment (sand and mud) with varying proximity to marine plants. No damage occurred to marine plants during the extraction of signs. Where the water jet was required to remove a post, the limit of any sediment disturbance was 0 to 0.5 m radius of the post with a small plume approximately 2 to 3 m created, which dissipated within 5 minutes.

Figure 4 Manual winching signpost out at Site 6

Table 1 Sign extraction before and after photos

Site	Location (GDA94 Zone 56)		Before extraction	After Extraction	Extraction Method & Comments
	Easting	Northing			
Site 2	504561	7081869			Waterjet / Manual
Site 3	504300	7081484			Manual

Site	Location (GDA94 Zone 56)		Before extraction	After Extraction	Extraction Method & Comments
	Easting	Northing			
Site 4	504451	7080720			Waterjet / Manual
Site 5	504980	7080597			Waterjet / Manual

Site	Location (GDA94 Zone 56)		Before extraction	After Extraction	Extraction Method & Comments
	Easting	Northing			
Site 6	505144	7080846			Manual Winch
Site 7	505478	7080725			Manual Winch

Site	Location (GDA94 Zone 56) Easting	Northing	Before extraction	After Extraction	Extraction Method & Comments
Site 8	506152	7080581			Waterjet / Manual
Site 9	507049	7081172			Manual

Site	Location (GDA94 Zone 56) Easting	Northing	Before extraction	After Extraction	Extraction Method & Comments
Site 10	507135	7081730			Winch
Site 11	508038	7080214			Manual / Winch

Signposts and signage remains at 4 sites in the Weyba Creek catchment and will be removed following the completion of the trial oyster restoration project (Table 2).

Table 2 Location of signposts at remaining trial oyster reef restoration areas

Site	Location (GDA94)		Comments
	Easting	Northing	
Site 12	507682	7079962	Sign and post in good condition. One float repositioned
Site 13	507106	7078793	Sign and post in good condition
Site 14	507093	7078704	Underwater obstruction sign missing – located on bottom surrounding the post. Signage damaged due to poor fixing and movement. Sign replaced and old sign removed from the site. Swapped out for a more suitable bracket
Site 16	506202	7075594	Sign and post in good condition

Water Quality Monitoring

Surface water quality was logged for a period of at least 1 minute before, during extraction and a further minute after extraction or until values stabilised at background. There was no change in the water quality among periods before, during or after for all parameters measured except for turbidity (Table 3). Turbidity increased by less than 2 NTU at all sites, and was largely dependent on the substrate partical size distribution at a particular site (Table 3).

Table 3 Average water quality parameters logged in situ, before, during and after each sign post extraction

SITE	Period	Temperature (°C)	Specific Conductance (µS/cm)	Salinity (PSU)	pH	Dissolved Oxygen (% Sat)	Dissolved Oxygen (mg/L)	Turbidty (NTU)
Site S2	Before	24.2	43196	27.8	7.9	92.9	6.64	26.5
	During	24.2	43299	27.9	7.9	92.7	6.63	25.4
	After	24.3	43293	27.9	8.0	92.5	6.61	21.3
Site S3	Before	24.7	33388	20.9	8.0	94.2	6.95	16.0
	During	24.7	33536	21.0	8.0	94.8	6.98	16.7
	After	24.7	33611	21.1	8.0	95.0	7.00	19.0
Site S4	Before	24.3	45847	29.7	8.0	93.7	6.62	17.4
	During	24.3	45927	29.8	8.0	92.1	6.51	19.3
	After	24.3	45979	29.8	8.0	91.7	6.47	**18.7**
Site S5	Before	24.1	45505	29.5	8.0	91.2	6.47	4.4
	During	24.1	45584	29.5	8.0	90.8	6.44	4.1
	After	24.2	45639	29.6	8.0	90.7	6.43	3.9
Site S6	Before	25.8	47580	31.0	8.1	99.4	6.80	4.7

SITE	Period	Temperature (°C)	Specific Conductance (µS/cm)	Salinity (PSU)	pH	Dissolved Oxygen (% Sat)	Dissolved Oxygen (mg/L)	Turbidty (NTU)
	During	25.9	47798	31.1	8.1	100.4	6.85	4.8
	After	26.0	47832	31.1	8.1	100.6	6.85	**5.1**
Site S7	Before	25.8	46932	30.5	8.1	101.8	6.97	3.5
	During	26.0	47074	30.6	8.1	103.3	7.05	3.9
	After	26.1	47210	30.7	8.1	104.3	7.11	**4.2**
Site S8	Before	24.9	47813	31.1	8.1	94.6	6.55	6.4
	During	24.8	48017	31.3	8.1	91.7	6.37	6.3
	After	24.8	48100	31.4	8.1	91.7	6.37	**8.0**
Site S9	Before	25.0	49673	32.5	8.1	97.1	6.67	1.7
	During	25.1	49678	32.5	8.1	97.3	6.67	1.7
	After	25.1	49684	32.5	8.2	97.5	6.68	**1.8**
Site S10	Before	25.1	49456	32.3	8.1	100.9	6.92	1.6
	During	25.2	49480	32.4	8.1	101.5	6.95	1.7
	After	25.2	49479	32.4	8.1	101.6	6.96	**1.7**
Site S11	Before	24.8	46175	30.0	8.0	88.4	6.19	2.3
	During	24.7	46201	30.0	8.0	88.3	6.19	2.3
	After	24.7	46201	30.0	8.0	88.3	6.19	2.2

Bold values indicate where turbidity was measured up to 1.6 NTU higher after, than prior to the signage removal but typically turbidity was the same or lower following sign removal

Health, Safety, Environment & Community

There were no incidents or issues from a health and safety perspective. No public comments while removing signs. As discussed, there were several unofficial corflute 6 knot speed signs that had been secured to the sign posts for the trial reefs that were also removed.

Alannah, if you have any questions, please let me know.

Regards,

Dr Simon Walker

Principal Ecologist

On behalf of Ecological Service Professionals Pty Ltd

ISO9001 Quality Assured

Appendix B. Calibration Record

Document: ESP-SOP-1-001.3A
Date: 05.08.2019

ESP Calibration Record

Ecological Service Professionals
Sustainable Science Solutions

Details: YSI ProDSS

Serial Number:

Date: 17/04/2020
Name: Paul Tompkins

Parameter	Standard	Pre-Cal Reading	Calibration Required? Y / N	Calibration Successful? Y / N	Post-Cal Reading	Comments
Temperature	°C 24.4		NA	NA		No Cal required
Specific Conductance	50 mS/cm @25°C	50.020	Y	Y	50000	
Dissolved Oxygen	100% Saturated Air	99.8	99.6	Y	99.6	
pH	4.00 pH units	2.37	Y	Y	4.00	
7.01 @ 25°C	7.00 pH units	5.63	Y	Y	7.01	
	pH MV @ 7.00 pH	5.3				
10.01@24°C	10.00 pH units	8.86	Y	Y	10.01	
Depth	Zeroed in air @ __ mmHg					
Turbidity	0 FNU/NTU	-0.2	Y	Y	0.0	
	124 FNU/NTU	117.2	Y	Y	124	
Hach 2100Q S/N15060C0 41641	10 NTU	9.56	N			X
	20 NTU					
	100 NTU					
	800 NTU					

I Paul Tompkins certify that calibration was completed and successful.

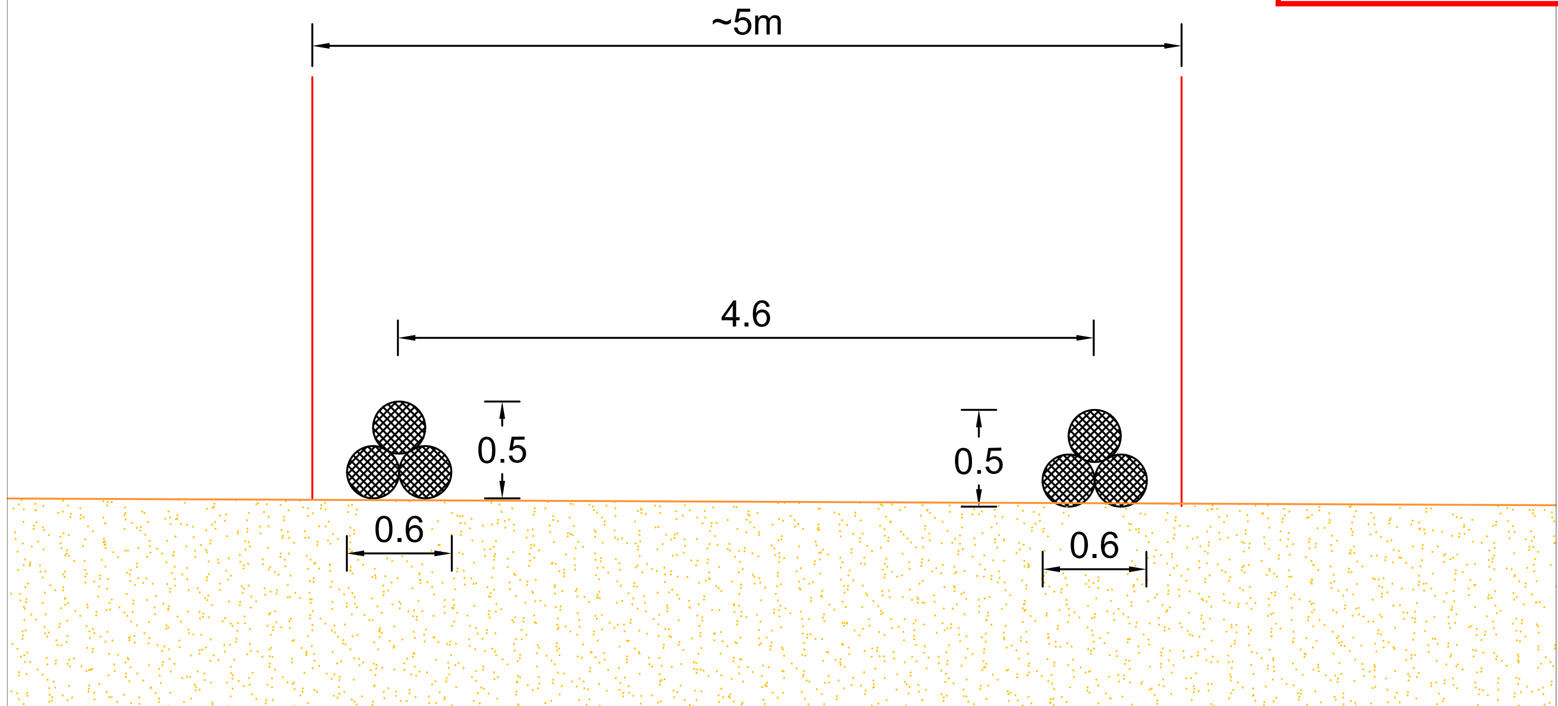
Date: 17/04/2020

Signature:

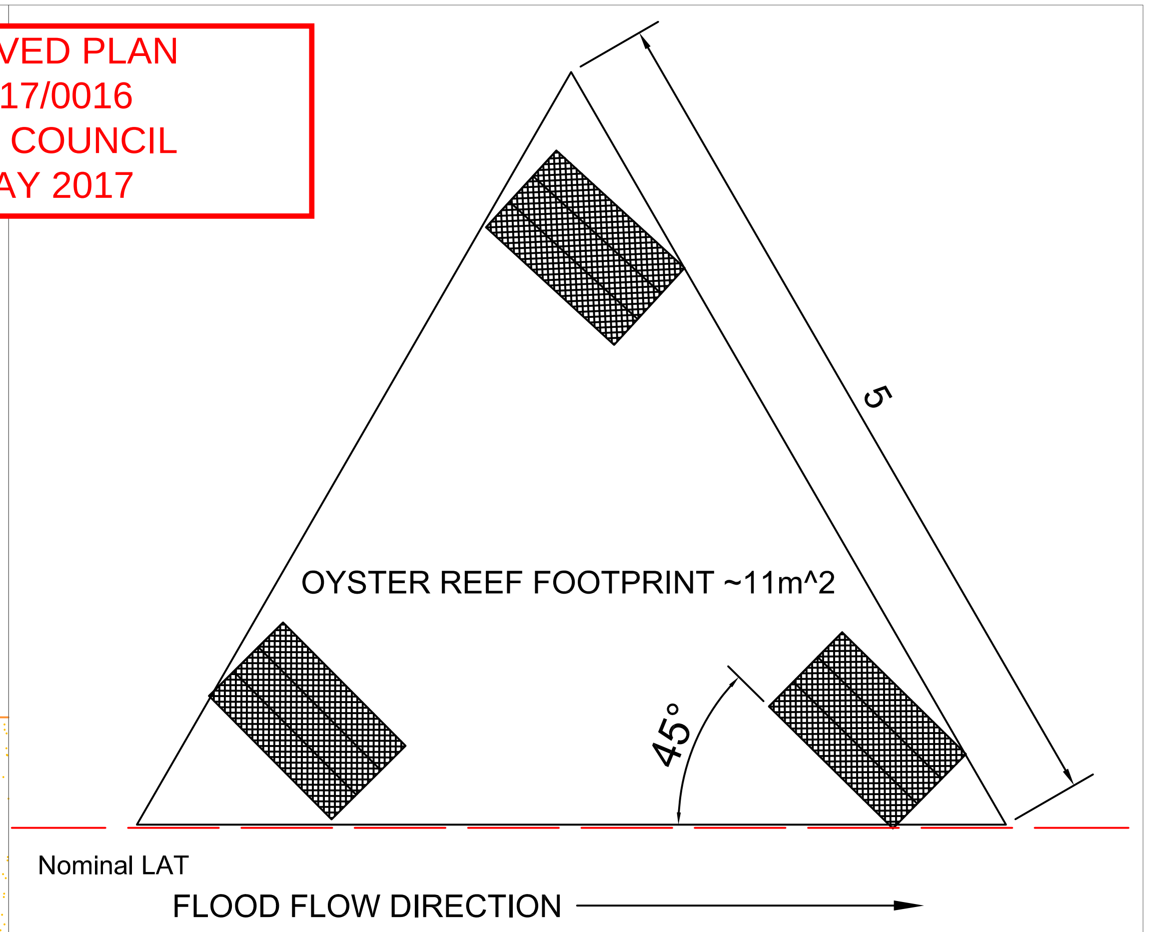
Appendix B Location of Initial Deployment Sites and Restoration Unit Design

Note that reefs were not deployed at Sites 1 and 15 and nothing further was undertaken at those sites.

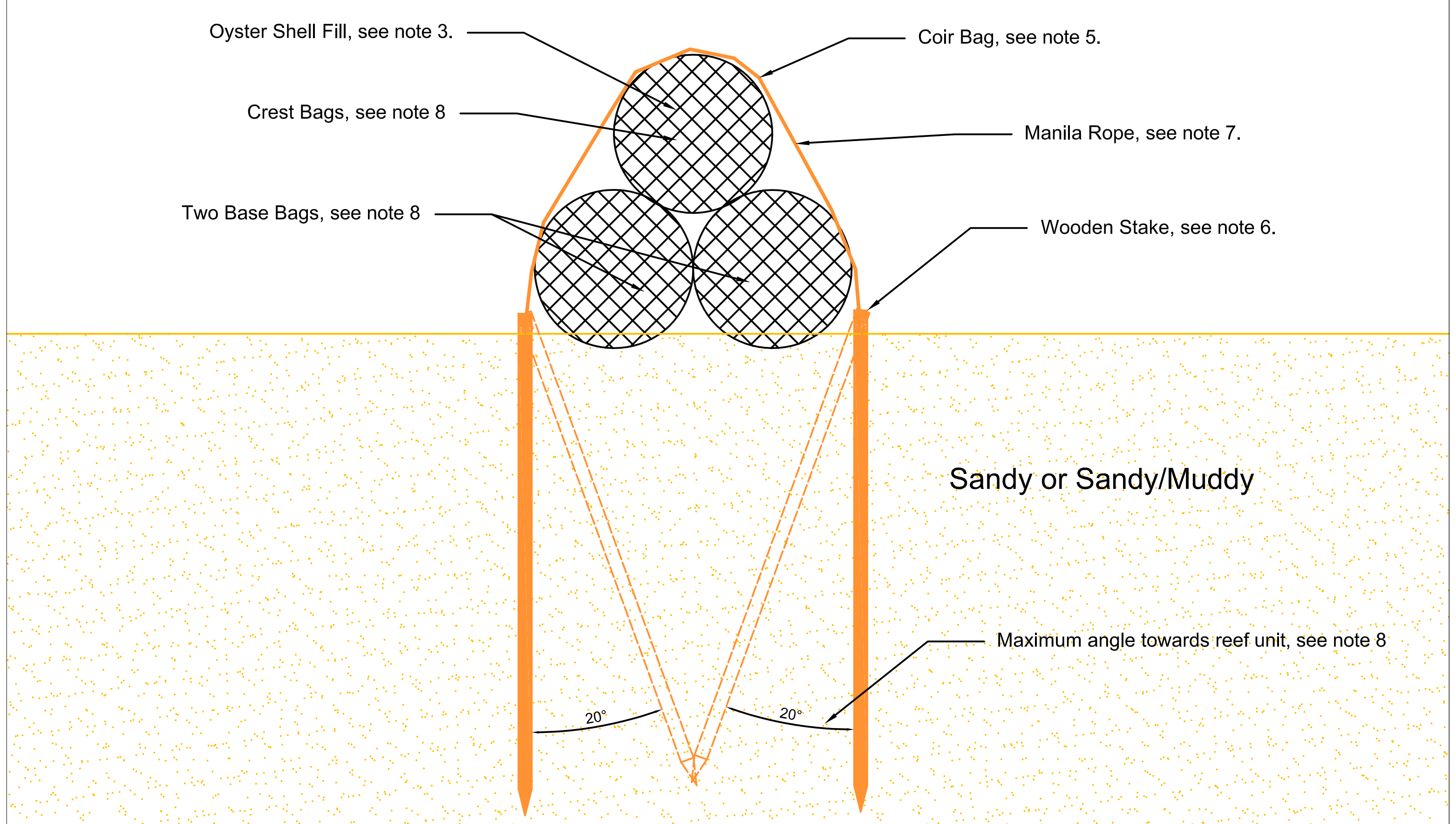
APPROVED PLAN
OPW17/0016
NOOSA COUNCIL
18 MAY 2017



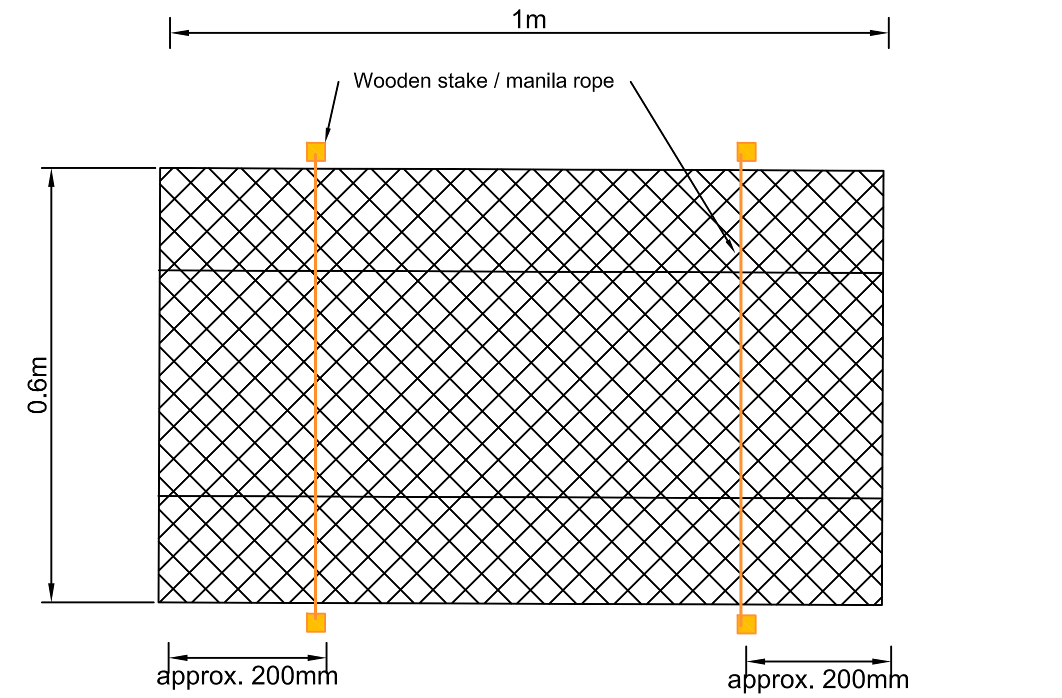
OYSTER REEF - XSECTION



OYSTER REEF - PLAN

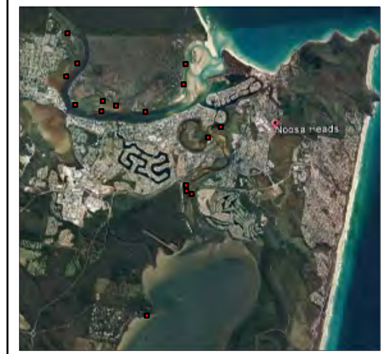


REEF UNIT - XSECTION



REEF UNIT - PLAN

LOCALITY PLAN



NOTES

1. Measurements are in meters.
2. The reef general layout will be placed in a 5m equilateral triangle.
3. Oyster shells are:
   - To be whole (not fragments)
   - Not to be sourced from within any Fish Habitat Area
   - To be boiled for at least 10 minutes in accordance with biosecurity principles
4. Unfilled coir bags are:
   - to be 0.3m in diameter
   - to be 1.3m in length with one end closed during manufacturing
   - to have an apeture of approx. 20mm.
   - to be Geofabrics Australia CoirLog or engineer approved equivalent
5. Coir bags are to be filled with the oyster shell mix to 1m length of the bag.
   - Remaining 0.3m length of bag to be used to tie end closed
   - Oyster fill is to be well packed using a tube sleeve
   - Bag end closed using approx 0.3m of manila rope to form a single Miller's (bag) knot, followed by a single overhand knot
   - Two coir bags at base of reef unit to be in direct contact with minimal space betwen
6. Wooden stakes
   - to be 0.6m length hardwood with 25x25mm thickness
   - to be suitable for marine environments
   - to have 10mm diamter hole drilled approx 30mm from top of stake
7. Manila rope
   - to be 8mm diameter Emmett's Ropes Three-Strand Hawser Laid Manila or engineer approved equivalent
   - length for anchorage to be approx. 2m
   - to be tied to wooden stakes such that approx. 1.3m length of manila rope remains between stakes
   - to be attached to wooden stakes by threading rope through drill hole, followed by a double stopper knot. The remaining manila rope end is to be hitched back onto the wooden stake
8. Anchorage to be manila rope tied between two hardwood stakes, see note 6 and 7.
   - stake/rope anchors to be placed approx. 0.2m from ends of reef unit
   - wooden stakes to be driven vertically or angled up to 20° toward reef unit. Wooden stakes NOT to be angled away from reef units
   - manila rope to be pulled tight across coir bags such that crest bag is NOT able to roll
   - Reefs to be relocated where hard substrate is encountered

VERTICAL DATUM: AHD | HORIZONTAL DATUM: MGA

REVISION REGISTER

REV.NO.	DATE	DESCRIPTION	BY	ENG.	APP.

International Coastal Management
OFFICE 50 / G Arm, SYC Marina, Main Beach, 4217, QLD, Australia
POST PO Box 306, Main Beach LPO, Main Beach QLD, 4217, Australia
TELEPHONE +61 7 55640564 FAX +61 7 55329147
WEBSITE www.coastalmanagement.com.au

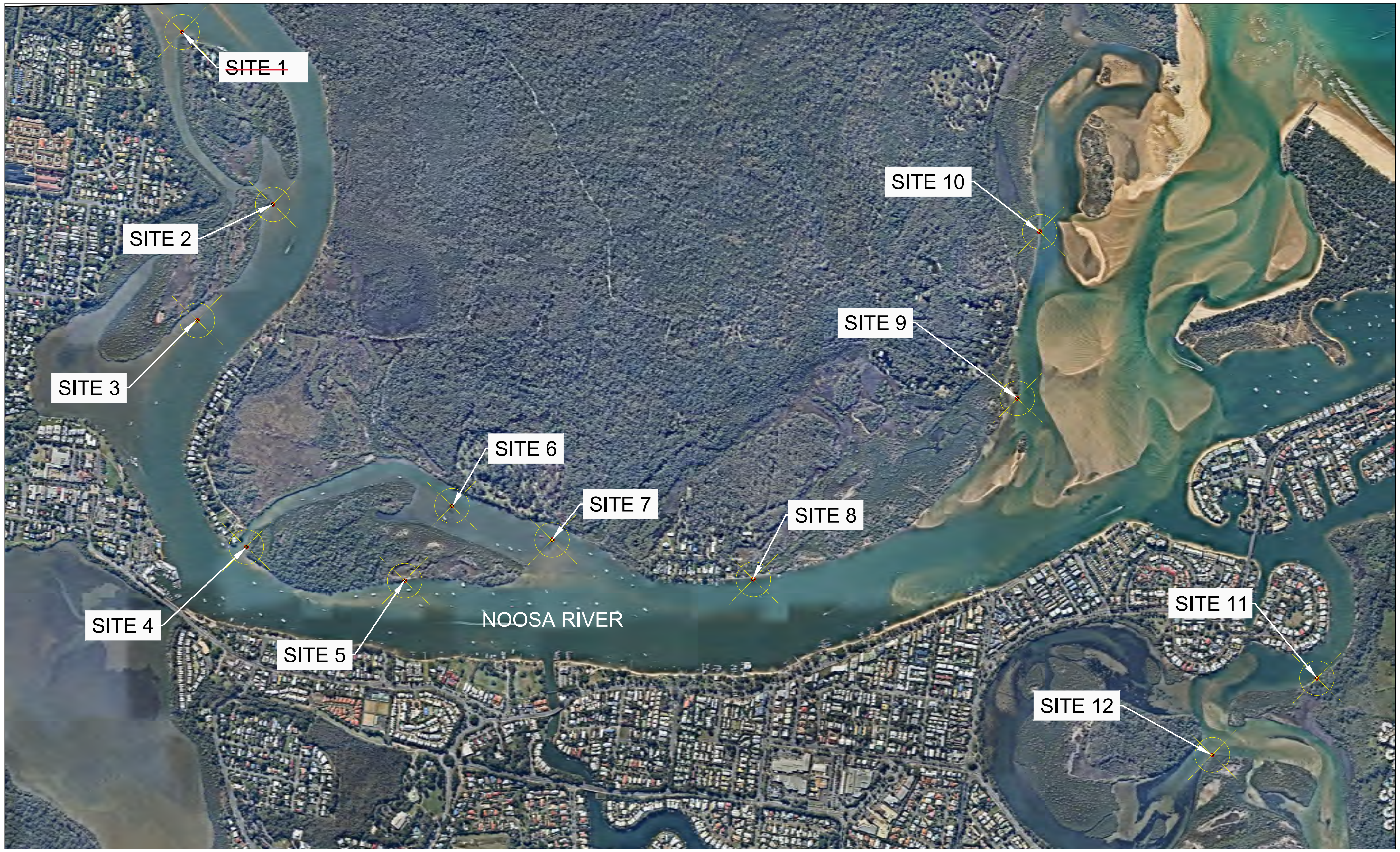
PROJECT NAME
NOOSA RIVER OYSTER REEFS

DRAWING TITLE
REEF DETAIL

DRAWING No. 2016.0028 - 020
REVISION: A

DRAWN : SK | CHECKED : BC | APPROVED : AJ
RPEQ 2876

SIZE: A3 | SCALE : | DATE : 12 Sep, 2016



Point Table

Site Number	Easting	Northing	
~~1~~	~~504267~~	~~7082454~~	Reef Not Deployed
2	504561	7081869	
3	504300	7081484	
4	504451	7080720	
5	504980	7080597	
6	505144	7080846	
7	505478	7080725	
8	506152	7080581	
9	507049	7081172	
10	507135	7081730	
11	508038	7080214	
12	507682	7079962	

NOTES:

1. Locations given are indicative based on available survey data.
   Final locations may be adjusted on site to ensure design intent is achieved
   - Site coordinate located at approximately LAT
   - Crest of reef units NOT to be above HAT
   - Reef units are placed within a 5m equilaterial triangle footprint
   - Where possible, 2 reef units to be placed with base at LAT
2. Resource Allocation Area (RAA) to be 90m^2 circle of 5.35m radius centered at site coordinates provided

CREATED: 15 January 2018 JOB SUB #: FILE NAME: F:\Jobs\2200\2214 Noosa Biosphere_Noosa Oyster Reef\Drawings\Drawing\2214.DRG.002.dwg

REV	DESCRIPTION	DATE	BY

Data Sources:
Photography:
Topography:
Cadastre:
Ecosystem:
Other:

Legend:
Oyster Reef Site
Resource Allocation Area (RAA) (5.35m Radius)

ISSUE FOR APPROVAL

N

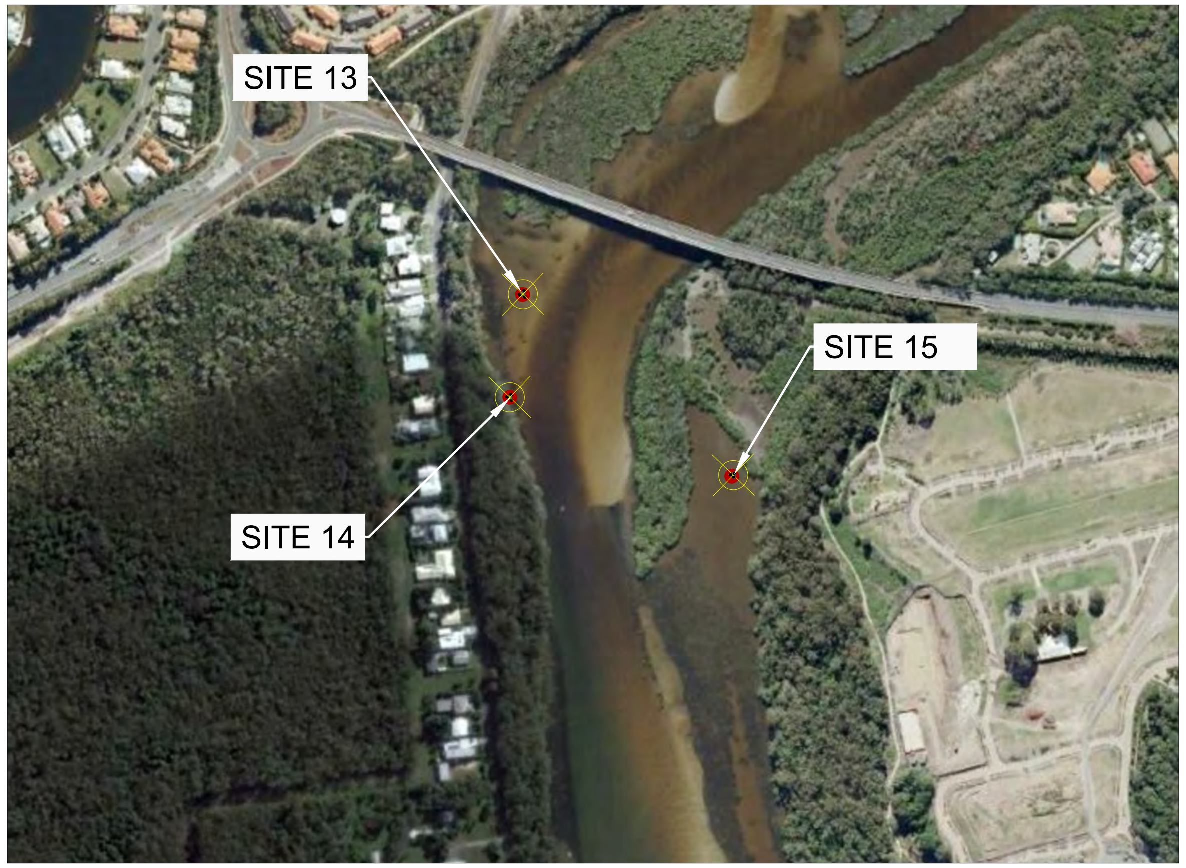
PROJECT: Noosa Oyster Reef Restoration

CLIENT: Noosa Biosphere

TITLE: Plan Layout Site 1 - 12

GROUNDWORK plus
PH: +61 7 3871 0411
WWW.GROUNDWORK.COM.AU

DATE: 15 January 2018	DRAWN: JS	DRAWING NUMBER: 2214.DRG.002B	REVISION:
PRINTED: 15 January 2018	CHECKED: MF	DATUM: HORIZONTAL / VERTICAL / ZONE MGA / AHD / 56	



Point Table		
Site Number	Easting	Northing
13	507106	7078793
14	507093	7078704
~~15~~	~~507284~~	~~7078634~~

Reef Not Deployed

NOTES:

1. Locations given are indicative based on available survey data.
   Final locations may be adjusted on site to ensure design intent is achieved
   - Site coordinate located at approximately LAT
   - Crest of reef units NOT to be above HAT
   - Reef units are placed within a 5m equilateral triangle footprint
   - Where possible, 2 reef units to be placed with base at LAT
2. Resource Allocation Area (RAA) to be 90m^2 circle of 5.35m radius centered at site coordinates provided

Point Table		
Site Number	Easting	Northing
16	506202	7075594

FILE NAME: F:\Jobs\2200\2214 Noosa Biosphere_Noosa Oyster Reef\Drawings\Drawing\2214.DRG.002.dwg

JOB SUB #:

CREATED: 15 January 2018

REV	DESCRIPTION	DATE	BY

Data Sources:
Photography:
Topography:
Cadastre:
Ecosystem:
Other:

Legend:
Oyster Reef Site
Resource Allocation Area (RAA) (5.35m Radius)

ISSUE FOR APPROVAL

N

PROJECT: Noosa Oyster Reef Restoration

TITLE: Plan Layout Site 13 - 16

CLIENT: Noosa Biosphere

GROUNDWORK plus
PH: +61 7 3871 0411
WWW.GROUNDWORK.COM.AU

DATE:	15 January 2018	DRAWN:	JS
PRINTED:	15 January 2018	CHECKED:	MF

DRAWING NUMBER: 2214.DRG.002C
REVISION:
DATUM: HORIZONTAL / VERTICAL / ZONE
MGA / AHD / 56