Monitoring of the Noosa River Oyster Reefs; November 2017 - November 2018

Report to Noosa Council, and Queensland Department of Agriculture and Fisheries

V2.0, following comments from Noosa Council

Dr Ben Gilby
Prof Thomas Schlacher,
Dr Andrew Olds,
Mr Nicholas Ortodossi,
Mr Ashley Rummell,
Dr Christopher Henderson,
Mr Thomas Brook,
Miss Cassandra Duncan,
Ms Felicity Hardcastle.

USC

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Executive summary

1) **Background & Rationale**
The principle objective of the Noosa Oyster Reef Restoration Project is to restore ecologically-functioning oyster reefs to the Noosa River Estuary. Reef units were installed in November 2017 to begin the restoration. An annual monitoring is part of the approval (OPW17/0016) that needs to report on: a) reef unit stability; b) oyster spat recruitment processes; c) lack of negative community usage; and d) impact on marine plants and shoreline erosion. This report addresses these requirements, reporting on the findings of two mandated monitoring events (May 2018, Nov. 2018) done by USC. The methods used were precisely those prescribed in the approved monitoring schedule, with no modifications.

2) **Stability and Position**
The reef units can be considered stable. The mean recorded change in position over 12 months was 0.16 m (+/- 0.12 m SD). All oyster reef restoration units moved less than 0.65 m over one year. No reef unit moved from the designated resource allocation areas at any site. No reef unit was physically displaced from its anchor points in the sediment or removed otherwise. These observations demonstrate that Unit Location Stability within year 1 are within the nominated Performance Objectives and therefore no corrective actions are required.

3) **Recruitment**
Substantial spat fall and oyster growth was found in both monitoring events. In May 2018, an average spat fall of 387.5 oysters/m^2 (+/- 537.7 oysters/m^2 SD) was recorded, and in November 2018 it was 306.1 oysters/m^2 (+/- 575.1 oysters/m^2 SD). There was a significant increase in the size of newly recruited oysters on the reefs. Here oysters increased in size from 14.3 mm (+/- 6.5 mm SD) in May 2018, to 19.1 mm (+/- 8.9 mm SD) in November 2018. The favourable spat fall and oyster growth are an encouraging bellwether for the reefs to develop into biologically stable systems over the coming years. The key performance indicators were for successful spat recruitment in at least 1 of the three years. This performance objective has been met. Insufficient data is available after 1 year of monitoring to demonstrate whether the key performance indicators of upward trends in sessile benthic invertebrates is available. Additionally, establishment of biogenic matrix is to be measured after three years, therefore no corrective actions are required in relation to recruitment at this stage.

4) **Interaction with Public**
There were signs of damage to a few reef units most likely caused by boat propellers and anchors, evident during the November 2018 monitoring event. We repaired these units where possible. Limited data suggest that the use of the oyster reefs by recreational fishers possibly appears to have increased over time. We suggest that closer monitoring of this aspect may be useful in coming years. No complaints were received in relation to the oyster restoration units. As such, no corrective actions were necessary.

5) **Marine Plants & Shoreline Erosion**
Whilst there was some change to the edges of seagrass beds, there were no significant changes to the distribution, cover, or species composition of existing seagrass beds or mangroves forests within 50 m of each reefs. We found no shoreline erosion in the vicinity of the reef units. At two sites in Lake Weyba and Weyba Creek dugong grass *Halophila ovalis was* found near reef sites where it was not recorded at the time of reef placement. Given that these results do not indicate substantial or consistent loss of marine plants or erosion, corrective actions in relation to this performance objective are not required at this time.

6) **Conclusions**

Overall, the results of the 2018 monitoring of the Noosa oyster reefs are encouraging and positive. Two of the targets have been fully met (reef unit stability, no impact on plants and shorelines). The target of oyster and other invertebrate growth is tracking very favourably. The observation of reef unit damage from anchoring needs consideration of closer monitoring and possibly targeted education / information may be considered for this issue. The next scheduled monitoring event is mandated for May 2019.

Introduction and context

Oyster reef restoration in the Noosa River;

The principal objective of the Noosa River Oyster Reef Restoration project is to restore natural oyster reef habitat in the Noosa Estuary. This requires the addition of suitable hard substrate for oyster spat to settle, and allowing natural recruitment and reef-formation processes to recover to areas that historically supported oyster reefs.

The oyster settlement substrate comprises *oyster reef restoration units*. These units are made from the most suitable recruitment material - oyster shells held together by a natural coir fiber bag. The units are raised above the muddy and sandy marine substrates, thereby mimicking the vertical relief of the original oyster reefs to facilitate natural recruitment processes (Figure 1, 2). We expected that natural recruitment processes would cement the dead shell together and form part of the mosaic of habitats within the estuary including both soft and hard structural habitat types, thereby creating a structurally diverse mosaic of habitats that is predicted to be beneficial to a range of fish species, including species of harvested in commercial and recreational fisheries (e.g. yellowfin bream, estuary cod, tailor, mangrove jack, and moses perch).

The restoration sites that were chosen as locations for oyster reef restoration in the Noosa River (Figure 3) because they:

1) are in reaches of the lower Noosa River estuary and in Weyba Creek from which oysters were harvested historically;
2) are within the depth range known to be suitable for oyster reefs to grow;
3) are in locations where viable oyster larvae were recorded during recent recruitment studies; and
4) have an extent where the final restored area will not exceed the historical areal extent of oyster reefs before commercial harvesting took place.

Figure 1 Coir mesh bag filled with recycled oyster shells; the principle restoration unit

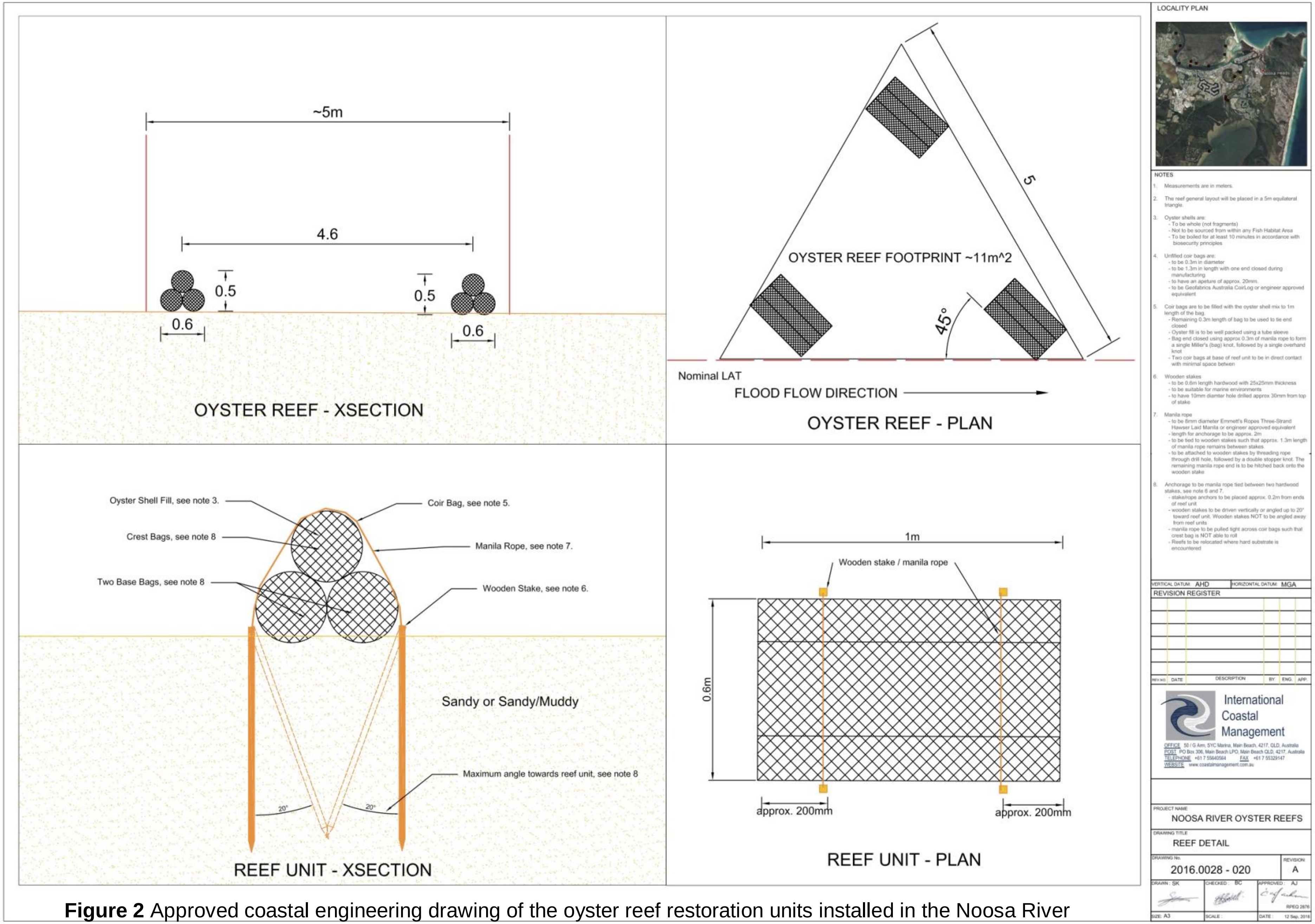

Figure 2 Approved coastal engineering drawing of the oyster reef restoration units installed in the Noosa River

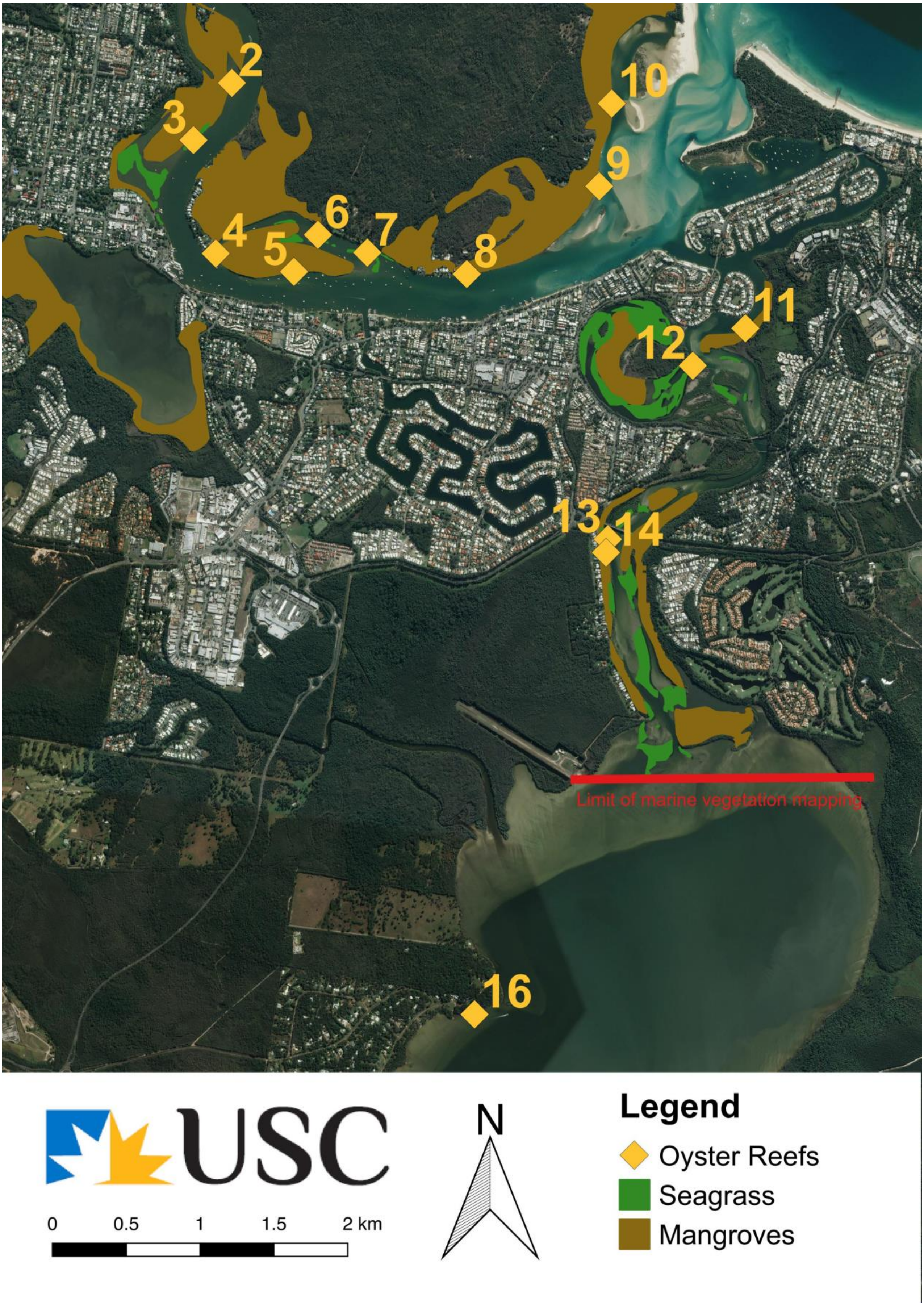

Figure 3 Map of oyster restoration sites and marine habitats in the Noosa River

Oyster reef unit installations
The installation of oyster reef units to the Noosa River was done during a period of three days, from 20 to 22 November 2017 (Figure 4). All works and surveys were conducted by a team comprising professionals of Noosa Jetty Builders, and marine scientists from the University of the Sunshine Coast. All oyster reef units and signs were installed exactly according to specifications set out in the permit conditions and any instructions provided regarding procedures (Table 1). All reef units are located to avoid any damage to marine plants or surrounding ecosystem (Table 1, Figure 4). Key observations during the placement of the reef units and associated signage include the following:

- No marine plants were disturbed during the installation of the reef units or signs. Before each reef unit was placed on the seafloor, we carefully examined the site to ascertain that no seagrass, mangrove aerial roots, or any other marine vegetation was present. This ensured that no direct placement impacts occurred at any of the sites (Table 1). Pre and post installation photographs are available from the USC team.
- All operations were localised to the immediate site where reef units were sunk onto the seabed. Thus, no habitat outside the RAA area was impacted in any form by the reef units or the signage.
- Poles holding the signs were installed using a narrow water jet 'spear'. Use of this gear ensured that only a very narrow (< 20 cm diameter in all cases) area of the seabed was disturbed (Figure 4). Sign posts were then driven further into the substrate, to a mean depth of 2.7 m (min 1.8 m, max 3.5 m; Table 1), using a post driver (Figure 4).
- According to engineering specifications, we used marine grade hardwood stakes (sourced from the Australian Hardwood Stake Company) to secure the reef units on the seafloor. The stakes were hammered into the seabed to a mean depth of 0.9 m (min 0.5 m, max 1.2 m) - depending on hardness of the seabed (Table 1), at a mean angle of 82.4º (min 75 º, max 90 º).
- Pre- and post-installation photographs and videos of all sites are available electronically (OneDrive folder). Full access to the all electronically stored imagery has been provided to Noosa Council. In addition, we are happy to grant access to whoever may require it (please email: bgilby@usc.edu.au).

Figure 4 The resulting very small footprint of sign posts following installation by the water jet (left) and a completed oyster reef in Weyba Creek (right).

Table 1. Completed oyster-reef installations in the Noosa River, listing their exact position, the date of placement, characteristics of posts and stakes driven into the seabed to secure signage and reef units, and any presence and/or damage to marine vegetation.

Site Number	Position		Installation date	Depth to which sign post is driven into the seabed (m)	Stakes to secure reef units		Presence of, or damage to, marine plants and/or adjacent habitats or ecosystems.
	Latitude	Longitude			Depth of stake into seabed (m)	Angle of stake relative to seabed (degrees)	
1	reef units not installed - seabed not compact enough						
2	-26.38333096	153.045835	20/11/17	2.8	1.2	79	None
3	-26.38673804	153.043291	20/11/17	2.8	1.2	75	None
4	-26.39367197	153.044599	20/11/17	2.9	1.1	84	None
5	-26.394757	153.049933	20/11/17	2.4	0.5	82	None
6	-26.39245399	153.051636	20/11/17	3.2	1.2	85	None
7	-26.39351204	153.054941	20/11/17	3.3	1.2	77	None
8	-26.39491903	153.061679	20/11/17	2.4	1.2	90	None
9	-26.38954598	153.070696	21/11/17	1.8	0.5	86	None
10	-26.38452999	153.071546	21/11/17	2.0	0.6	87	None
11	-26.39817104	153.080595	21/11/17	2.3	0.5	76	None
12	-26.40045603	153.077035	21/11/17	2.9	0.5	79	None
13	-26.41099703	153.071263	22/11/17	3.5	1.2	87	None
14	-26.41184301	153.0712	22/11/17	3.2	0.5	83	None
15	reef units not installed – presence of seagrass						
16	-26.43981904	153.062079	22/11/17	2.9	0.6	84	None

Noosa River oyster reef restoration monitoring schedule

As part of the development approval for installing the oyster reefs, the stakeholders report yearly (in December) to Queensland Department of Agriculture and Fisheries on the progress of the oyster restoration project, especially relating to;

1. Oyster restoration unit stability (i.e. oyster reef restoration units remain within the allocated resource allocation areas);
2. Restoration of natural recruitment processes over long term (i.e. spat recruitment rates demonstrate that the biogenic matrix will be sufficient to hold the structure of the oyster reef restoration units in place following complete degradation of the supporting coir material during the establishment phase and to facilitate ongoing natural recruitment processes);
3. Equitable Community Impacts (i.e. ensuring fair community use of the river system is not impacted by placement of the Oyster Reef Restoration Units within the Resource Allocation Areas - to be monitored using a council operated community feedback system); and
4. No negative impact on marine plants or shoreline erosion (i.e. ensuring the oyster restoration units do not impede natural marine plant growth or accelerate coastal erosion processes).

These performance objectives are quantified using established monitoring protocols for oyster reef restoration, and follow international best practice for monitoring restored oyster habitats (Baggett et al. 2014). The monitoring program is designed to be adaptive, with annual reviews against the performance objectives for the project (See Table 2 for detailed monitoring requirements).

Two monitoring events occurred in 2018; one 6 months post installation in May 2018, and the other 12 months post installation in November 2018. The results of these monitoring events are covered in this report. There have also been detailed surveys of the fish and crustacean assemblages associating with the reefs throughout 2018. Although the details of these surveys are not covered in this report, they are available from USC upon request.

Table 2 Noosa oyster reef restoration monitoring schedule as agreed to by all stakeholders in RAA 2016CA0575, and including mark-ups from Department of Agriculture and Fisheries dated 6 January 2017.

Performance objective	Monitoring method	Frequency	Corrective action where performance objective is not met	Page in this report
1. Oyster Restoration Unit location stability				
Oyster restoration units remain within the designated Resource Allocation Areas.	Visually inspect the stability of oyster reef units and record the precise GPS position (± cm scale), and size of each unit (following international best practice: Baggett et al. 2015). Use GIS software to contrast the position, footprint, size and area of oyster reef restoration units between monitoring events and assess any potential movement.	Every 6 months for a minimum of three years Additional monitoring will be conducted within 2 weeks of substantial rainfall events (i.e. events that exceed 50-year Average Rainfall Intervals).	A professional coastal engineer shall be consulted to suggest remedial action for any oyster reef restoration units that collapse, or shift by > 1 m. Any oyster reef restoration units that move outside the designated Resource Allocation Areas within 3 years will be removed. A professional ecologist will confirm the cause of the shift.	Page 14
2. Natural Recruitment Processes				
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. The Key Performance Indicators for this are: **1.) Oyster recruitment**: successful recruitment of oyster spat in at least 1 out of the 3 years (i.e. 33% of the time) post deployment (following international best practice of 40%: Baggett et al. 2015).[1]; 2**.) Cover of oysters and other sessile benthic invertebrates**: an upward trend in the cover of sessile benthic invertebrates growing on restoration units; and	Quantify the recruitment of oysters and other sessile benthic invertebrates to reef restoration units, and measure changes in the cover of oysters and other sessile benthic invertebrates over time (following international best practice: Baggett et al. 2015).[1] The monitoring methods for each Indicators are: **1.) Oyster recruitment**: marked oyster shells will be fastened to the outside of restoration units. These shells will be harvested at regular intervals (15 oyster shells per location on each event – i.e. 5 shells per unit) and the density and size of recruits recorded; 2**.) Cover of oysters and other sessile benthic invertebrates**: photographs of ten quadrats (25 cm x 25cm), distributed in a stratified random design, across each oyster reef restoration unit will be taken at regular intervals to quantify the change in cover of oysters and other sessile benthic invertebrates (Baggett et al. 2015)[1]. **3.) Establishment of stable biogenic matrix**: assess the structural integrity of each oyster reef restoration unit and monitor the degradation of coir material. Structural integrity will be quantified by	Every 6 months for a minimum of three years, unless otherwise detailed within corrective actions	We will contrast: 1) the rate of oyster recruitment; 2) the cover of oysters and all other sessile benthic invertebrates; and 3) the stability of the biogenic matrix among oyster reef restoration units and between monitoring events. Any restoration units that fail to meet the Key Performance Indicators within 3 years will be removed. If major damage occurs to the coir mesh of any oyster reef restoration units before a stable biogenic matrix has formed, and loose oyster shells are being lost from the structure, it will be repaired *in-situ* by hand weaving. Any such repairs will be conducted carefully, and by hand, to ensure that there is no damage to established areas of biogenic matrix.	Page 23

3.) Establishment of stable biogenic matrix: 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.	measuring the proportion of oyster shells (from 10 shells that are selected at random at each location), which can be removed easily by hand manipulation. The rate of coir degradation will be measured by monitoring changes to the condition of coir mesh over time from the ten photo-quadrats, which are collected twice per year to assess changes in the cover of benthic invertebrates at each oyster reef restoration unit.			
3. Community use and enjoyment of the declared Fish Habitat Area				
Oyster restoration units do not significantly impair community use and enjoyment of the declared Fish Habitat Area, particularly fishing activities.	Maintain records of community feedback, evidence of vandalism, and vessel strikes on the trial oyster reef restoration units. Records will be comprehensive and include, as a minimum set: 1) the number and type of **complaints** received (also, to allow the Department to gauge the success, any positive comments should also be provided); 2) the type, nature, and severity of any acts of **willful vandalism**; and 3) the type and severity of any **vessel strike**.	Annual reporting of all complaints, cases of willful vandalism, and instances of vessel strike received for the three-year trial period.	**Complaints**: within 3 months of receiving each complaint, an investigation (including interview with the complainant if possible) will be conducted to determine whether complaints are directly related to oyster reef restoration units. Potential response actions will be provided to the Department of Agriculture and Fisheries in the annual report. If complaints persist, and grievances exceed the direct benefit of oyster reef restoration, the particular oyster reef restoration unit will be removed as soon as practical, and prior to the 4th anniversary post deployment. **Willful vandalism and vessel Strikes** If there are consistent and / or significant cases of willful vandalism to, or instances of vessels striking, the oyster reef restoration units, the cause of the impact will be identified and used to guide the delivery of a community education campaign aimed at reducing these types of incidents. If the education campaign does not reduce cases of willful vandalism and / or instances of vessel strike, the oyster reef restoration units that are responsible will be removed prior to the 4th anniversary post deployment.	Page 27

4. Other potential effects:				
Oyster reef restoration units do not cause a decline in the extent of marine plants within a 50 m radius of the restoration units, and are not attributed to erosion of adjacent shorelines or other ambient environmental impacts.	Map the area of marine plant habitats (seagrass, mangroves) in the immediate vicinity (i.e. with a 50 m buffer) of each oyster restoration area, using high-resolution GPS (cm scale) and field-validated aerial imagery (sourced from Nearmap). Monitor changes in the composition coverage and condition of seagrass within 50 m radius around the oyster reefs. Map the location and condition of estuarine shorelines that occur in the immediate vicinity (i.e. with a 50 m buffer) of each oyster reef, using high-resolution GPS (cm scale) and field-validated aerial imagery (sourced from Nearmap).	Annually for a minimum of three years, or until any failed restoration units have been removed.	Where monitoring shows that there are substantial, and consistent, losses of marine plants, or erosion of estuarine shorelines, in the immediate vicinity of oyster reef restoration units, and these changes can unambiguously be attributed to oyster reef restoration activities, the problem units that are responsible for such impacts shall be removed (as soon as practical and prior to the following annual reporting anniversary).	Page 31

Monitoring criteria 1- Oyster restoration unit location stability

Performance objective

Oyster restoration units remain within the designated Resource Allocation Areas.

Monitoring method and frequency

Visually inspect the stability of oyster reef units and record the precise GPS position (± cm scale), and size of each unit (following international best practice: Baggett et al. 2015). Use GIS software to contrast the position, footprint, size and area of oyster reef restoration units between monitoring events and assess any potential movement.

Frequency: Every 6 months for a minimum of three years. Additional monitoring will be conducted within 2 weeks of substantial rainfall events (i.e. events that exceed 50-year Average Rainfall Intervals).

Was the performance objective met?

No units moved by more than 1 m or outside of the RAA area, and all repairable reefs were repaired. Therefore, all aspects of this performance objective were met, and no further action is necessary.

Supporting Evidence

We used a CHC X91 RTK GPS to measure the positions of the reef units. The unit connects to the surrounding mobile network (Telstra) which has a known position, and so our measures a fixed, known positional error of +/- 1cm horizontally, and +/- 2cm vertically.

No oyster restoration units moved beyond the RAA areas, and no units moved more than 1 m during either monitoring event (Table 3). Maps of each of the sites (Figures 5 to 18) are provided below to support this lack of movement of bags. High-resolution maps and csv files of the locations of the reefs at all three survey points (following installation, and at 6 and 12 month monitoring events) are available from USC upon request.

Table 3 List of reef site sites and reef units, their positions as given by the coastal surveyor, and the distance these units had moved from the initial installations (as recorded by the coastal surveyor) to the 6 and 12 month monitoring events. Distances measured are from the center points of oyster restoration units.

Site	Surveyor ID	Easting (GDA94)	Northing (GDA94)	Distance moved 6 months (m)	Distance moved 12 months (m)
2	2.1	504557.693	7081870.54	0.01	0.12
	2.2	504562.401	7081871.525	0.09	0.04
	2.3	504561.797	7081866.981	0.11	0.06
3	3.1	504297.232	7081482.809	0.05	0.17
	3.2	504300.191	7081487.149	0.21	0.08
	3.3	504302.058	7081482.224	0.30	0.03
4	4.1	504447.682	7080720.227	0.39	0.09
	4.2	504451.864	7080722.81	0.33	0.28
	4.3	504452.517	7080718.084	0.13	0.17
5	5.1	504977.921	7080596.146	0.20	0.02
	5.2	504980.268	7080598.985	0.08	0.11
	5.3	504983.03	7080596.309	0.28	0.37
6	6.1	505140.806	7080848.337	0.19	0.09
	6.2	505147.768	7080846.296	0.20	0.42
	6.3	505142.59	7080842.496	0.20	0.14
7	7.1	505475.222	7080728.716	0.02	0.21
	7.2	505481.921	7080724.223	0.06	0.07
	7.3	505476.882	7080722.755	0.20	0.20
8	8.1	506148.168	7080578.329	0.44	0.11
	8.2	506151.843	7080583.145	0.12	0.16
	8.3	506154.632	7080579.701	0.57	0.65
9	9.1	507047.3	7081174.147	0.24	0.22
	9.2	507052.487	7081172.727	0.46	0.12
	9.3	507048.33	7081169.39	0.03	0.15
10	10.1	507131.275	7081731.424	0.10	0.21
	10.2	507136.871	7081731.471	0.18	0.11
	10.3	507135.843	7081726.658	0.27	0.10
11	11.1	508035.278	7080213.498	0.03	0.17
	11.2	508040.293	7080216.237	0.15	0.14
	11.3	508038.955	7080212.182	0.23	0.07
12	12.1	507678.59	7079963.401	0.17	0.07
	12.2	507684.058	7079964.39	0.18	0.11
	12.3	507683.416	7079959.64	0.06	0.10
13	13.1	507103.328	7078792.463	0.20	0.12
	3.2	507107.243	7078796.008	0.16	0.08
	13.3	507107.661	7078790.417	0.06	0.15
14	14.1	507090.833	7078704.893	0.18	0.25
	14.2	507094.457	7078706.761	0.20	0.39
	14.3	507094.824	7078701.819	0.12	0.13
16	16.1	506199.719	7075595.579	0.21	0.07
	16.2	506204.963	7075595.325	0.18	0.04
	16.3	506200.595	7075590.153	0.16	0.19
			Mean	0.18	0.16
			StDev	0.12	0.12

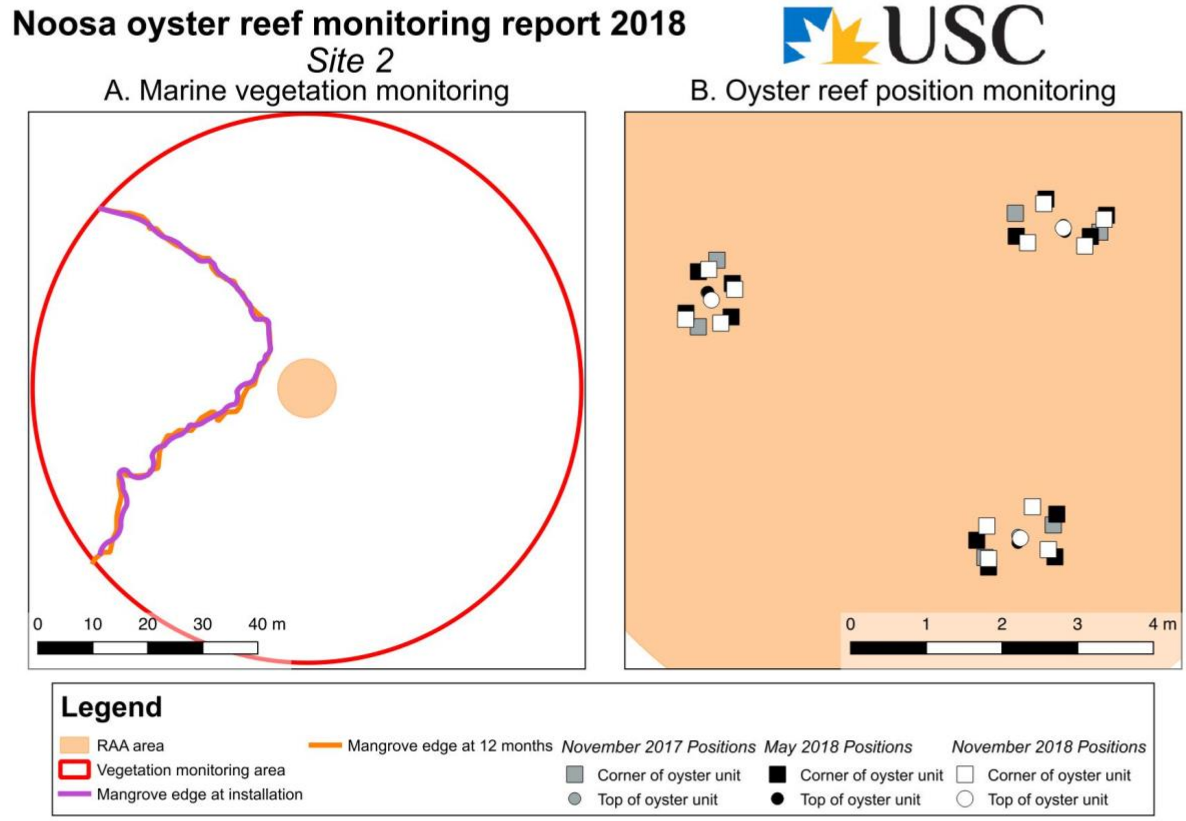

Figure 5 Map of (A) mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 2 in the Noosa River.

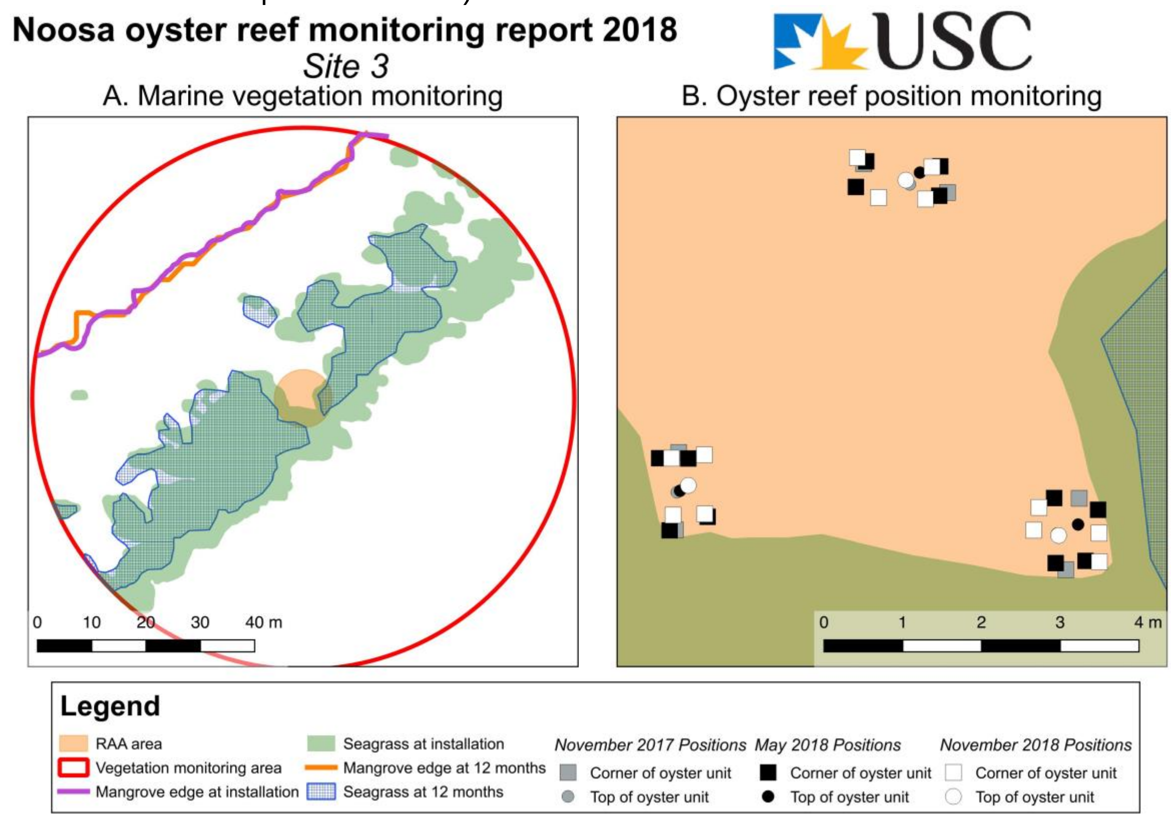

Figure 6 Map of (A) aerial extents of seagrass and mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 3 in the Noosa River.

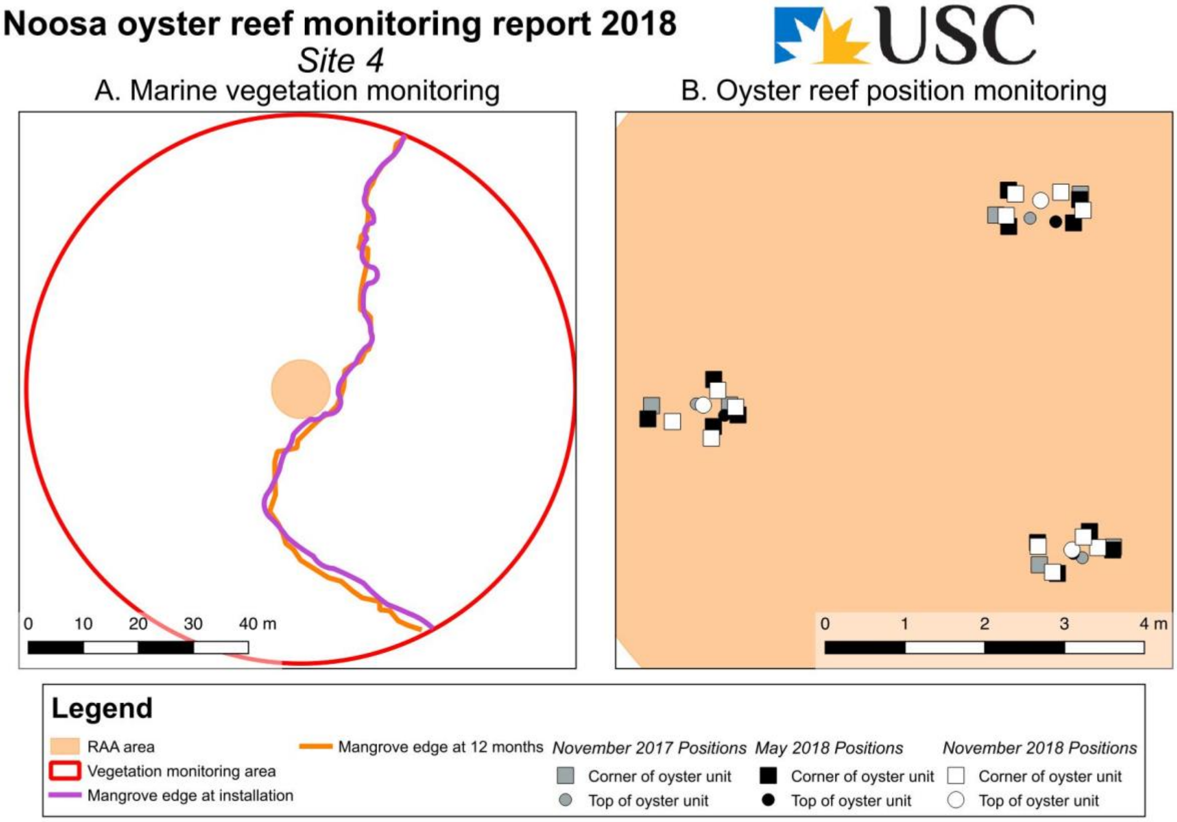

Figure 7 Map of (A) mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 4 in the Noosa River.

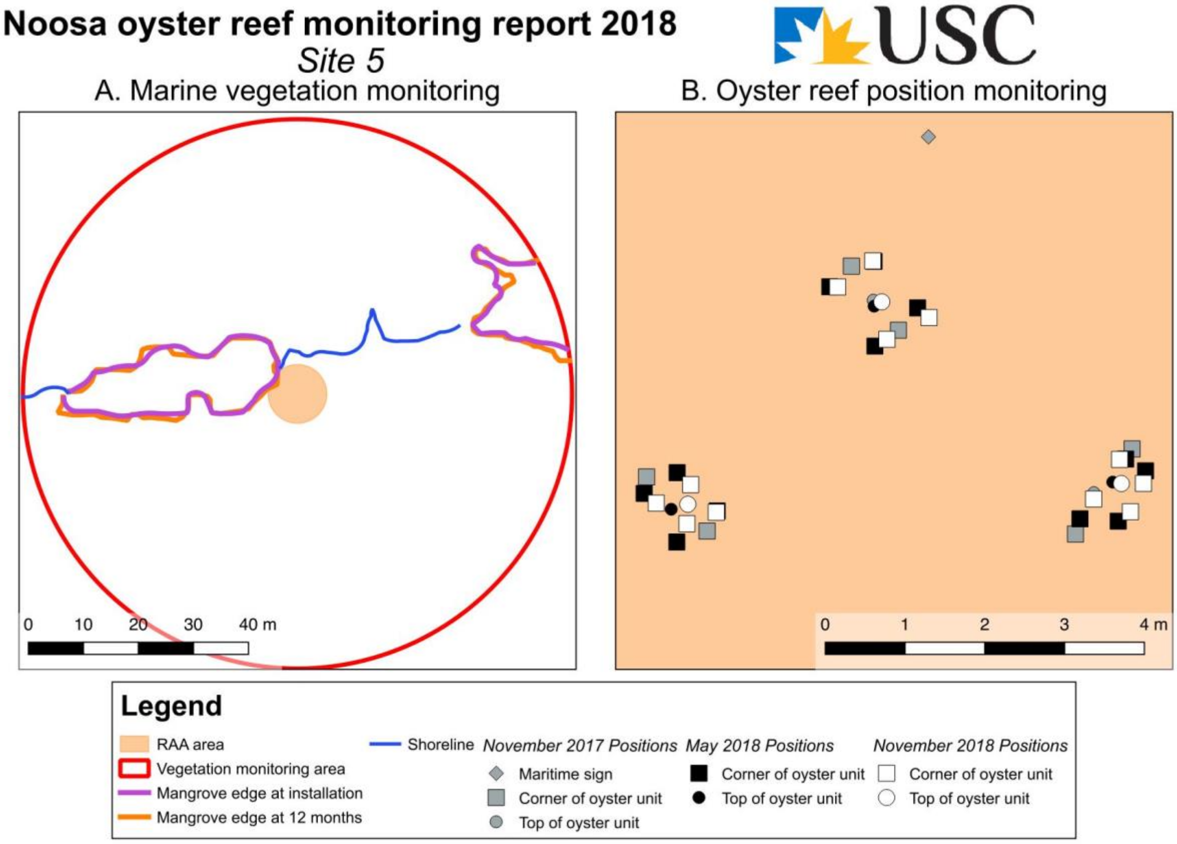

Figure 8 Map of (A) aerial extents of seagrass and mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 5 in the Noosa River.

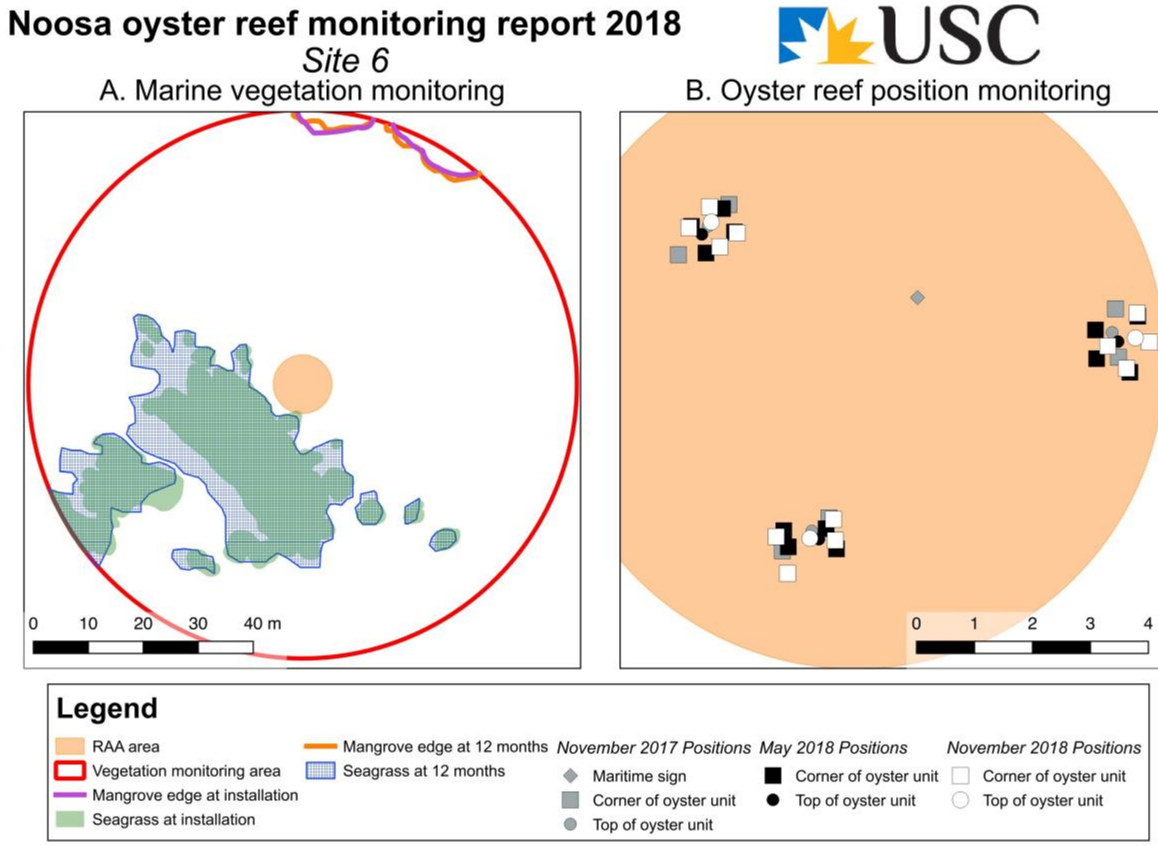

Figure 9 Map of (A) aerial extents of seagrass and mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 6 in the Noosa River.

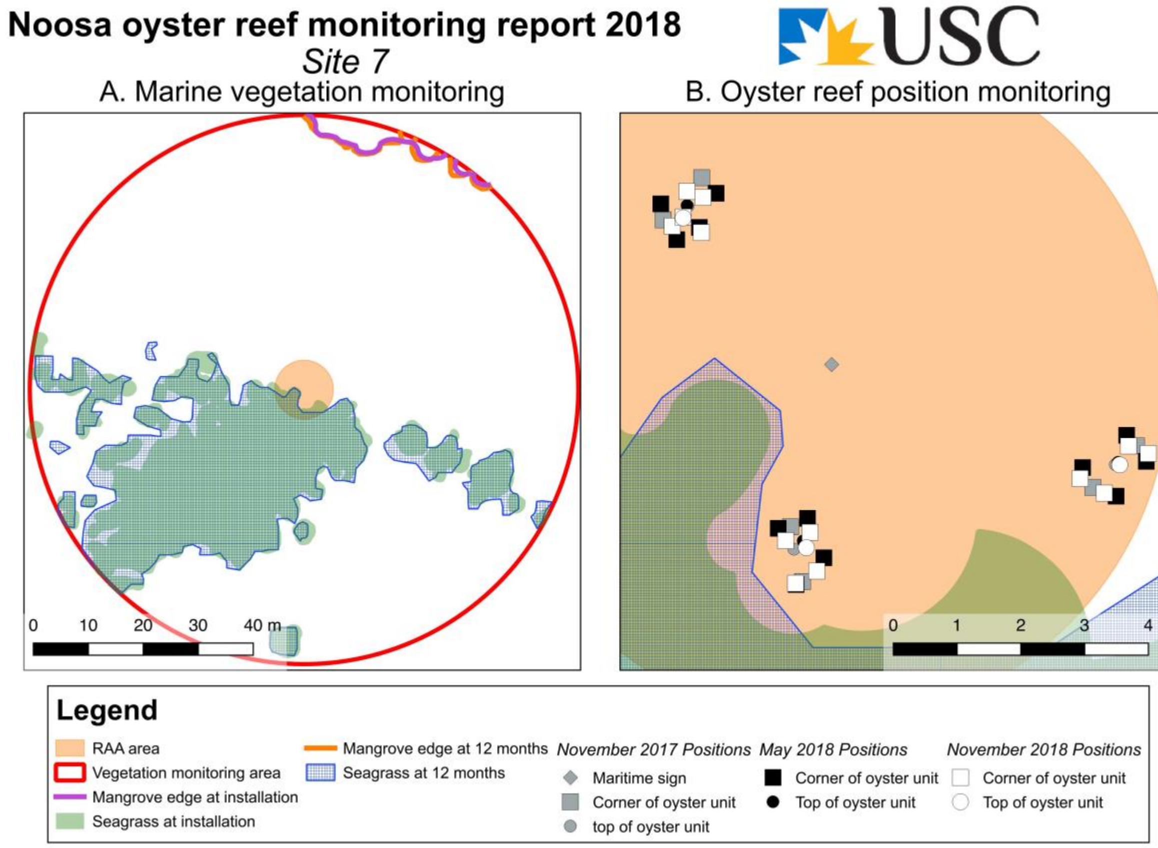

Figure 10 Map of (A) aerial extents of seagrass and mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 7 in the Noosa River.

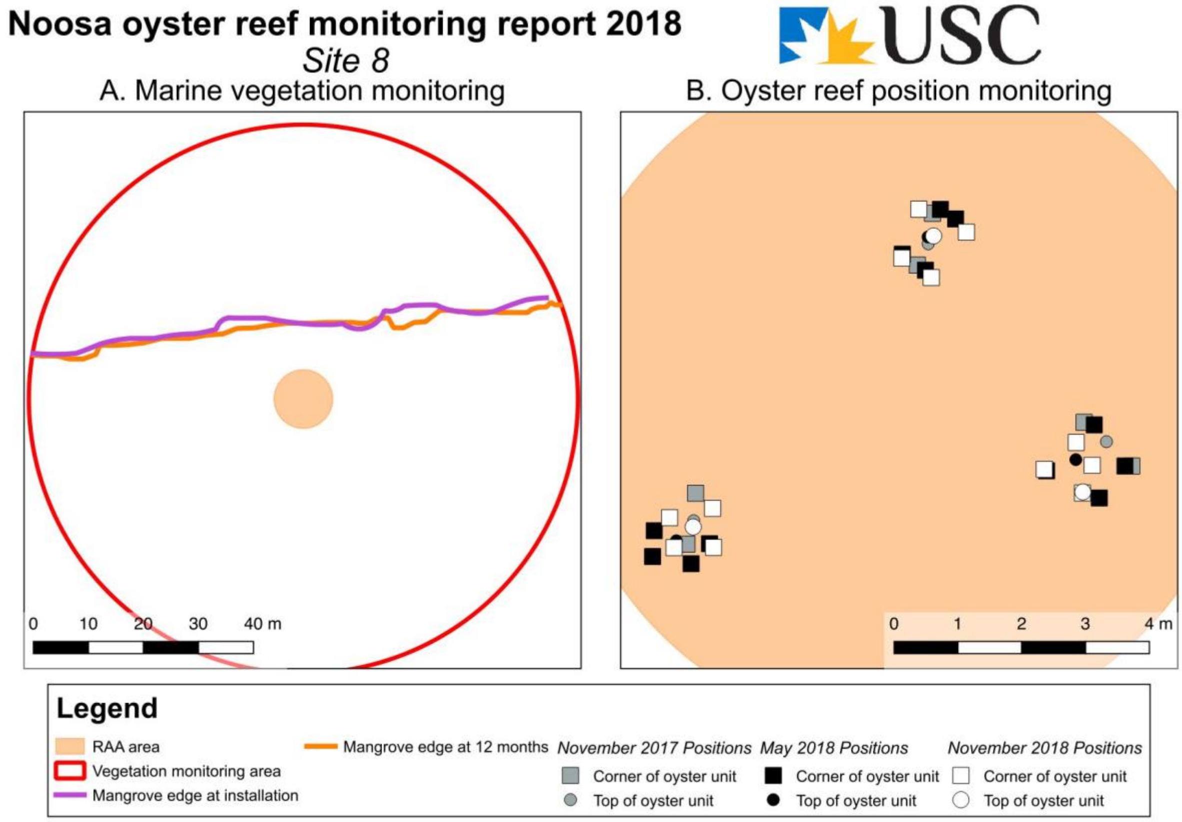

Figure 11 Map of (A) mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 8 in the Noosa River.

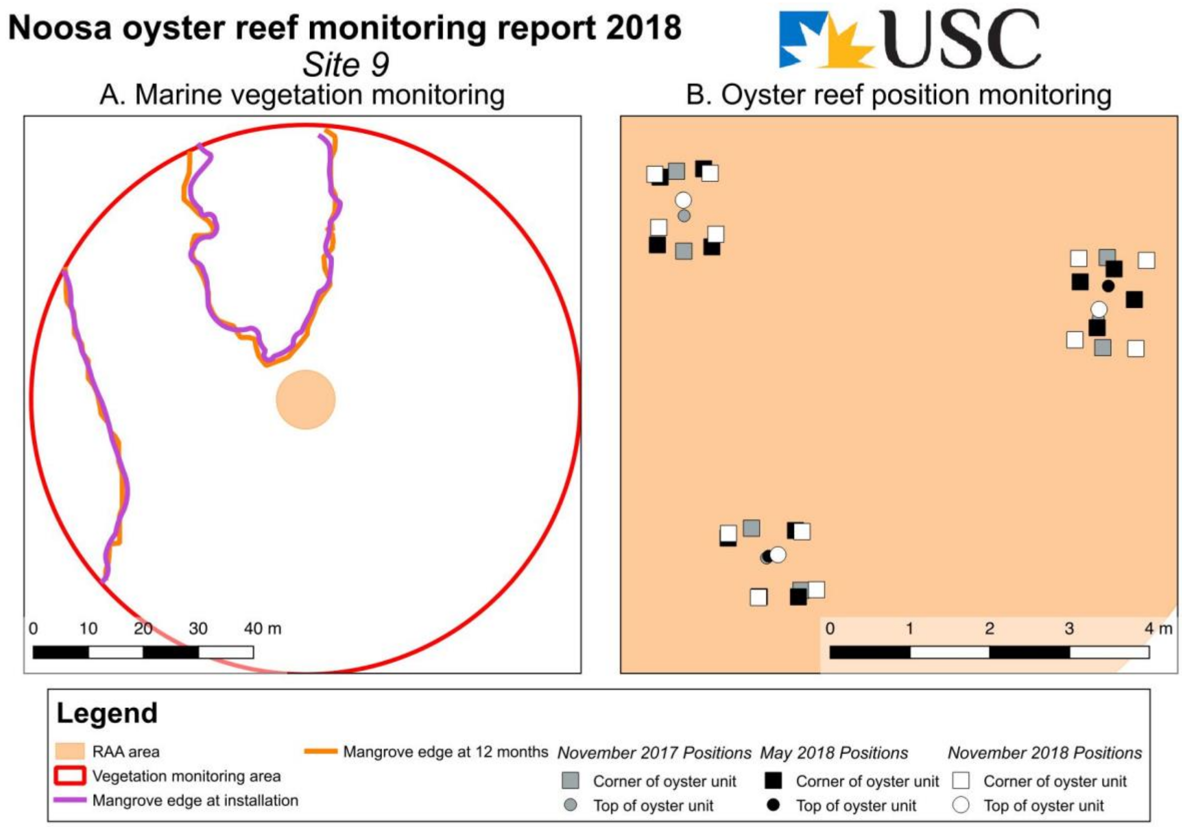

Figure 12 Map of (A) mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 9 in the Noosa River.

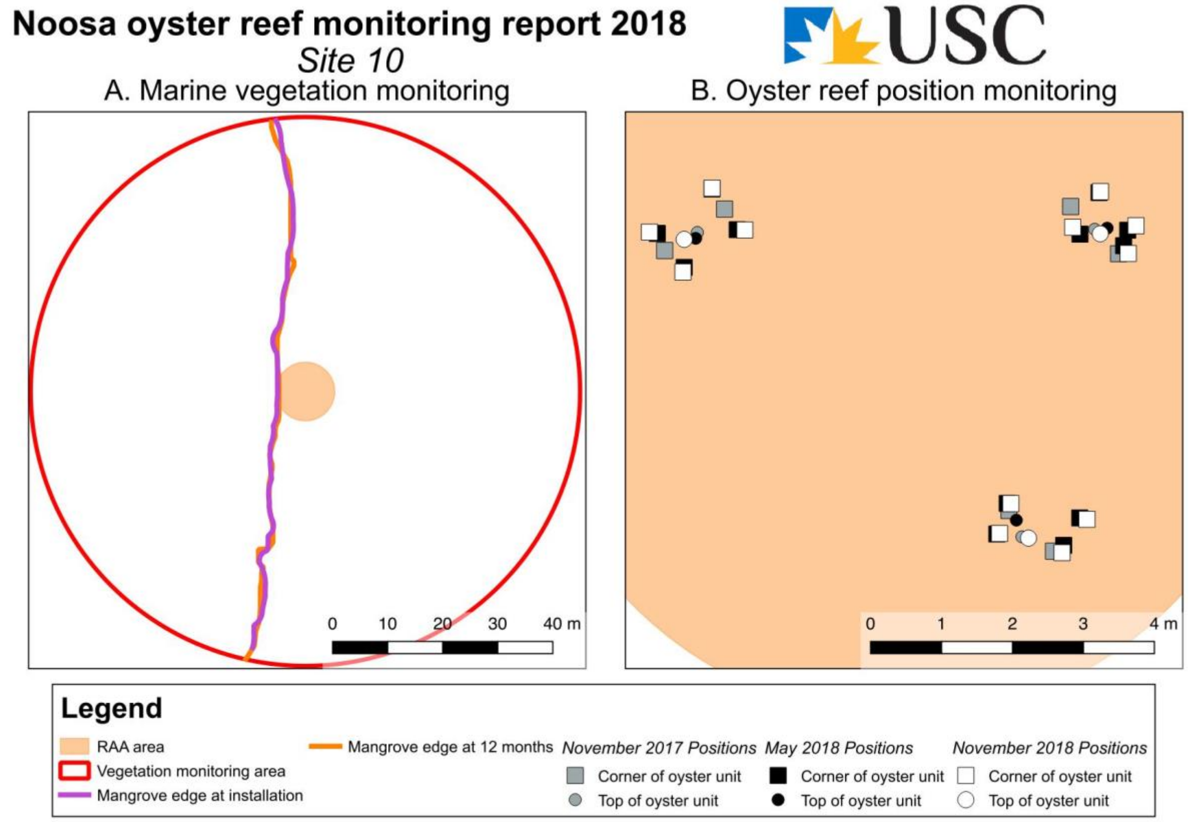

Figure 13 Map of (A) mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 10 in the Noosa River.

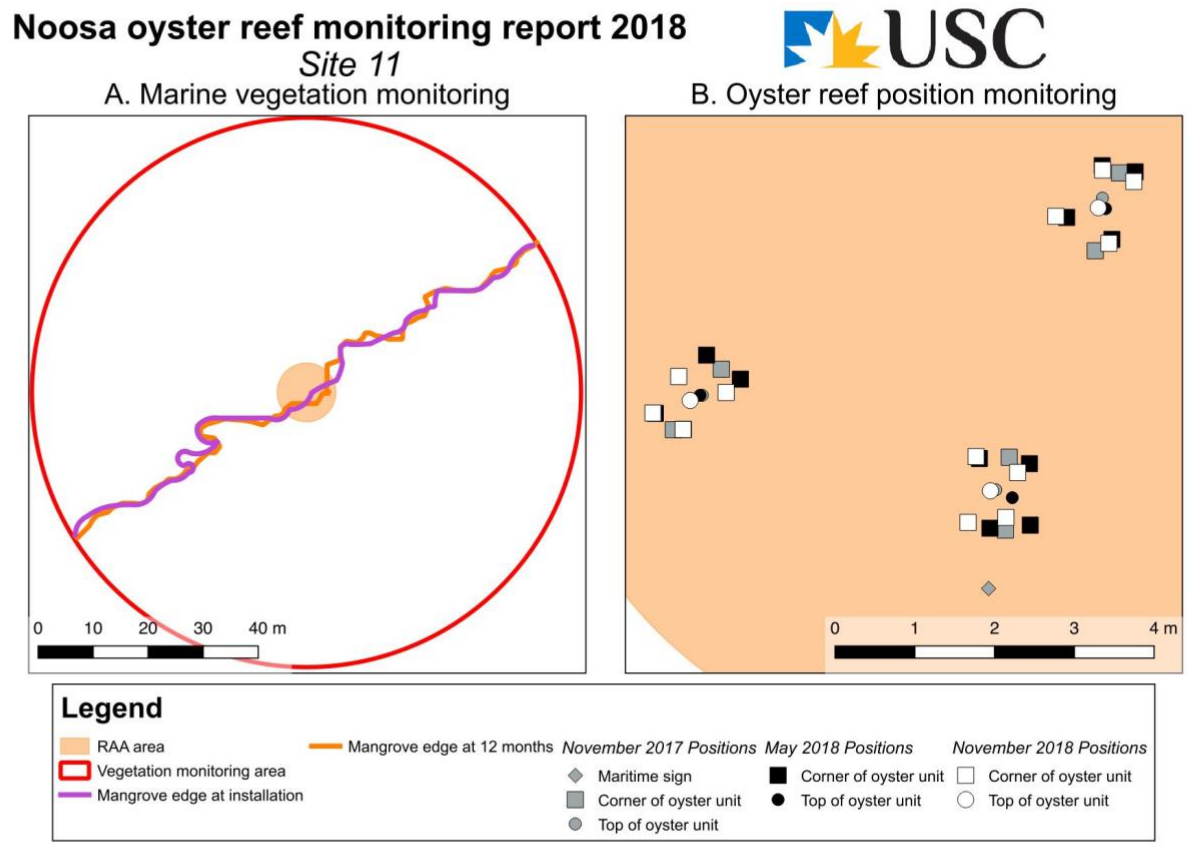

Figure 14 Map of (A) mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 11 in the Noosa River.

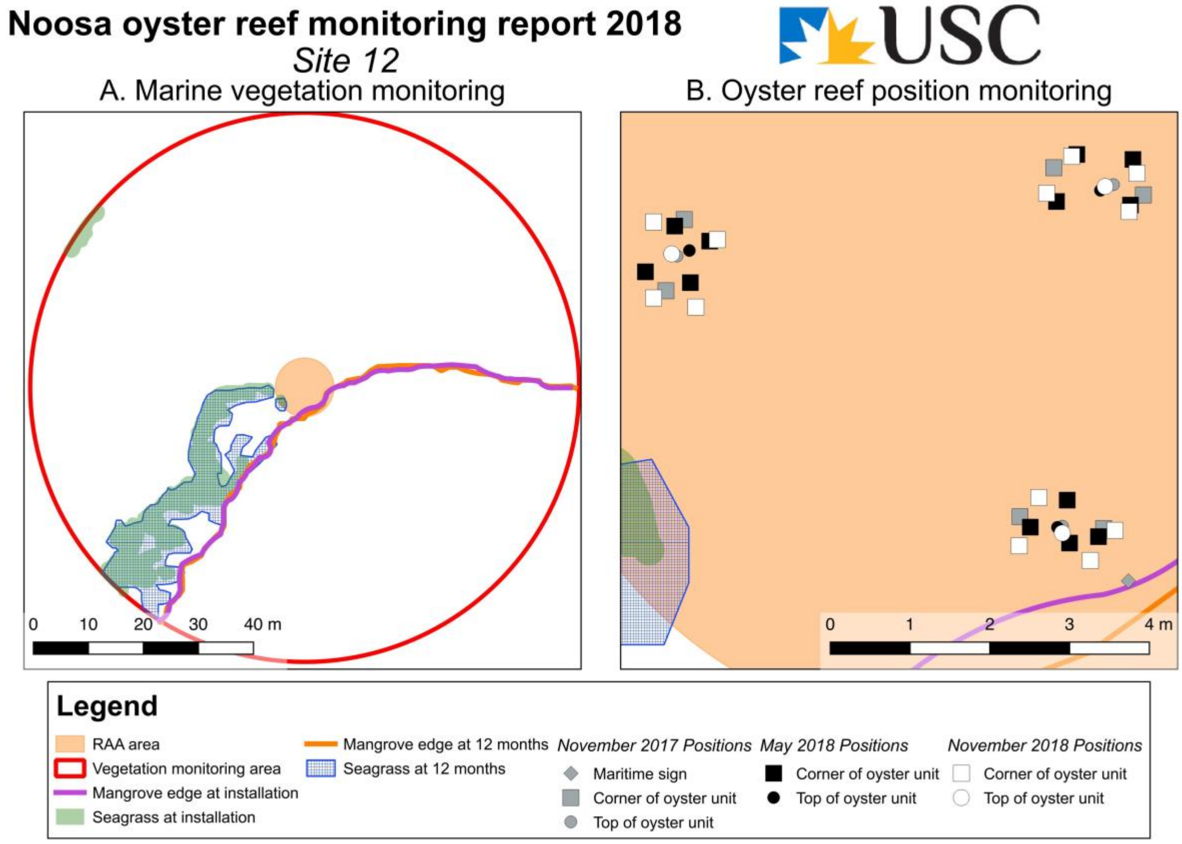

Figure 15 Map of (A) aerial extents of seagrass and mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 12 in the Noosa River.

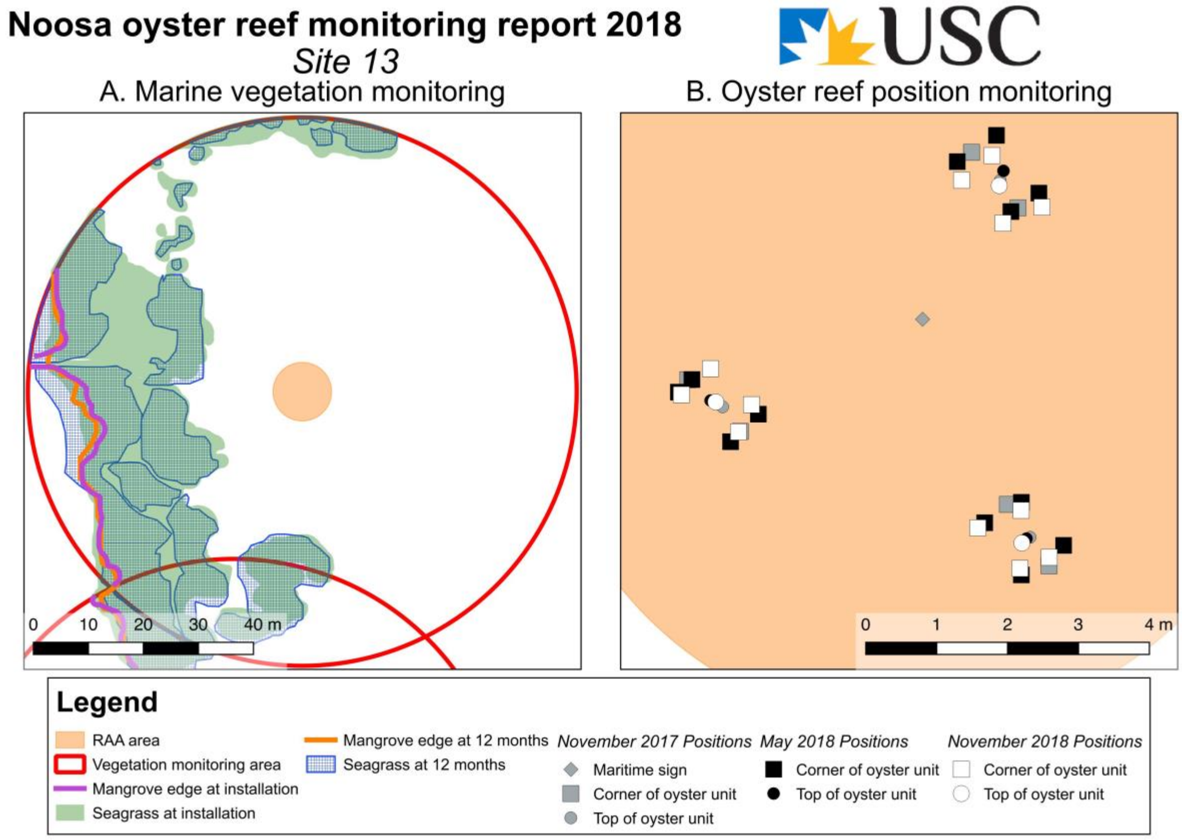

Figure 16 Map of (A) aerial extents of seagrass and mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 13 in the Noosa River.

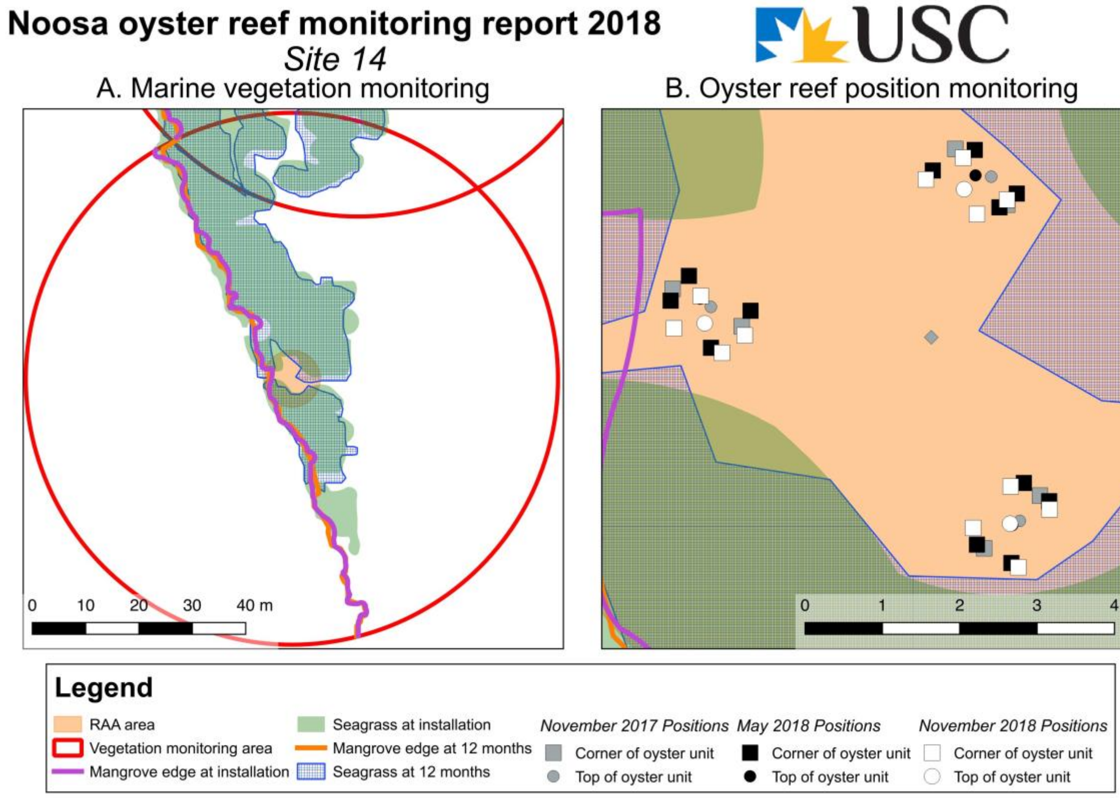

Figure 17 Map of (A) aerial extents of seagrass and mangrove edges and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 14 in the Noosa River.

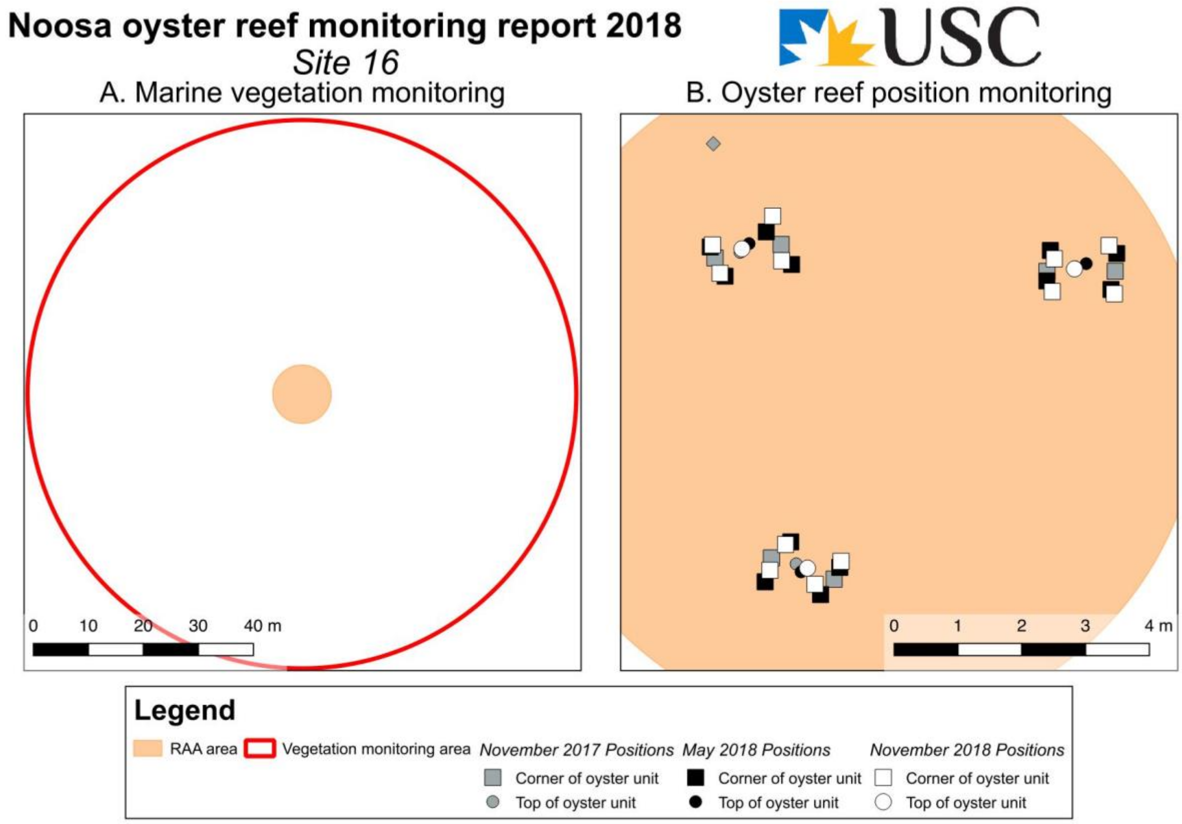

Figure 18 Map of (A) vegetation monitoring area (note there was no seagrass or mangroves at this site) and (B) oyster reef unit positions (at installation, and at 6 and 12 months post installation) at site 16 in the Noosa River.

Monitoring criteria 2- Natural recruitment processes

Performance objective: 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. The Key Performance Indicators for this are:

1. **Oyster recruitment**: successful recruitment of oyster spat in at least 1 out of the 3 years (i.e. 33% of the time) post deployment (following international best practice of 40%: Baggett et al. 2015);
2. **Cover of oysters and other sessile benthic invertebrates**: an upward trend in the cover of sessile benthic invertebrates growing on restoration units; and
3. **Establishment of stable biogenic matrix**: 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.

Monitoring method: Quantify the recruitment of oysters and other sessile benthic invertebrates to reef restoration units, and measure changes in the cover of oysters and other sessile benthic invertebrates over time (following international best practice)(Baggett et al., 2015). The monitoring methods for each Indicators are:

1. **Oyster recruitment**: marked oyster shells will be fastened to the outside of restoration units. These shells will be harvested at regular intervals (minimum of 15 oyster shells per location on each event – i.e. 5 shells per unit) and the density and size of recruits recorded;
2. **Cover of oysters and other sessile benthic invertebrates**: photographs of ten quadrats (25 cm x 25cm), distributed in a stratified random design, across each oyster reef restoration unit will be taken at regular intervals to quantify the change in cover of oysters and other sessile benthic invertebrates (Baggett et al., 2015).
3. **Establishment of stable biogenic matrix**: assess the structural integrity of each oyster reef restoration unit and monitor the degradation of coir material. Structural integrity will be quantified by measuring the proportion of oyster shells (from 10 shells that are selected at random at each location), which can be removed easily by hand manipulation. The rate of coir degradation will be measured by monitoring changes to the condition of coir mesh over time from the ten photo-quadrats, which are collected twice per year to assess changes in the cover of benthic invertebrates at each oyster reef restoration unit.

Frequency: Every 6 months for a minimum of three years, unless otherwise detailed within corrective actions

Was the performance objective met?

We identified significant oyster spat settlement and growth at all oyster reefs. Whilst this has not yet proliferated to cover of oysters on the outside of the restoration units, or to fully cementing shells within the units together, these positive spat fall and growth results indicate that these performance criteria are likely to be met in the coming years. Therefore, no further action is necessary at this early stage of the project.

Supporting evidence

Oyster recruitment

Oyster restoration units are defined as the piles of three bags at the corner of the equilateral triangle of reefs at each resource allocation authority area. We collected shells from two sources form each oyster restoration unit;

1. 5 shells collected from within the coir bags at each oyster restoration unit (henceforth ‘bags’), and
2. 5 shells collected from ‘oyster necklaces’ which were strings of drilled oyster shells tied together with fishing line and then affixed to the top of the oyster restoration units during installation (henceforth ‘necklaces’).

This resulted in 30 shells being collected from each location (i.e. 3 oyster restoration units times 10 (5 necklaces, 5 from the bags) at each), thereby satisfying the requirement of ‘a minimum if 15 shells from each location'. . All live oysters growing on the shells were identified to species, counted, and their height measured, and the density of oysters calculated as number of oysters per square meter of shell (as recommended by Baggett et al., 2015).

We identified significant oyster settlement during both monitoring events on both necklaces and in the oyster restoration unit bags (Figure 19, Figure S1, Table 4, Table 5). Overall, we identified an average of 387.5 spat/m^2 in May 2018, 306.1 oysters/m^2 in November 2018, and 349.9 oysters/m^2 across both monitoring events (Table 4). Whilst we identified some changes in the densities of oysters at specific restoration sites (Figure S1, Table 5), with some sites showing increased oyster density between sampling events, and others lower oyster density, the overall pattern was for a reduction in oyster density between monitoring events 1 and 2 (Table 4). This change was, however, offset by a significant change in the size-frequency distribution of oyster shells on the reefs (Figure 20, Figure S2). Here oysters increased in size from 14.3 mm (+/- 6.5 mm SD) in May 2018, to 19.1 mm (+/- 8.9 mm SD) in November 2018. Consequently, it is likely that intermediate sized oysters (6-15 mm in length) in May 2018 grew to the larger sizes (i.e. <30 mm) by November 2018, and that the smaller oysters (<6mm) either grew to an intermediate size, or did not survive the winter. Consequently, despite a reduction in overall average density, this was offset by a larger average oyster size during the second monitoring event.

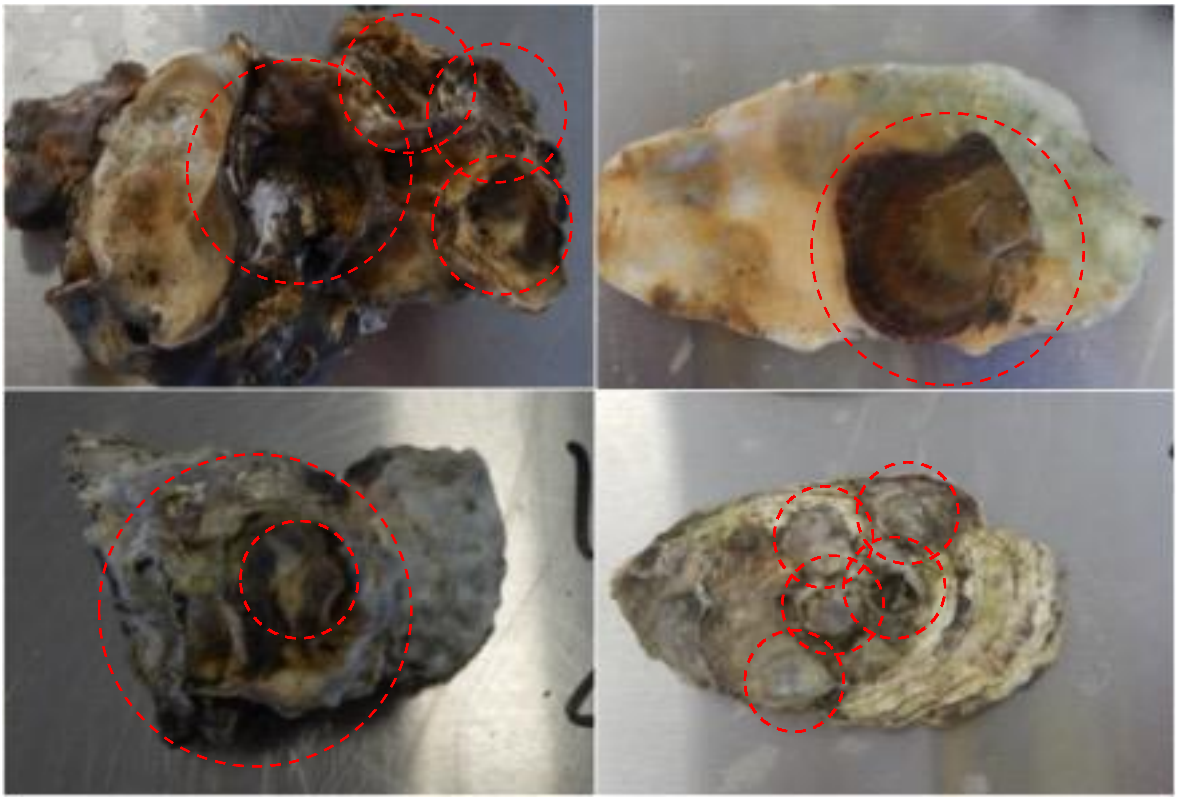

Figure 19 Example images of juvenile oysters growing on shells collected from within the oyster reef restoration units. Spat shown using red dashed circles.

Table 4 List of oyster quantification methods, and the average densities (with standard deviations) of oysters during both monitoring events, and for all monitoring events in 2018.

	Monitoring event 1		Monitoring event 2		Overall (both events)	
	Average (spat/m^2)	StDev	Average (spat/m^2)	StDev	Average (spat/m^2)	StDev
Necklaces	543.7	643.5	493.9	513.4	525.8	599.3
Bags	272.9	413.3	230.9	438.2	251.9	425.9
All	385.7	537.7	306.1	475.1	349.9	511.7

Table 5 Summary of average oyster density (with standard deviation) across all oyster restoration sites. Note that all sites recorded significant spat settlement. Necklaces were unrecoverable from three sites in November 2018 sue to anchor damage.

	May 2018				Nov 2018			
	Bags		Necklace		Bags		Necklace	
Site	Avg (spat/m^2)	StDev	Avg (spat/m^2)	StDev	Avg (spat/m^2)	StDev	Avg (spat/m^2)	StDev
2	114.7	153.4	159.9	413.5	135.7	153.3	212.5	316.4
3	131.5	132.8	217.9	219.4	37.9	82.4	320.2	364.6
4	49.6	75.1	229.0	274.9	72.4	92.7	317.6	305.0
5	544.8	307.4	1399.2	961.6	473.1	315.7	550.5	601.5
6	165.8	181.3	475.0	562.5	282.8	323.9	No shells recoverable	
7	191.1	279.7	664.4	363.3	94.5	195.3	No shells recoverable	
8	810.0	944.4	1229.5	527.7	1101.2	984.6	0.0	0.0
9	300.5	374.0	611.7	861.9	57.8	172.3	672.9	278.2
10	145.7	156.9	842.1	722.7	82.1	131.5	No shells recoverable	
11	279.8	321.7	409.9	377.3	178.6	277.4	666.1	764.4
12	340.5	308.6	825.5	548.3	86.5	126.6	758.9	511.0
13	589.8	527.2	551.3	316.8	475.4	518.8	1056.5	425.7
14	142.0	178.3	428.7	675.4	117.2	164.2	793.7	468.3
16	15.5	60.0	0	0	37.8	79.2	45.5	150.8

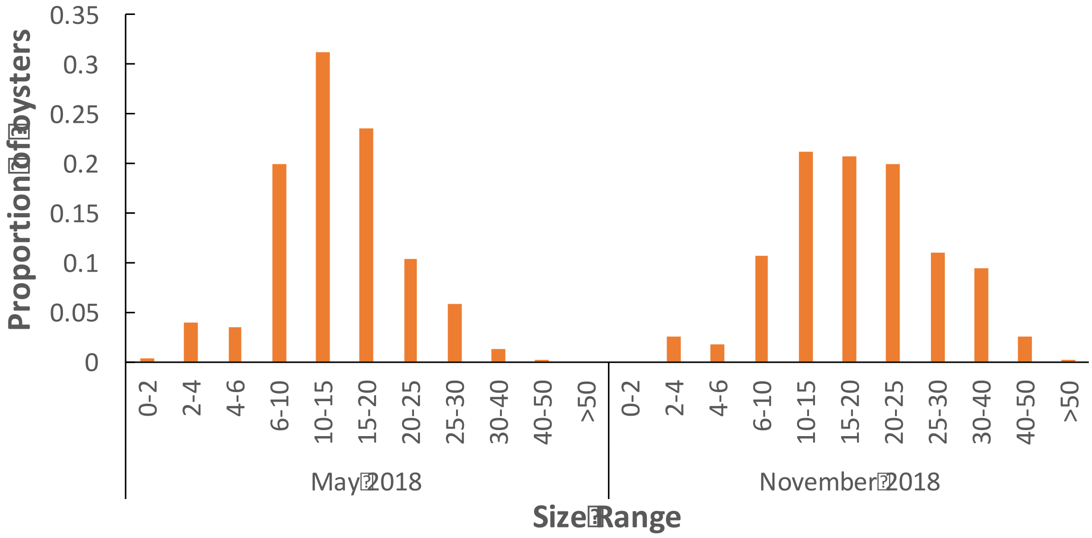

Figure 20 Size frequency distribution of oyster shells across all samples taken in May and November 2018.

Cover of oysters and other sessile invertebrates

At this stage, we were not able to identify any significant settlement of invertebrates on the outside of the coir bags. This is unsurprising as significant growth of invertebrates on the outside of the coir mesh bags was not expected within the first year, and therefore not a compulsory success criteria for the first year in the monitoring program. We anticipate, however, that given the positive indications of spat recruitment and oyster growth, that it is likely that this target will be achieved fully in the coming years. Similarly, we not that there is minimal macroalgal coverage on the bags (<1% in all cases), meaning that there is no significant fouling occurring that would limit the settlement of oysters either on, or into, the oyster restoration units into the future.

Establishment of stable biogenic matrix

The development of the reefs is in the early stages, therefore 100% of randomly selected oyster shells were still easily moved during both monitoring events. This is unsurprising as the development of stable biogenic matric was not expected within the first year, and the performance objective is to be assessed in year 3. Despite this, no loose oyster shells were lost from in-tact bags. We anticipate, however, that given the positive indications of spat recruitment and oyster growth, that this performance criteria will likely will be achieved in the coming years. We were, however, able to use the quadrat samples (see figure 21) to show that there has been no significant degradation of the coir mesh, that it is still strong, and that the gauge of the rope has not been narrowed by any natural decomposition as yet.

Figure 21 Example images of quadrat photos taken on oyster reef restoration units, here at reefs 13 (top row) and 16 (bottom row). We did not identify any significant growth of invertebrates on the outside of the oyster reef units, but there was also no significant degradation of the coir mesh noted.

Monitoring criteria 3- Community use and enjoyment of the declared fish habitat area

Performance objective: Oyster restoration units do not significantly impair community use and enjoyment of the declared Fish Habitat Area, particularly fishing activities.

Monitoring method: Maintain records of community feedback, evidence of vandalism, and vessel strikes on the trial oyster reef restoration units. Records will be comprehensive and include, as a minimum set:

1. the number and type of complaints received (also, to allow the Department to gauge the success, any positive comments should also be provided);
2. the type, nature, and severity of any acts of wilful vandalism; and
3. the type and severity of any vessel strike.

Frequency: Annual reporting of all complaints, cases of willful vandalism, and instances of vessel strike received for the three-year trial period.

Was the performance objective met? Noosa Council holds the data / information on any complaints from the public. We did not identify any willful vandalism of the reefs, but we did identify several instances of boat propeller and anchor strikes in the November 2018 monitoring event.

Supporting Evidence

Noosa Council is the designated contact for comments regarding the oyster reef restoration project in the Noosa River, and of how this project affects the use and enjoyment of the declared fish habitat area by the community. This is clearly stated on the signage at each oyster reef restoration site (Figure 22). One complaint was received regarding concern that an oyster bag had moved outside of the oyster restoration area. However the results of the monitoring demonstrate the bags did not move, and so no further action was necessary.

We identified some damage to oyster reefs during the monitoring events (summarized in Table 6). During the monitoring event in May 2018, only one reef required repairs. In November 2018, most reefs required repair, and some coir bags were unrepairable. It is likely that the majority of damage to the oyster reefs is caused by being struck by boat propellers (especially at sites where bags were torn), and/or poorly placed or dragging boat anchors (especially at sites where bags were torn and/or moved from their position on the reef). During the November 2018 monitoring event, four of the reefs were also badly fouled by fishing line and/or abandoned crab pots. This fishing gear was removed from the reefs and disposed of. Combined, this damage resulted oyster spat necklaces being impossible to retrieve from some reefs (see monitoring criteria 2, Table 5). Corrective action was taken to remove fouled fishing gear from all affected reefs, and to repair reefs according to the details listed in Table 6.

Members of the USC team have conducted several surveys on the fish fauna associated with the oyster reefs in the Noosa River, beyond the monitoring events detailed here. In association with these surveys, team members have taken note of the number of reefs where fishing activities have been occurring (Table 7). Whilst this is simply a snapshot view of the types of activities taking place around the reefs, it is indicative of the potential damage occurring to the reefs. The key observation is a general increase in the number of fishing boat at the reefs with time since installations. This is likely due to 1) the general public becoming increasingly familiar with the locations and benefits of the reefs, 2) media reports of the positive results regarding fish assemblages coming to light, and 3) the timing of September school holidays.

Whilst we did not identify any acts of willful vandalism of the oyster reef restoration units during our monitoring events, many marker buoys (placed on the corner of the reef units; a compulsory condition of the development approval) were missing during monitoring events.

These were immediately replaced by the USC team. Some buoys were, however, removed from sites the night after being reinstalled, thereby indicating very regular removal of reef hardware by members of the public at some sites. This lack of buoys on the corner of the oyster reefs is likely a contributor to some of the reefs being hit by boat propellers etc. Regular monitoring of these buoys is required to ensure that they stay in place. No site signage was damaged or modified during the past year, so no maintenance or replacement has been necessary (Figure 22).

Figure 22 Oyster reef restoration signage being installed at an oyster reef restoration site in the Noosa River, with text on the sign indicating the contact details at Noosa Council for comments on the broader oyster restoration project.

Table 6 List of recorded damage and repairs to oyster reefs during both monitoring events

Site	Damage May 2018	Repairs conducted	Damage November 2018	Repairs conducted
2	None	NA	All top bags torn. Buoy missing.	Repairs to bags completed where possible by restitching with coir rope. Replaced buoy.
3	None	NA	All top bags torn. Buoy missing.	Repairs to bags completed where possible by restitching with coir rope. Replaced buoy.
4	None	NA	Bottom right, and top right bag torn. Middle reef unit covered by significant sand. Right hand reef unit and nearby buoy tangled with crab pot.	Repairs to bags completed where possible by restitching with coir rope. Crab pot removed.
5	Reef struck by boat which broke mooring, one buoy missing	Reef repaired by restitching with coir rope, and put back in place. Replaced buoy.	All top bags torn. Buoy missing.	Repairs to bags completed where possible by restitching with coir rope
6	None	NA	Middle top bag ripped.	Repairs to bags completed where possible by restitching with coir rope
7	None	NA	Middle top bag ripped.	Repairs to bags completed where possible by restitching with coir rope
8	Right hand bag moved and torn, 1 buoy missing	Repaired and put back on reef. Replaced buoy.	Right hand top bag torn. Buoy missing.	Repairs to bags completed where possible by restitching with coir rope
9	Right hand bag moved and torn, 2 buoys missing.	Repaired and put back on reef. Replaced buoys.	Left hand top bag torn, right hand reef significantly covered by sand, middle top bag ripped.	Repairs to bags completed where possible by restitching with coir rope
10	One buoy missing.	Replaced buoy.	Top middle bag destroyed, significant covering by sand. Buoy missing.	Repairs to bags completed where possible by restitching with coir rope. Replaced buoy.
11	Two buoys missing.	Replaced buoys.	Top middle bag torn.	Repairs to bags completed where possible by restitching with coir rope. Replaced one stake.
12	None	NA	Right top bag torn.	Repairs to bags completed where possible by restitching with coir rope
13	None	NA	None	NA
14	None	NA	None	NA
16	None	NA	None	NA

Table 7 List of days USC team members have surveyed the reefs, and the number of reefs upon which fishing activities have been noted during these surveys.

Date of field work	Number of days	Sites visited	Activity being completed	Sites with boats present
25-26 November 2017	2	3-8	Ecological function study	0
27-30 November 2017	4	All	Fish surveys	0
29-30 December 2017	2	All	Fish surveys	2
29-30 January 2018	2	3-8	Ecological function study	0
15-16 February 2018	2	All	Fish surveys	1
26-27 March 2018	2	3-8	Ecological function study	2
29-30 March 2018	2	All	Fish surveys	1
31 May, 1 June 2018	2	3-8	Ecological function study	0
15-18 May 2018	4	All	Fish surveys	2
20-22 May 2018	3	All	6 month monitoring	3
27-28 June 2018	2	All	Fish surveys	4
16-17 August 2018	2	All	Fish surveys	2
1-2 October 2018	2	All	Fish surveys	2
19-20 November 2018	2	All	Fish surveys	3
26-27 November 2018	2	All	12 month monitoring	1

Monitoring criteria 4- Other potential effects

Performance objective

Oyster reef restoration units do not cause a decline in the extent of marine plants within a 50 m radius of the restoration units, and are not attributed to erosion of adjacent shorelines or other ambient environmental impacts.

Monitoring method

Map the area of marine plant habitats (seagrass, mangroves) in the immediate vicinity (i.e. with a 50 m buffer) of each oyster restoration area, using high-resolution GPS (cm scale) and field-validated aerial imagery (sourced from Nearmap) (NearMap, 2018). Monitor changes in the composition coverage and condition of seagrass within 50 m radius around the oyster reefs. Map the location and condition of estuarine shorelines that occur in the immediate vicinity (i.e. with a 50 m buffer) of each oyster reef, using high-resolution GPS (cm scale) and field-validated aerial imagery (sourced from Nearmap).

Frequency

Annually for a minimum of three years, or until any failed restoration units have been removed.

Was the performance objective met?

All aspects of this performance objective were met, so no further action is necessary.

Supporting evidence

Mangroves and seagrasses were successfully mapped at each site using the described methods (Figures 8-21). We identified no significant change in the distribution of mangroves or seagrasses within the 50 m monitoring area (Table 8; t test, $P>0.9$), or any erosion to nearby shorelines. Whilst the footprint of seagrass was lower at some sites, there was no loss of seagrass attributable to the installation of the reefs (i.e. significant decline of seagrass away from the reefs, especially within the RAA areas) (Table 8). Photographs of the mangrove fringe and shoreline within the 50 m monitoring area both before the installation, and during the 12 month monitoring event are available from USC upon request.

Table 8 Extent of seagrass and length of mangrove edge at within 50m of each oyster restoration site at installation and 12 months post installation.

Reef	Mangroves at installation (m)	Mangroves at 12 months (m)	Seagrass at installation (m^2)	Seagrass at 12 months (m^2)
2	113.9	119.4	0	0
3	92.0	87.9	1995.9	1443.6
4	135.6	133.8	0	0
5	162.3	175.2	0	0
6	39.4	43.6	1372.1	1590.0
7	43.1	48.2	1480.8	1913.5
8	108.8	112.0	0	0
9	180.8	181.8	0	0
10	110.7	114.4	0	0
11	138.5	137.5	0	0
12	114.4	116.9	151.9	499.0
13	81.7	82.3	2105.0	1707.5
14	134.5	136.2	854.6	765.5
16	0	0	0	0

No change to seagrass composition or density was identified at any restoration sites. All sites were dense (>70% cover) and long (>20 cm) eelgrass (*Zostera capricorni*) (except for sites 13 and 16- see below). During the 12 month monitoring event, we identified small (leaf height <1 cm), low coverage (<5%) growth of dugong grass *Halophila ovalis* inside the RAA area at site 13, and some small patches within the rocky shore adjacent to site 16. This seagrass was not present at the sites during installation (Table 1). The growth of seagrass at these sites is likely due to lower runoff in Lake Weyba and Weyba Creek over the past year, and especially in the past 6 months, and the stabilizing and baffling effects of the reefs on surrounding sediments (especially at site 13). Here, the calmer waters around the restored reefs allow the smaller, more delicate *Haliophila* to establish. This finding, however, does not suggest that there is increased siltation around the reefs; a conclusion not supported by our results. Further monitoring will be required on these growing seagrasses.

Conclusions

In this report, we show that;

1. Oyster restoration units have not moved from the RAA area, nor have they moved greater than 1 m within the RAA area.
2. There has been significant spat settlement and oyster growth at all oyster reef restoration sites. Whilst this has not yet proliferated to coverage of invertebrates on the outside of the coir bags, or to the proper stabilisation of shell within the bags (i.e. cementing of the biogenic reef matrix), these oyster growth results are a positive sign for the likely success of the reefs in achieving these performance criteria in the near future.
3. Whilst we did not identify any wilful damage to the oyster restoration units, we did identify that marker buoys were regularly removed from the oyster restoration sites, and there have been several instances of boat propeller and anchor strikes on the reefs. This was repaired where possible (i.e. corrective actions), and a further education campaign is required to educate river users.
4. There has been no significant change to the distribution, composition or quality of seagrass or mangroves around the oyster reef sites. Similarly, there has been no shoreline erosion at oyster reef sites.

Consequently, two of the four monitoring targets reported on here have been fully met, the third relating to oyster growth is tracking very favorably with the criteria likely to be met in the coming years, and the final relating to community usage may require closer monitoring.

We identified some damage to the oyster reef units from boating activities (principally anchor and prop damage) at many sites during the November 2018 monitoring event. We have some evidence to suggest that the use of oyster reefs by fishers has increased over time, and that some of the ecological benefits of the reefs might therefore be being offset by fishing. Corrective actions have been made to these reefs immediately following the monitoring period in November 2018. The three reefs more distant from the main boating activities in Lake Weyba and Weyba Creek (due to the combined effects of limits on access to hire boats, and difficulty of access due to shallow waters) are the most intact oyster reefs, with no damage recorded in either 2018 monitoring events. Whilst these reefs do not necessarily have the highest rates of settlement (the exception being reef number 13, which has the highest average live oyster density), their success might be the most guaranteed as they are less likely to be damaged by the sorts of impacts occurring on reefs in the central stretch of the river.

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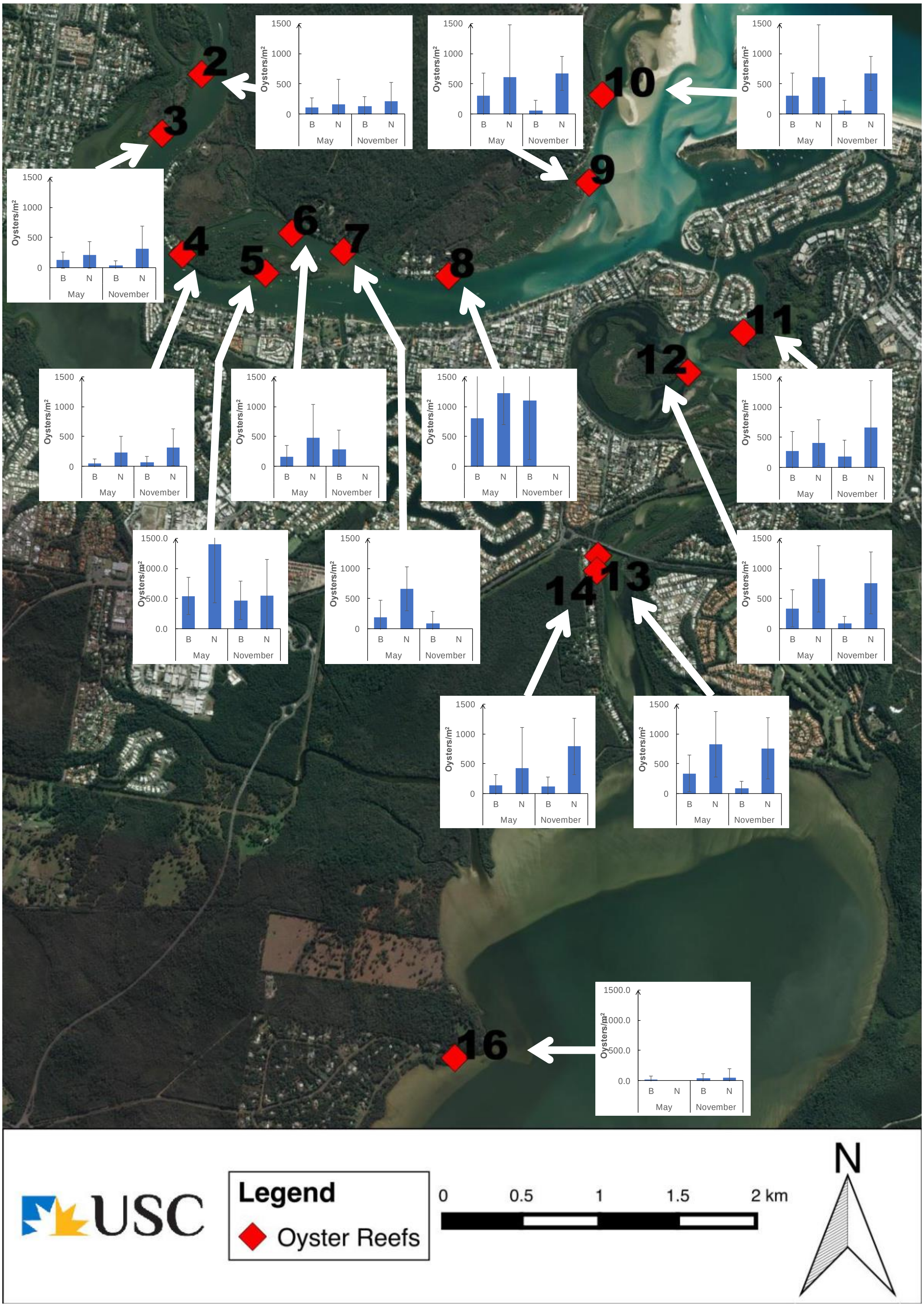

Figure S1 Map of oyster reef restoration sites with average (+/- SD) values for oyster density during May and November 2018 monitoring events in the oyster reef bags (B) and on the oyster necklaces (N).

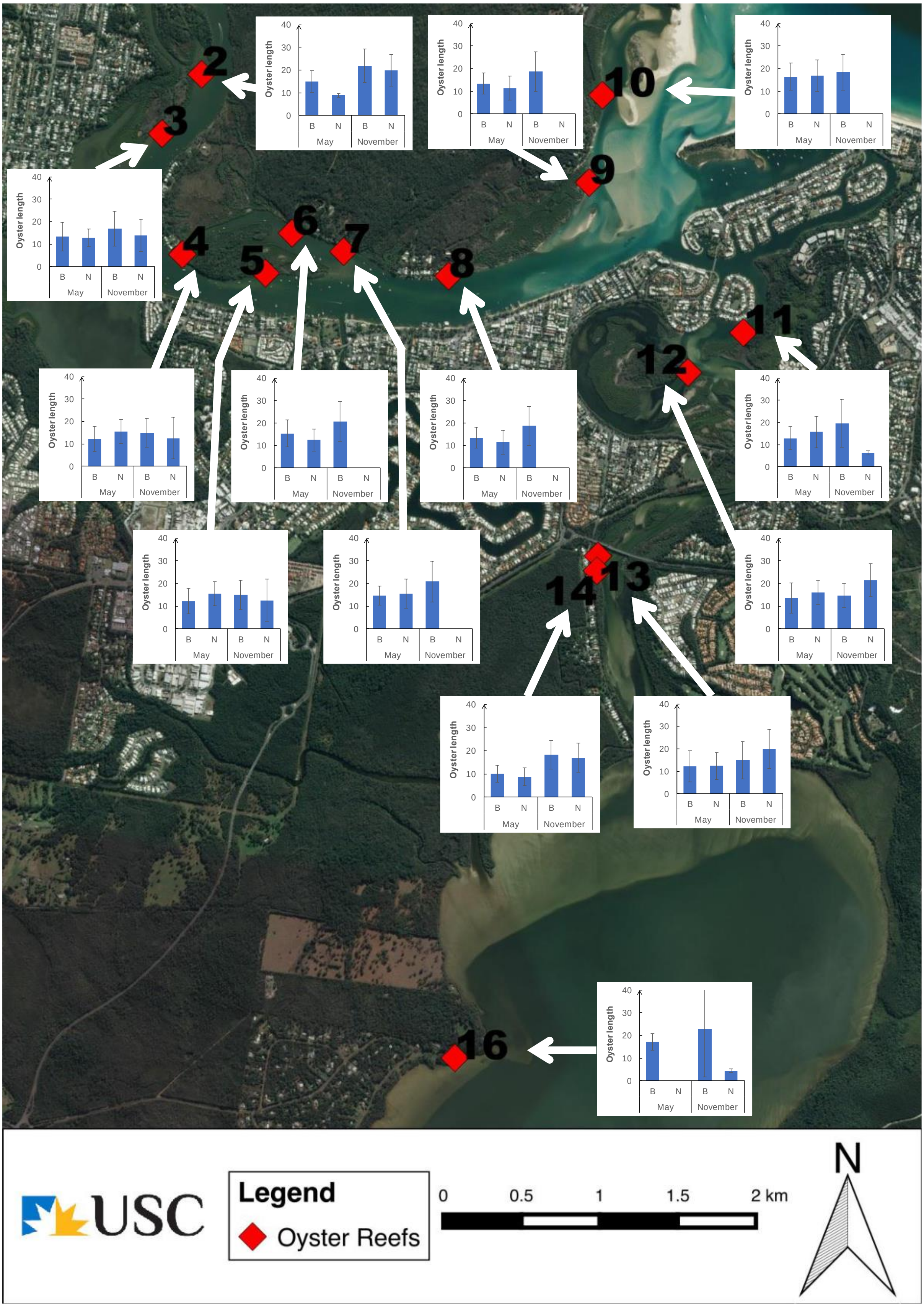

Figure S2 Map of oyster reef restoration sites with average (+/- SD) values for oyster length during May and November 2018 monitoring events in the oyster reef bags (B) and on the oyster necklaces (N).