Ecological Service Professionals
Sustainable Science Solutions

Restoration of Noosa Estuary

An Assessment of Oyster Recruitment

Prepared by The Nature Conservancy & Ecological Service Professionals

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Executive Summary

With the support of the Noosa Shire Council and The Thomas Foundation, The Nature Conservancy undertook an assessment of oyster recruitment in the Noosa Estuary. This assessment is a critical piece of information to inform the viability and design or future oyster reef restoration projects in the estuary.

This report presents the findings of the assessment, which involved deploying over 160 settlement tiles (10 cm x 10 cm squares made from fibrous cement sheet) for periods of up to 5 months between December 2014 and June 2015. Settlement tiles were deployed at seven intertidal (0.1 m above low water mark) and five subtidal sites (typically 1 m below the surface) around the Noosa River Estuary. Key findings from the analysis of these settlement tiles are:

- Oysters recruited in moderate numbers at nearly all sites, with the highest observed recruitment occurring in Weyba Creek, the main channel around Tewantin, and in the narrow channel between Goat Island and Noosa North Shore. The growth rates oysters recruiting onto the settlement tiles was reasonably fast.
- There were at least two major oyster recruitment events in intertidal habitats (December–January and March–April), with the greatest number of oysters recruiting in approximately March-April 2015. Two to five times fewer oysters recruited to tiles deployed at subtidal depths than intertidal.
- Sediment was a major issue and prevented oyster recruitment of the upper surface and most vertical surfaces such that settlement was restricted to the underside of the tiles.
- Two species of oysters dominated the recruitment, *Planostrea pestigris* and *Pinctada maculate*. Surprisingly, no Sydney rock oysters (*Saccostrea glomerata*) were observed settling despite the widespread presence of adults in the estuary. Possible explanations for the lack of *S.glomerata* recruitment include, the presence of high sediment loads associated with runoff and re-suspension of fine sediments early in this past summer, or that settlement occurred at a different time of the year. The lack of *S. glomerata* does not preclude settlement and recruitment of this species on restored reefs, however it is an important consideration because the species of oysters that did recruit successfully during this assessment are not known to be reef building species. The oyster species that did recruit to the tiles do still provide structural habitat and an important food source for commercially and recreationally important fisheries species.
- An encouraging sign was the recruitment of numerous other species of marine life on the settlement tiles, including barnacles, mussels, bryozoans, ascidians, sponges, and polychaete worms. These types of sessile species provide an important

component of the overall biodiversity of estuarine systems and are likely to contribute to food webs and provide a filtration function similar to that of commercial oyster species. There was also evidence of both crabs and fish utilizing the newly created habitat associated with the settlement tiles and structures.

Based on these findings, our recommendations are:

- The Council look to support the establishment of some small scale pilot oyster reef restoration projects. These should be treated as experiments, and developed in conjunction with a university group, perhaps the University of the Sunshine Coast.
- The most promising location for these pilot reefs is upper Weyba Creek, but the main branch near Tewantin would also provide an interesting learning opportunity because of the high siltation rates but also high presence of oyster larvae.
- Pilot reef should trial a number of different designs and materials, and include surface orientations that maximise overhanging areas to ensure that recruits are not smothered by sediment and algal growth. Pilot reef should be located in an area where it will not interfere with normal vessel movement through the estuary (i.e., outside main channels, primarily along the banks). Reef should be located at an appropriate depth. Although oysters recruited in both intertidal and subtidal depths to <1.5 m deep, the greatest total number of oysters were found in the intertidal zone approximately 0.1-0.2 m above the Low Tide Mark.
- Timing the deployment of pilot reefs to coincide with period of maximum recruitment potential (late summer to autumn based on the results if this study).
- A range of surface materials including concrete and recycled plastic could be suitable for use as initial settlement structures.
- We expect that establishment of a few trial reefs to cost in the order of $50-100K, including detailed monitoring.
- We also suggest that settlement monitoring is continued in concert with this pilot reef program. This will provide information about inter-annual variation in recruitment, and hopefully the reasons why Sydney rock oysters do or do not recruit successfully in different years. We also recommend that a key variable tested in the next iteration of settlement monitoring is settlement onto oyster shells.
- Hatchery oyster stock may be needed to boost larval supply but this should not be considered until at least another season of studying natural recruitment, because involving a hatchery increases the costs and complexity of restoration projects.

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1 Introduction

To provide a pathway for a coordinated response to rehabilitation of estuarine habitats in the Noosa River Estuary and Lakes, The Nature Conservancy in collaboration with its donors completed an assessment of possible estuarine restoration activities and / or management options available to local council and the broader community. This was completed in October 2014 through an expert elicitation workshop. Enhancement of fisheries habitat through the restoration of oyster reefs was identified as one potential rehabilitation measure; however, there was uncertainty regarding natural oyster recruitment and survival in the system.

This study was commissioned to assess the recruitment potential of oysters and to determine the viability of restoring oyster reefs in the Noosa River Estuary. This report presents the findings of the assessment, which was completed by deploying settlement tiles at various locations within the study area.

1.1 Background

Estuarine habitats and the diversity of species that they support provide substantial benefits through the goods and services provided including food / fisheries productivity, nutrient recycling, improving water clarity and quality, and tourism (natural recreational enjoyment including recreational fisheries) (Beck et al. 2001; Lotze et al. 2006). Restoring ecological functions to estuaries is an emerging management and conservation priority in Australia (FRDC 2012; Gillies et al. 2015) and restoration of oyster reefs to restore ecological function is an established practice in parts of the USA (Brumbaugh et al. 2006; Schulte et al. 2009).

In Southeast Queensland (SEQ), the Noosa River catchment and estuary is considered the best performing catchment in region in terms of water quality, diversity of in-stream habitats and fish production (Sunshine Coast Regional Council 2012; Healthy Waterways 2013). However, the relatively un-modified and good condition of the system is often juxtaposed against the fact that Noosa is a high demand recreational area for tourism, fishing and agriculture, which contribute heavily to the local economy (Sunshine Coast Regional Council 2012). The tourism industry dominates the gross domestic product in the Sunshine Coast, attracting $2,324 million in 2010/11 (Regional Development Australia Sunshine Coast Inc. (RDASC) 2012).

The enhancement of fisheries habitat through restoration of functional oyster reefs in estuarine ecosystems has become a conservation priority in many locations (Brumbaugh et al. 2006) (as a mechanism to improve the ecological function of estuaries through the provision of increased habitat, improved water filtration and enhanced biodiversity, particularly of recreational fish species), and was identified as a potential restoration activity an expert workshop held in October 2015 in Brisbane by The Nature Conservancy. Natural oyster reefs in estuaries globally have been in decline relative to historical records, due primarily to overfishing (among other factors), and are considered functionally extinct in many coastal estuaries, including along the East Coast of Australia (Beck et al. 2011).

Oysters have previously been a favourite food source for local indigenous populations in the lower Noosa River Estuary, as evidenced by shell remains in midden mounds (Brown 2000). Furthermore, according to historical accounts, Sydney rock oysters (*Saccostrea glomerata*) grew extensively on rocks and other molluscs in the intertidal, and also in the shallow muddy bottoms of the river channels and lakes at Noosa (Brown 2000). The Moreton Bay Oyster Company dredged oysters from the Noosa River in the early 1900's (Brown 2000). The culture (seed oysters) was then sent to Moreton Bay for fattening, until environmental changes from urbanisation and agricultural changes in the catchment destroyed the trade (Brown 2000; Lergessner 2006).

Subtidal and intertidal reefs of Sydney rock oysters were also once extensive in nearby Pumicestone Passage down to at least 4 m below the low tide mark (Lergessner 2006). However, oyster reefs are now functionally extinct in Pumicestone Passage due largely to a failure of oyster recruitment from declining water quality (Diggles 2013). Similarly, oyster reefs are not currently a dominant ecosystem type within the Noosa estuary: suitability for oystering has not been identified as a environmental value for any waters in the Noosa Catchment under Schedule 1 of the EPP Water (DERM 2010).

2 Methodology

2.1 Survey Area – Noosa River Catchment

The Noosa River Catchment covers 841 km^2 and is within the Noosa Drainage Basin. The Noosa River flows south from its headwaters in the Cooloola Section of the Great Sandy National Park to the ocean, north of Noosa Headland. The river is spring fed from major sand deposits and has continuous freshwater flows. Noosa Estuary is a Holocene Tidal Delta, dominated by soft sediments, with several shallow lakes (Cootharaba, Cooroibah, Doonella, Weyba) throughout the system, the largest of which is Lake Cootharaba (Figure 1). Estuarine habitat has been mapped upstream of Lake Cootharaba, although depending on the flow of freshwater, salinity is typically low in these lakes. The sediments in the estuary consist largely of undifferentiated deposits of lagoonal and estuarine sands and muds, and coastal muds including muds incorporated into mangrove sediments (Lloyd 1980). The Catchment has a subtropical climate, which receives on average 1600 mm of rainfall annually. Temperatures range from 22 to 28°C in Summer and 11 to 21°C in Winter (BOM site 040908 Tewantin RSL Park – averages based on data collected from 1994 to 2014). Tides in the estuary are semi-diurnal with a tidal range of 1.4 m at the mouth, decreasing to 0.9 m at Tewantin (Stephens 1973). During spring tides, tidal currents can reach 2.5 knots in the main river channel (Stephens 1973).

2.2 Approach

Settlement tiles (10 cm x 10 cm squares made from fibrous cement sheet) were deployed at seven intertidal (0.1 m above low water mark) and five subtidal sites (typically 1 m below the surface) around the Noosa River Estuary (Figure 1 & Table 1) to determine the potential for recruitment[1] of oysters at different depths and surface orientations. At each site, the settlement tiles were deployed in an array of 4 replicate tiles in two different orientations (vertical and horizontal) and secured to a cement block (Figure 2a,b).

[1] Recruitment is defined as the point at which the pelagic (swimming) larvae of oysters settle out of the water column onto another oyster shell or other hard surface and survive long enough to be counted in the population (sensu Hunt & Scheibling 1997)

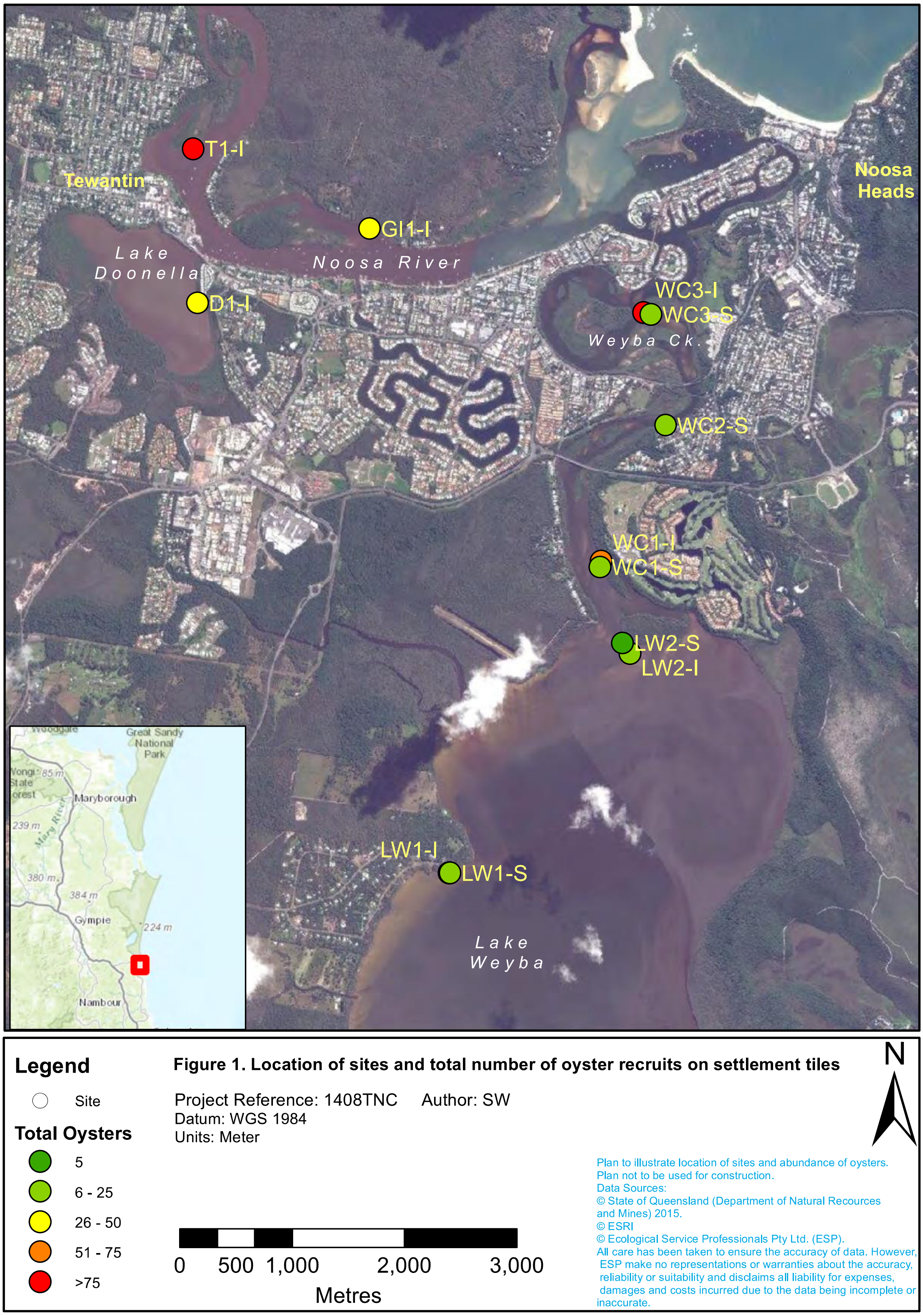


Figure 1. Location of sites and total number of *Planostrea pestigris* oyster recruits on settlement tiles

Figure 2. Vertical and horizontal settlement tile array in (a) Lake Doonella, and (b) Weyba Creek

Tiles were deployed in December 2014. The intertidal tile arrays were checked and cleared of silt in February 2015, then retrieved in May 2015. At the subtidal sites, one array was collected and new tile arrays were redeployed in February 2015; all remaining tiles were retrieved in May 2015 (Figure 3). Assessing recruitment over time by deploying tiles in December 2014 and February 2015 allowed us to determine temporal differences in the recruitment of oysters, and the period when recruitment was maximised during summer/autumn. An additional array of 4 horizontal and 4 vertical tiles was deployed under a jetty in Noosa Sound in February 2015, and an additional array of 4 horizontal and 4 vertical tiles was also deployed 0.5 m from the bottom at Site WC2 in Weyba Creek for 5 months. A total of 206 tiles were deployed and examined over the duration of the project. Eight tiles were lost during the project, all from site WC3 (Table 1).

Tiles were collected in the field by hand, photographed and the size and number of oysters, and presence of other sessile species on each settlement tile (and associated deployment structures) was recorded. A stereoscope was used to confirm the species of oyster and presence of any recent recruits that were not visible in the field.

The number of barnacles, mussels and pearl oysters and presence of bryozoans, ascidians and sponges were also noted for each plate (however, these groups were only identified to a high taxonomic level as they were not the primary focus of this project).

Figure 3. Collecting the intertidal settlement tile array from Site G1-I at Goat Island, in May 2015

Table 1. Treatments deployed at each site

Location	Site	Treatment			
		Intertidal - Horizontal	Intertidal - Vertical	Subtidal - Horizontal	Subtidal - Vertical
Lake Weyba	LW1	b	b	a,b	a,b
	LW2	b	b	a,b	a,b
Weyba Creek	WC1	b	b	a,b	a,b
	WC2			a,b	a,b
	WC3	b	b	a,b^	a,b^
Noosa Sound	NS1			c	c
Lake Doonella	D1	b	b		
Noosa Estuary (Tewantin)	T1	b	b		
Noosa Estuary (Goat Island)	GI1	b	b		

[a] Deployed for 2 months from December 2014 to February 2015
[b] Deployed for 5 months from December 2014 to May 2015 ^Tiles deployed at site WC3 for 2 months were lost
[c] Deployed for 3 months from February 2015 to May 2015

2.3 Data Analysis

Differences in the total number of oyster recruits (*Planostrea pestigris*) were compared between vertical and horizontal among sites using a 2 factor PERMANOVA (with site and orientation as factors) (Anderson et al. 2008). Separate analyses were completed for intertidal and subtidal habitats due to differences in the spatial location of some sites (i.e. those in the Noosa River Estuary). The analyses were completed using untransformed data converted to a Euclidean similarity matrix. Differences in the total number of recruits per site and orientation were compared using pairwise comparisons.

Growth and Size-Frequency Distribution of Oysters

In the absence of a more detailed growth estimate, a rough linear growth rate was estimated based on the average size of the oyster *P. pestigris* (pooled among all subtidal sites) after 2 months, 3 months and 5 months deployment. An average growth rate of approximately 4 mm (± 1.5 mm) per month was estimated assuming linear growth over the 5 months deployment, which was used to define the size class estimates. The oyster recruits were pooled among replicates at each site to examine variation in the size frequency distribution. This was done only for the intertidal depth, as there was an insufficient number of recruits on subtidal tiles to warrant any meaningful analysis. Oysters were sorted into ten, 4 mm size classes, between 1 and 40 mm and the number of oysters in each size class was graphed for each site.

3 Results

A variety of organisms colonised the settlement tiles including two species of oyster (*P. pestigris* & *Pinctada maculata*); hairy mussels (*Trichomya hirsuta*); barnacles (*Amphibalanus variegatus & A. amphitrite*); bryozoans (*Biflustra* sp., *Hippopodina* sp., & *Schizoporella unicornis*) ascidians (*Leptoclinides* sp. & *Ascidia* sp.), sponges (*Ircinia* sp. & *Batzella* sp.) and serpulid polychaete worms (*Spirorbis* sp.). There was no recruitment of rock oysters (*Saccostrea glomerata*) onto settlement tiles or deployment structures at any of the sites examined, despite adults being present in the estuary. Numerous mobile species were also associated with the sessile organisms, including amphipods, crabs and polychaetes. The abundance and distribution of mobile species were not examined further as part of the assessment.

Predators such as the mulberry whelk (*Morula granulata*) were absent from observations by the field team and were not recorded on any of the intertidal or subtidal settlement tiles (note that specific surveys for predatory species were not completed as part of this preliminary assessment, and these species may have dropped off when retrieving the settlement arrays). Mulberry whelks are typically very common on intertidal shores, particularly where oysters are present (e.g. intertidal shore on Stradbroke Island Figure 4).

Figure 4 Sydney rock oysters and predatory mulberry whelks on an intertidal shore at North Stradbroke Island

3.1 Spatial Variation in Recruitment of *Planostrea pestigris*

Intertidal Oyster Recruitment

The number of oysters recruiting to tiles deployed intertidally was greatest at Site WC3 in Weyba Creek and Site T1 in the Noosa River at Tewantin, and was lowest at site LW1 in Lake Weyba (Figure 5 and Figure 6. A greater number of oysters recruited onto horizontal than vertical tiles, and the differences among sites was less pronounced for vertical tiles due to fewer recruits overall (Figure 5[2]). There was a distinct lack of oysters recruiting to the upper surface of the horizontal tiles deployed intertidally, likely due to exposure at low tide and smothering from a thick layer of sediment. Similarly on vertical tiles only 6 oysters recruited to the outer surfaces, with the majority of oysters recorded to the inner surface. Oysters generally recruited in far greater numbers onto the underside of horizontal plates than on plates oriented vertically (Figure 5).

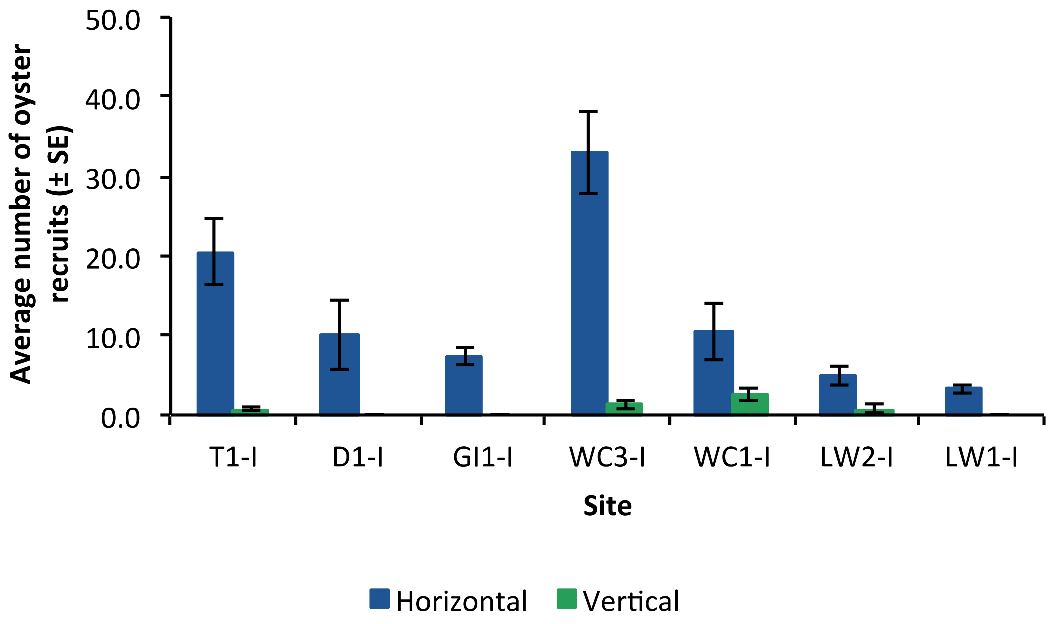


Figure 5. Average number (± SE) of oyster recruits (*P. pestigris*) on horizontal and vertical surfaces deployed at intertidal sites

[2] PERMANOVA: site x orientation interaction pseudo-$F_{6,42}$ = 8.89, p = 0.0001

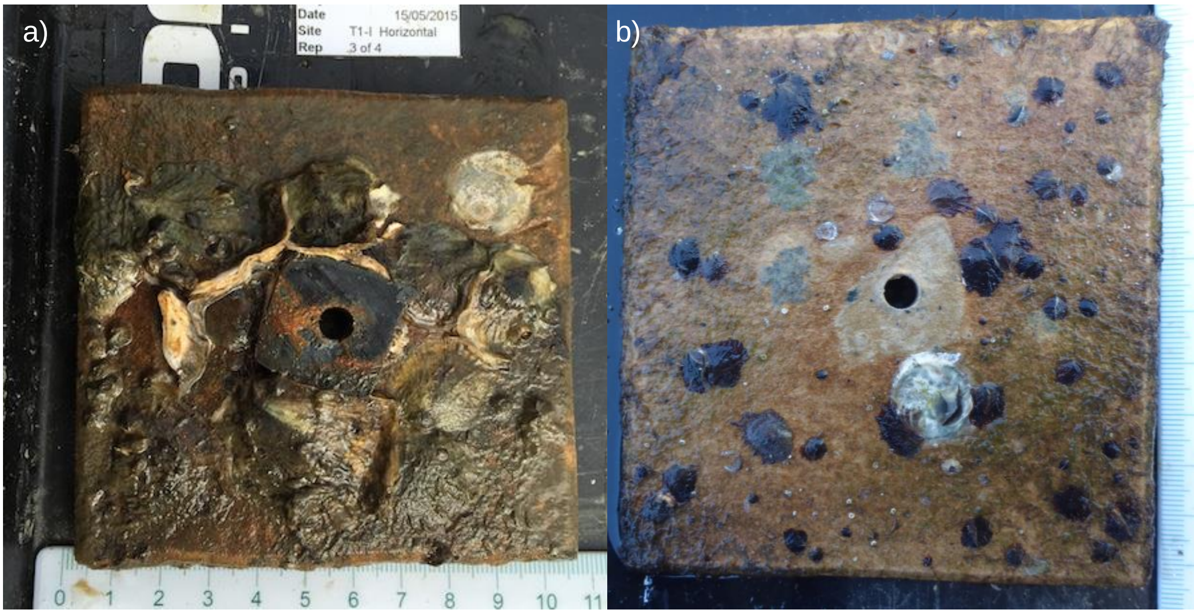


Figure 6. Recruitment of oysters on intertidal tiles from (a) Site T1-I- and (b) Site WC3-I, after 5 months

There were at least two major oyster recruitment events in intertidal habitats (December–January and March–April), as demonstrated by the bimodal nature of the size-frequency graph (Figure 7). The greatest number of recruits was recorded at Site WC3, with these oysters likely recruiting in March-April 2015 assuming growth rates of approximately 4 mm per month (see growth rate estimate below).

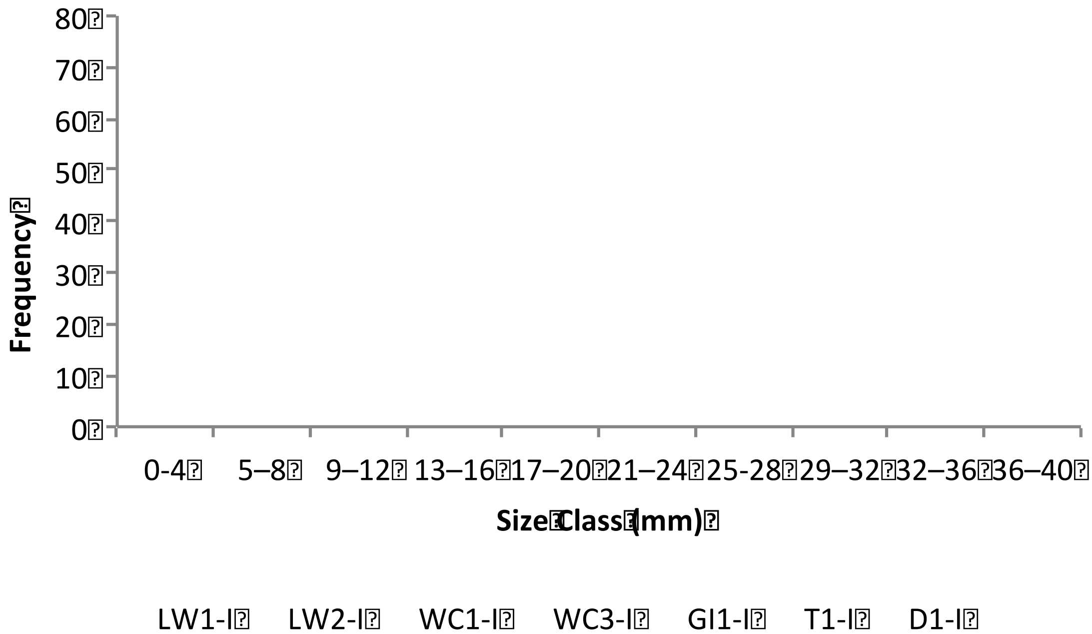


Figure 7. Size-frequency distribution of oysters (*P. pestigris*) deployed at intertidal sites

Subtidal Oyster Recruitment

In general, 2–5 times fewer oysters recruited to tiles deployed at subtidal depths than intertidally (Figure 5 & Figure 8). In contrast to the result for intertidal tiles, there was no substantial difference in recruitment between surface orientations for plates deployed subtidally, with a similar number of recruits on each surface (Figure 8[3]). There was also no significant difference in the average number of recruits among sites[4]; although recruitment was very low at site LW2-S compared with that found at other sites (Figure 8). This is likely due to a reduction in the suspended sediment loads at depth, and not being exposed at low tide. There was an increase in the recruitment of other sessile species on subtidal tiles, particularly barnacles, bryozoans and sponges.

Between February and May 2015, tiles deployed under a private jetty in Noosa Sound had a much higher rate of oyster recruitment (mean ± SE of 2.8 ± 1.11 on horizontal and 5.0 ± 1.78 on vertical surfaces) than other sites throughout Weyba Creek and Lake Weyba (mean ± SE of <2.0 ± 1.22 on horizontal and <0.8 ± 0.48 on vertical surfaces). There were a high number of small polychaete worm tubes (Serpulids), and the bryozoan *Schizoporella unicornis* covered more than 60% of the surface area of tiles deployed in Noosa Sound.

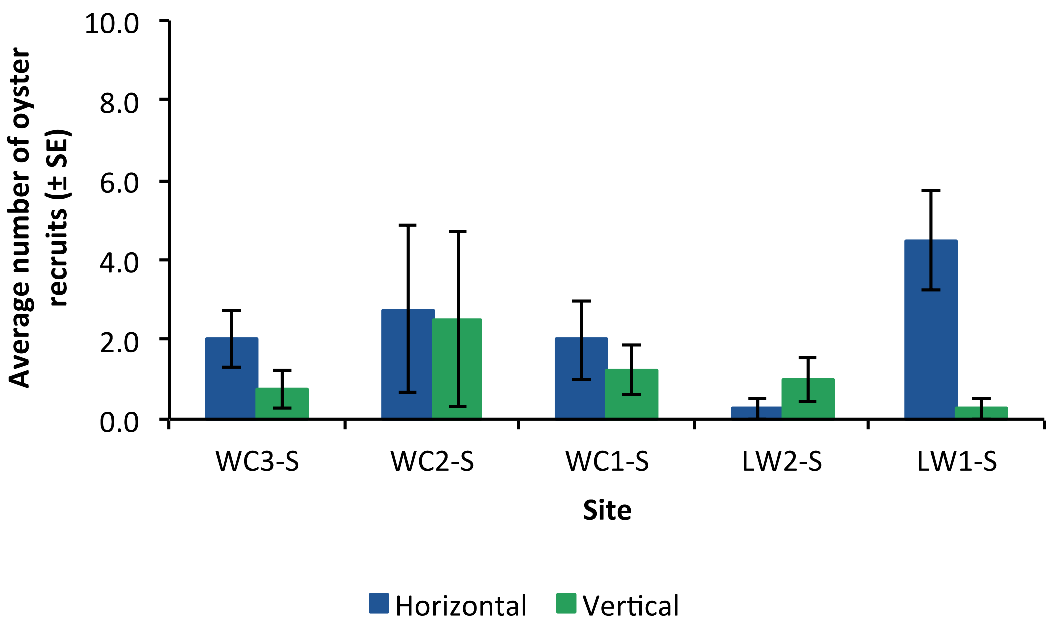


Figure 8. Average number (± SE) of oyster recruits (*P. pestigris*) on horizontal and vertical surfaces deployed at subtidal sites

3 PERMANOVA: orientation main effect pseudo-$F_{1,30}$ = 2.48, p = 0.13
4 PERMANOVA: site main effect, pseudo-$F_{4,30}$ = 0.97, p = 0.44

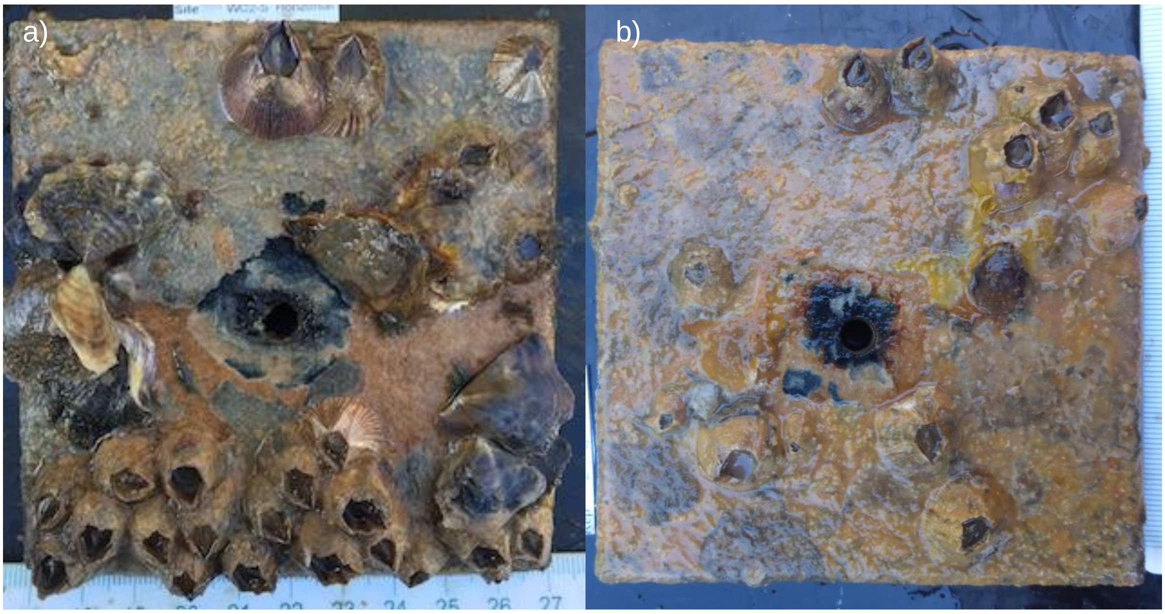


Figure 9. Recruitment of oysters on subtidal tiles from (a) Site WC2 and (b) Site LW2 after 5 months

3.2 Estimated Growth Rate of *Planostrea pestigris*

The initial average size of oysters after 2 months deployment was 3 mm, with a maximum size of 8 mm. After 3 months, average size was 14 mm, and after 5 months the average size was 20 mm, and maximum size was 38 mm (excluding oysters under 12 cm as having settled more than 2 months after deployment). This assumes that settlement and recruitment of oysters occurred in the first month of deployment, otherwise this represents a low estimate of growth.

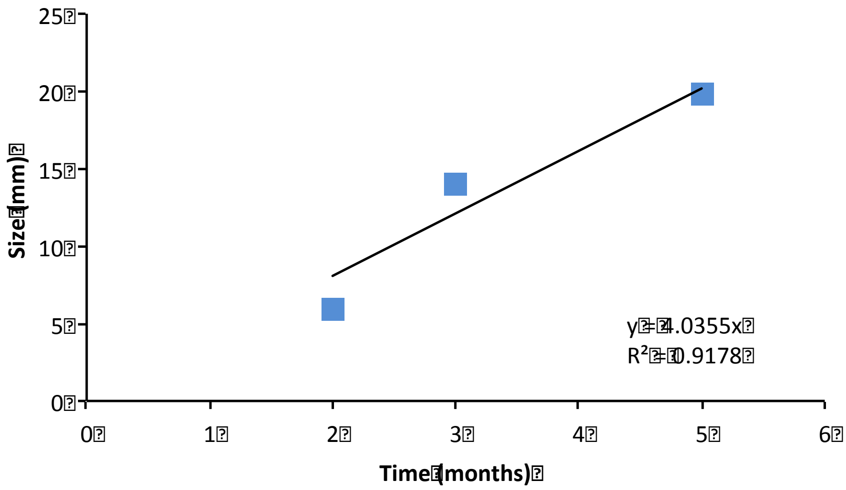


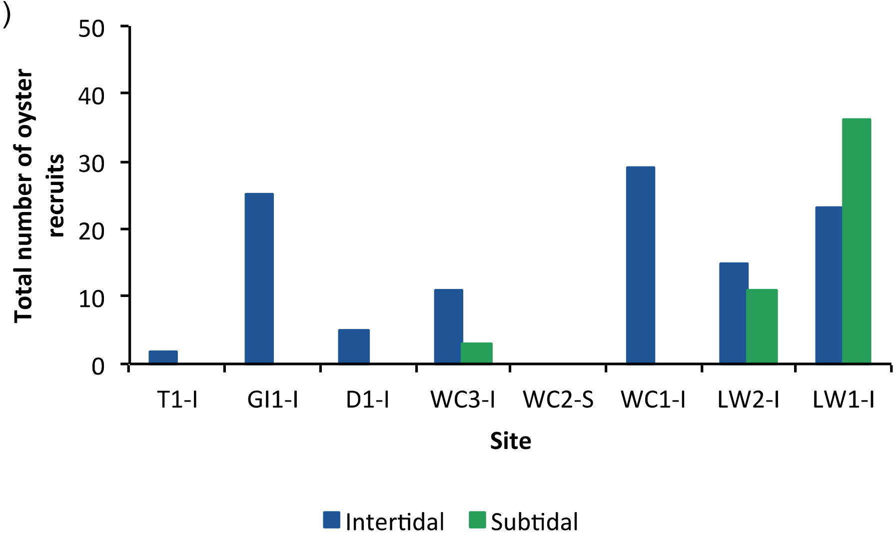
Figure 10. Estimate of linear growth rate using average size of the oyster (*P. pestigris*) after 2, 3 and 5 months deployment

3.3 Recruitment on Support Structures

Recruitment of oysters onto the support structures had similar spatial patterns to that found in the settlement plates, with the greatest number of recruits found in Weyba Creek and Tewantin (Figure 11a,b; Figure 12). Although, in several instances there were more oysters on the support structures than on the settlement tiles, particularly in sections of the deployment structures that were protected from sediment smothering (Figure 11b). A total of 160 oysters recruited on the inside of the cement blocks and 129 on the plastic rods used to secure settlement tiles. The oysters ranged in size from 2 mm to 40 mm (i.e. within the range settling on the tiles).

Figure 11. Recruitment of oysters onto (a) cement blocks, and (b) under settlement tiles on plastic support structures

a)



b)

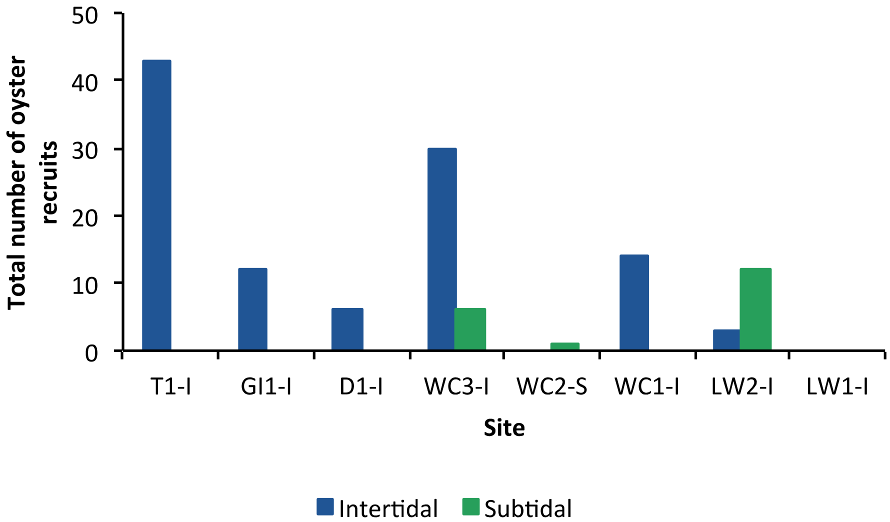


Figure 12. Total oyster recruits (*P. pestigris*) on (a) cement blocks, and (b) plastic rods after 5 months

4 Discussion and Recommendations

4.1 Spatial Variation in Recruitment in Noosa Estuary

Surface orientation can be an important determinant of intertidal and subtidal sessile assemblages, with common differences in the type and diversity of species found between vertical and horizontal surfaces (Glasby & Connell 2001; Walker et al. 2007). In this case, differences in recruitment between horizontal and vertical surfaces were most pronounced in intertidal habitats. The most likely cause of the lack of recruitment, particularly on the upper horizontal surface, which were smothered by fine sediment (Figure 13).

Figure 13. Sediment smothering upper horizontal surface of settlement tiles after 2 months

Spatial differences in recruitment of oysters between intertidal and subtidal areas could be due to a range of factors including: variation in the length of time oysters are exposure to predators (intertidal sites can be exposed to lower predatory stress); increased sedimentation in shallow intertidal habitats; and differences in the success of settlement and in larval supply through stratification of larvae in the water column similar to that found in barnacles (Grosberg 1982; Cummings 1994; Walker et al., 2007). Differences are also likely to be due to competition with other sessile organisms such as the bryozoan *S. unicornis*, which was particularly common and covered a large area on tiles deployed subtidally. While they add to the overall biodiversity of sub-tidal reef habitats during early formation, fast growing pioneer species such as bryozoans and sponges can recruit quickly to new space and out-completing new oyster recruits for space by smothering (Walker et al. 2007; Walker & Schlacher 2014). This can prolong the length of time for some species to become established on sub-tidal reefs (Walker & Schlacher 2014).

Spatial differences in the recruitment of oysters throughout the study area is likely due to a variety of factors including the supply of larvae from nearby adult populations (while not specifically examined, this is a critical first step for successful establishment of reef restoration), preference for settlement surface, post settlement survival (including competition with other species such as bryozoans) and environmental factors such as the degree of sedimentation, local currents and decreased in salinity from freshwater flows. The greatest number of recruits occurred in areas that were generally well flushed with tidal water and in close proximity to the mouth of the estuary.

A surprising result of this project was the lack of Sydney rock oysters (*S. glomerata*) recruited to the settlement tiles, despite numerous rock oysters growing on hard engineered surfaces (e.g. pylons, jetties and seawalls) within the Noosa Estuary (Figure 14). A variety of environmental factors are critical for successful reproduction and recruitment of oysters, with the failure of recruitment attributed to declining water quality and sedimentation. Ambient environmental conditions such as salinity range are critical to the successful recruitment, growth and survival of commercial oysters (Neil & Holliday 1988), Larval growth rates generally highest at 23-39‰ and survival highest between 27 and 39‰ for Sydney rock oysters (Neil & Holliday 1988). Adult Sydney rock oysters can tolerate and survive at salinity levels from 15 to 55‰, which is within the salinity range found in Noosa estuary (Neil & Holliday 1988). Failure of oyster recruitment in Pumicestone Passage, approximately 50 km to the south of Noosa, has been attributed to a decline in water quality due to eutrophication and agricultural runoff in the catchment, which causes immunosuppression and disease in adults and disrupting reproduction and also increased sedimentation reducing the suitability of subtidal settlement sites for larval settlement and recruitment (Diggles 2013). The Noosa River Catchment is considered the best performing in South East Queensland (SEQ) in terms of water quality, diversity of in-stream habitats and fish production (Sunshine Coast Regional Council 2012) and therefore represents a location where restoration of functionally extinct habitats (such as oyster reefs) will likely have a high chance of success (i.e. due to a lack of other constraining factors) (Healthy Waterways 2013).

High rainfall and resulting freshwater runoff during the survey period may have been a contributing factor to the lack of recruitment of Sydney rock oysters. It is likely that the high degree of sedimentation, associated with runoff and re-suspension of fine sediments early in summer, created conditions that were unsuitable for recruitment of *S. glomerata* (as discussed by Diggles 2013). Furthermore, this assessment provided a spatially and temporally restricted assessment of the potential for recruitment of oysters (i.e. over 5 months), so the lack of *S. glomerata* does not preclude settlement and recruitment on restored reefs, which could occur at different times in the year or in different locations of the estuary. An encouraging sign for any reef restoration program, with the objective to enhance biodiversity and fisheries productivity, was the recruitment of numerous other species including non-commercial oyster species, barnacles and mussels on the settlement tiles and associated deployment structures. These types of sessile species provide an important component of the overall biodiversity of estuarine systems and are likely to contribute to food webs and provide a filtration function similar to that of commercial oyster species. The oysters that recruited to the tiles would also be suitable for collection for bait by recreational fishers and provide structural habitat and a food source for commercially and recreationally important fisheries species.

Figure 14. Growth of *S. glomerata* on a jetty in the lower Noosa Estuary

Subtidal reefs in the Sunshine Coast have a diverse benthic assemblage of corals, macroalgae, barnacles, ascidians, sponges and bryozoans (Hooper & Kennedy 2002; Walker & Schlacher 2014). There is also a diverse fish fauna that associate with both natural and artificial reefs including, with more than 192 species known to associate with these structures (Schlacher-Hoenlinger et al. 2009). Reintroducing oyster reefs into this shallow system could have positive benefits for the estuary through increased protection of banks, increased biodiversity and potentially increase the recreational fisheries productivity (particularly for reef loving species such as bream) as it has done in other estuaries in the Eastern USA (Cohen et al. 1999; Brumbaugh et al. 2006; Schulte et al. 2009).

4.2 Recommendations

Recommendations based on the results of this assessment of recruitment for the design of any artificial reef structure in the Noosa Estuary include:

- Incorporating a variety of surface orientations particularly horizontal surfaces designed to maximise overhanging areas to ensure that recruits are not smothered by sediment and algal growth. Recruitment occurred on lower horizontal surfaces despite being places in locations with high rates of sediment deposition such as Lake Doonella.
- Locating the reef in an area where it will not interfere with normal vessel movement through the estuary (i.e. outside main channels, primarily along the banks).
- Locating the reef in an appropriate depth of water – oysters recruited in both intertidal and subtidal depths to <1.5 m deep, although the greatest total number were found intertidally approximately 0.1-0.2 m above the Low Tide Mark.
- The success of any oyster reef reintroduction program will likely be maximised by locating reefs in the main estuary around Tewantin, in the narrow channel between Goat Island and Noosa North Shore, or in Weyba Creek.
- Timing the deployment period to coincide with period of maximum recruitment potential (summer to autumn based on the results if this study but further investigation is needed).
- A range of surface materials including concrete and recycled plastic could be suitable for use as initial settlement structures.
- Considering opportunities for multiple use benefits from the placement of structures – i.e. incorporating into seagrass friendly moorings the need for anchoring larger vessels in the main estuary to maximise return on investment.

Determining clear objectives for the placement of any artificial reef is essential to succuss of the program (Brumbaugh et al. 2006). In this case the objectives may include:

- Increasing biodiversity by providing a greater variety of habitats available (particularly hard surfaces), and therefore increasing settlement opportunities for a range of species with larvae currently present in the water column, but that are excluded from recruiting into the estuary due to a lack of suitable habitat.
- Provision of a shoreline buffer for erosion protection from boat wake – engineered structures such as oyster reefs can provide a useful mechanism to buffer against erosion from boat wake and exclude some vessels from a section of habitat by creating a physical barrier.
- Increased fisheries resources through habitat provision for various species. Although, further investigations would be necessary to determine if the reefs can provide a source of production rather than just an aggregation device for existing species, and the impact of improving habitat availability for predators in the system that have previously been excluded or remain in lower numbers due to the limited availability of habitat

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