Pumicestone Passage Shellfish Reef Habitat Restoration Project – December 2018 deployment

6 Month Invertebrate Monitoring

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Summary

Samples of oyster shells were obtained from two experimental subtidal oyster patch reefs deployed 6 months ago as part of the Pumicestone Shellfish Habitat Restoration Trial. Two samples of 100 oyster shells from different parts of each reef (n = 200 per reef) were examined for evidence of natural rock oyster (*Ostrea*, *Crassostrea*, *Dendostrea*, and *Saccostrea* spp.) spatfall and colonization by other invertebrates. Results confirmed that survival rates of naturally recruiting subtidal rock oyster spat were good (80.5-93%). The southern patch reef (made from dead oyster shells surrounded by 55 besser block fence modules) averaged 64 spat per 100 shells (80.5% survival) with a mean size of 19.2 mm (range 8-38 mm), while the northern patch reef (made from live and dead oyster shells covered with a geofabric cover surrounded by 45 besser block fence modules) averaged 71.5 spat per 100 shells (93% survival) with a mean size of 26.7 mm (range 11-75 mm). Evidence of anchor damage was observed on the fence modules surrounding the southern patch reef. Parts of the northern patch reef that were covered by geofabric mesh remained covered in sand and silt. In contrast, the uncovered section remained in good condition.

An opportunistic sample of 118 shells was obtained from a crate module (cage) reef 18 months after its deployment, including individual oyster shells with up to 10 recruited spat. Total spatfall per 100 shells was around double that of the 6 month old samples (118 spat per 100 shells) with mortality less than 5% and mean size 20.4 mm (range 10-50 mm). This provides evidence of spat recruitment and survival over 2 summer seasons. Again, shells sampled from all reef types displayed prolific colonisation by invertebrate epibionts including corraline algae, bryozoans, hydroids, colonial and solitary tunicates and soft corals, which helped cement the loose shells together into a monolithic reef formation. Evidence of spat recruitment and survival over successive years suggests that oyster reef restoration is feasible in Pumicestone Passage, and potentially also wider Moreton Bay.

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1.0 Introduction

Archaeological and historical records indicate the existence of extremely abundant populations of reef forming shellfish in the coastal bays and estuaries of Pumicestone Passage, Moreton Bay and other estuaries in Southern Queensland prior to European settlement (Diggles 2015). However, today most shellfish reef habitats in Australia are functionally extinct (Beck et al. 2011), including 100% loss of subtidal shellfish reefs and around 96% loss of vertical zonation of oysters in Pumicestone Passage over the last 125 years, due mainly to ecological processes associated with catchment development (Diggles 2013). Realization of the large extent of the loss of ecosystem services historically provided by shellfish reefs in Australia has led to recent efforts to restore them (Gilles et al. 2015), with shellfish reef restoration projects now occurring in several Australian States (Gilles et al. 2018, McLeod et al. 2018).

In Moreton Bay the historically dominant reef forming shellfish species was thought to be the Sydney rock oyster (*Saccostrea glomerata*) (see Smith 1981, Diggles 2015). Despite the extinction of subtidal shellfish reefs in Pumicestone Passage, micro-trials in 2014-16 confirmed the presence of natural subtidal recruitment of rock oysters in that waterway, suggesting shellfish restoration was feasible provided clean substrate was deployed at an appropriate time of year (Diggles 2017). Armed with that knowledge, the Pumicestone Shellfish Habitat Restoration Trial was undertaken with the aim of investigating various methods for restoring lost subtidal oyster reefs to the lower Pumicestone Passage.

In early December 2017, 16 modules of six different types of experimental oyster reefs (patch reefs filled with recycled oyster shells and surrounded by artificial (concrete module) fences with and without live oysters on top, steel wire cages (crates) filled with recycled oyster shells with and without live oysters on top, and a biodegradable matrix (BESE) with and without oyster shells) were deployed into a site in southern Pumicestone Passage (Figures 1, 2). A fish monitoring study 6 months later (May 2018) found a doubling in both total fish abundance and species richness when compared to baseline data from the area (Gilby et al. 2018). A study of invertebrate recruitment 9 months post–deployment found evidence of natural subtidal recruitment of rock oysters and substantial colonization and binding of the shell reefs by various other invertebrates, indicating significant increases in biodiversity and abundance had occurred compared to the shelly mud bottom previously present in the restoration area (Diggles et al. 2018). The present study is the second of 4 quarterly longitudinal studies of the invertebrate colonisation of 2 larger (c. 7 meter diameter) patch reefs that were deployed in the Pumicestone Passage shellfish reef restoration site in early December 2018 (Figure 2).

2.0 Method

During the low tide on 10 June 2019, divers undertook sampling of two 6 month old subtidal shellfish patch reefs c. 7 meters diameter, which had been deployed in 3.5-3.7 meters of water in the Pumicestone Passage shellfish reef restoration study area on 4-10 December 2018 (Figures 1, 2). The southern patch reef (constructed with c. 20 m^3 of dead oyster shells surrounded by 55 besser block fence modules), was located around 30 meters south east of the marker buoy, while the northern patch reef (a mix of 1.5 m^3 of live and c. 14 m^3 of dead oyster shells covered with a geofabric cover surrounded by 45 besser block fence modules) was located around 20 meters north east of the marker buoy (Table 1, Figure 2). Each of the reef modules was first located and marked with a marker buoy before the divers inspected them and obtained samples of shells by hand which were placed in a fine mesh (3 mm) dive bag and taken to the surface.

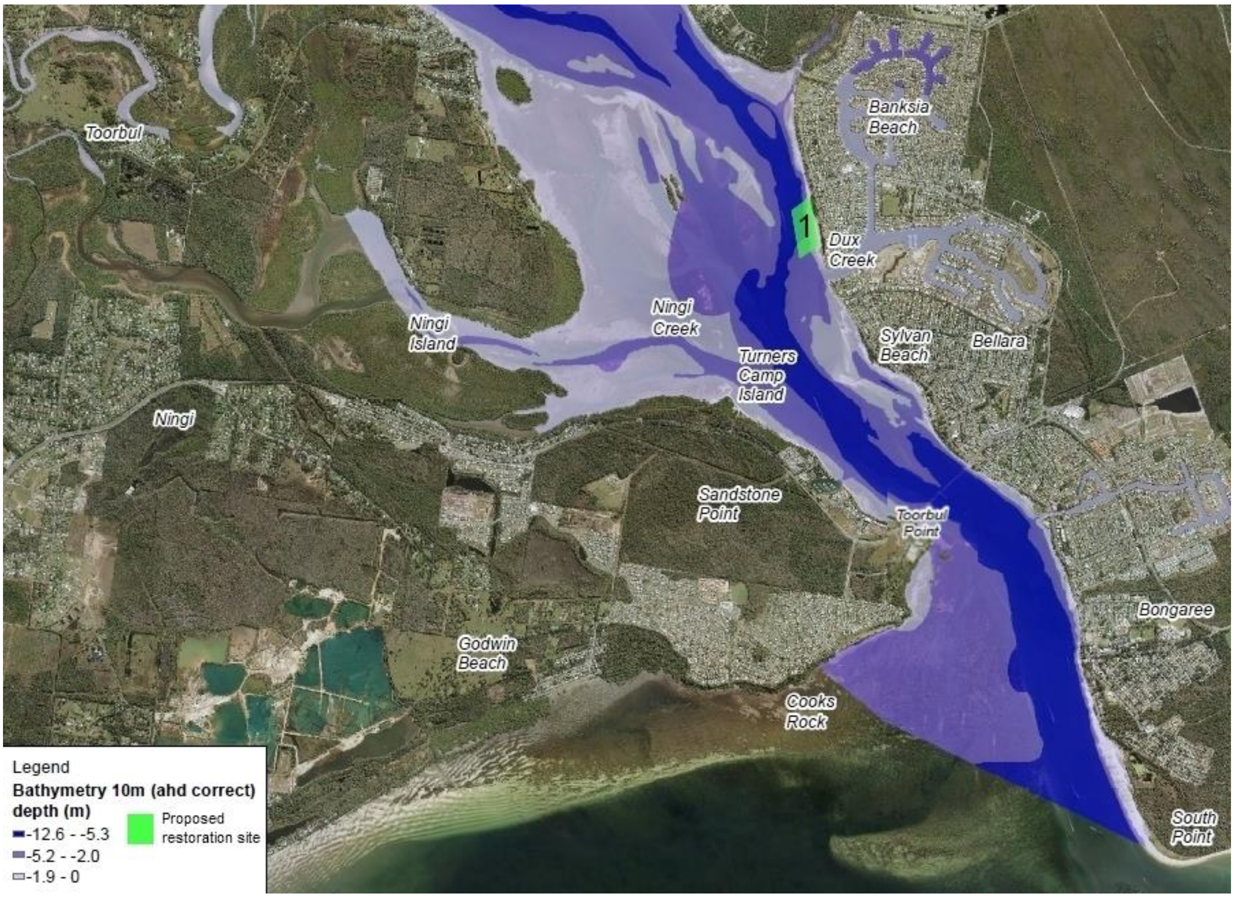

Figure 1. Location of the study area (1) in Pumicestone Passage, Northern Moreton Bay.

Table 1. Details of the locations and types of experimental oyster reefs examined at 6 months.

Reef Number / Name	GPS co ordinates Latitude	Longitude	Depth (m at LAT)	Reef type	Mean spatfall / 100 shells	Condition
17 North	27.03.027 S	153.07.974 E	3.7	Patch reef, c. 6.5 meters dia. 14 m³ dead and 1.5 m³ live shells with coir mesh cover, surrounded by 45 besser fence modules	71.5	Poor, smothered under coir mesh
18 South	27.03.054 S	153.07.985 E	3.5	Patch reef, c. 7.5 meters dia 20 m³dead shells, surrounded by 55 besser fence modules	64	Good, some anchor damage
Total				Mean spatfall per 100 shells	67.75	

Two samples of 100 oyster shells from different parts of each reef (n = 200 per reef) were collected by divers and returned to the boat in dive bags. Once on board the attending boat the shell samples were placed into fish bins and visually examined for recruitment of rock oyster (*Saccostrea* spp.) and other invertebrate symbionts. Photographs and video of the condition of the reefs were taken using an underwater camera (GoPro Hero3+) hand held by divers. In addition, an opportunistic sample of 118 oyster shells was obtained from crate module #1 (a wire cage reef filled with dead oyster shells), around 18 months after its deployment in December 2017. As for previous samplings, water quality data was obtained using a YSI85 DO/Temp/salinity/conductivity probe and a secchi disk.

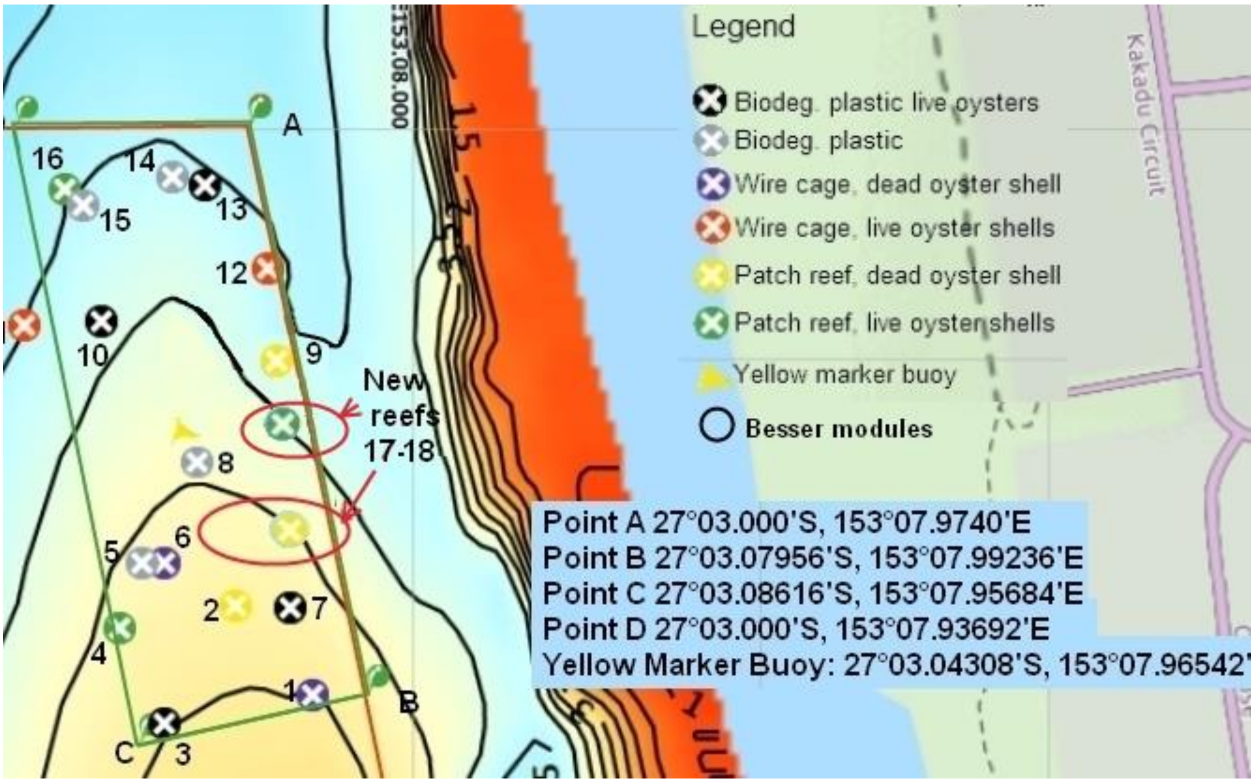

Figure 2. Detailed map of the project area showing bathymetry and layout of the new experimental reef modules #17 (north) and #18 (south) as well as location of crate reef #1. Description of reefs as per Table 1.

3.0 Results

3.1 Water quality

Water quality data obtained on the day (Temperature 18.5°C, salinity 36 ppt, DO 7.2 mg/L (96% saturation), secchi depth c. 3.5 meters) were typical of June in Pumicestone Passage and showed that conditions were suitable for oyster survival and growth, the latter albeit at a reduced rate compared to the summer months.

3.2 Rock oyster spatfall

Data from these samples suggested that natural rock oyster spatfall may have continued to occur on the northern patch reef since the previous 3 month sample, but there was little evidence of additional spatfall on the southern patch reef. The samples from the northern patch reef (#17) averaged 71.5 (range 60-83) spat per 100 shells (Table 2), up from an average of 34.5 spat per 100 shells after 3 months (Table 3). The increased mean spat settlement measured on this reef may have been due to the fact that both samples of 100 shells came from the uncovered section of the reef, and/or may be evidence of further recruitment on this reef since the 3 month sample. In contrast, the samples from the southern patch reef (#18) averaged 64 spat per 100 shells (range 62-66) (Table 2), which was nearly identical to the mean 65 spat/100 shells obtained from that reef after 3 months (Table 3).

Growth data showed that the mean size of spat sampled from the northern patch reef was 26.7 mm (range 11-75 mm) (Table 2), which was larger than the mean size measured at 3 months (14.7 mm, see Table 3). Some of this increase could be due to sampling of some the live oysters that were placed on this reef when it was built (i.e. those oysters measuring over 50 mm diameter were likely to be older than 6 months). For comparison, the mean size of spat sampled from the southern patch reef was 19.5 mm (range 8-38 mm) (Table 2), which was larger than the mean size measured at 3 months (15.6 mm, see Table 3).

Examination of the proportion of dead spat found that survival rates of the naturally recruiting rock oyster spat were good, ranging from 80.5% on the southern reef, to 93% on the northern reef (Tables 2, 3). An opportunistic sample of 118 shells was obtained from crate module (cage) reef #1 around 18 months after its deployment. The sample contained individual oyster shells with up to 10 recruited spat on the shell (Figure 3). Total spatfall per 100 shells from this cage was around double that of the 6 month old samples (118 spat per 100 shells) with mortality less than 5% and mean size 20.4 mm (range 10-50 mm) (Table 3). The fact that the number of spat per shell on this reef had doubled since the 9 month sampling in September 2018 provides evidence of subtidal spat recruitment and survival over 2 consecutive summer seasons for the modules deployed in December 2017.

Table 2. Details of rock oyster spatfall and other bivalves and invertebrates found in samples of 200 shells obtained from the 6 month old patch reefs.

Reef Number	Reef type	Mean spatfall /100 shells	Mean (range) spat size (mm)	Spat survival	Other invertebrates
17	Patch reef, c. 6.5 meters dia. with coir mesh cover	71.5	Overall 26.7 (11-75) Alive 26.9 (11-75) Dead 23.9 (11-50)	93%	+++ corraline algae +++ barnacles 2 amphipods 1 glory scallop 1 hammer shell 9 seasquirts 4 colonial ascidians 1 porcellanid crab 1 brittle star 1 xanthid crab 1 snapping shrimp
18	Patch reef, c. 7.5 meters dia.	64	Overall 19.5 (8-38) Alive 19.2 (8-38) Dead 19.8 (13-30)	80.5%	+++ corraline algae +++ barnacles 2 amphipods 1 glory scallop 19 sea squirts 7 colonial ascidians 2 polychaetes 3 serpulid polychaetes 1 brittle star 1 porcellanid crab 1 xanthid crab 1 snapping shrimp

Table 3. Summary table showing changes in spatfall numbers, growth and survival over time for 3 experimental shellfish reefs in Pumicestone Passage. * = Half of sample taken from under coir mesh cover. - = data not available.

Sampling Date post-deployment	December 2018 Deployment – North Reef #17 (dead and live shell)			December 2018 Deployment – South Reef # 18 (dead shell only)			December 2017 Deployment – Cage Reef #1 (dead shell only, wire cover)		
	Mean # spat/ 100 shells	% survival	Mean size (mm)(range)	Mean # spat/ 100 shells	% survival	Mean size (mm)(range)	Mean # spat/ 100 shells	% survival	Mean size (mm)(range)
3 months	34.5*(22-47)	91%	14.7 (7-30)	65 (58-72)	71%	15.6 (5-38)	-	-	-
6 months	71.5 (60-83)	93%	26.7 (11-75)	64 (62-66)	80.5%	19.5 (8-38)	-	-	-
9 months							79	95%	10.55 (5-25)
12 months							-	-	-
18 months							118	95.7%	20.4 (10-50)
24 months									

Table 4. Summary of links to videos taken of reef condition during invertebrate sampling.

Reef type	3 months post-deployment	6 months post-deployment	9 months post-deployment
December 2017 Deployment Patch Reef #16	-	-	https://youtu.be/lBuN0dCKjb4
December 2017 Deployment Cage (wire crate) Reef #1	-	-	https://youtu.be/bgnHSpUJK_c
December 2017 Deployment BESE (Potato starch) Reef #7	-	-	https://youtu.be/9Sdo6KXFdII
December 2018 Deployment North Reef #17 (dead and live shell)	https://youtu.be/2C32392FKTg	https://youtu.be/G5CY2apoZYQ	-
December 2018 Deployment South Reef # 18 (dead shell only)	https://youtu.be/pBC97OtMCis	https://youtu.be/om8NH7_8lO4	-

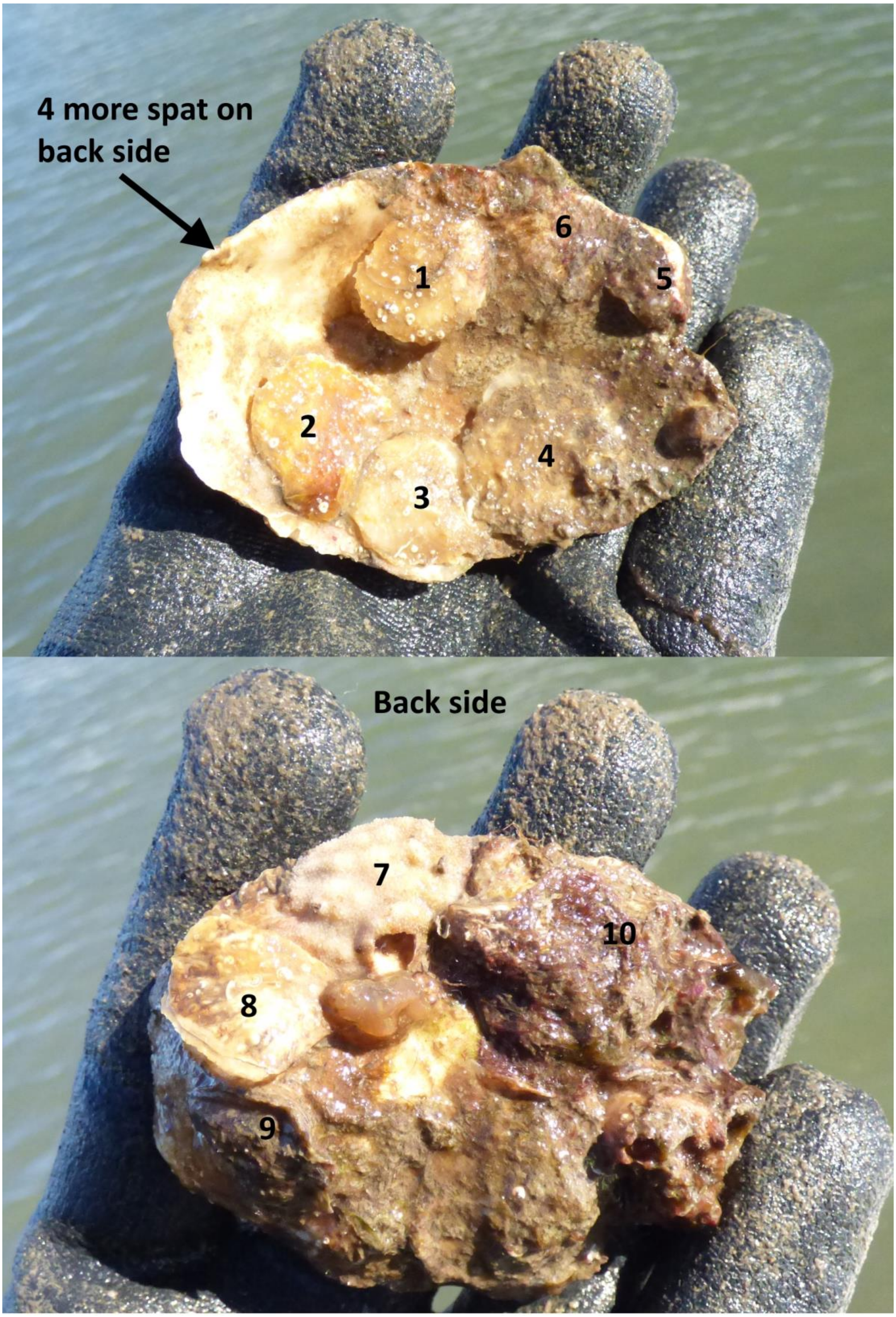

Figure 3. Opportunistic sampling of shells from crate reef #1 (dead oyster shells in wire cage) after 18 months found evidence of 2 years of recruitment (mean spatfall 118 spat/100 shells), and high survival (>95%) with up to 10 oyster spat on some shells.

3.3 Reef condition - Gopro footage of reef units

Diver inspection of the patch reefs found evidence of anchor damage on the fence modules surrounding the southern patch reef (Figure 4, underwater video available at https://youtu.be/om8NH7_8lO4). Parts of the northern patch reef that were covered by geofabric mesh remained covered in sand and silt, however in contrast, the uncovered section remained in good condition (Figures 5, 6, underwater video available at https://youtu.be/G5CY2apoZYQ). The geofabric was disintergrating in some areas where it was partially removed. A summary of the underwater videos documenting the condition of these reefs obtained by divers during invertebrate sampling trips is contained in Table 4.

3.4 Condition of seagrasses nearby

Early in the morning of 10 June 2019 prior to sampling of the experimental shellfish reefs it was noticed that seagrass beds near the Avon wreck were being smothered and choked by a bloom of *Ectocarpus* spp. (snotweed) (Figure 7). Blooms of snotweed have been recorded at this time of year in previous studies (e.g. Diggles 2017) and they now seem to be an annual event that coincides with increased water clarity during the winter months. The clear water allows sunlight penetration to the bottom where the eutrophic conditions of the Pumicestone Passage stimulates abundant algal growth, which reduces the functional surface area, fisheries productivity and ultimately the survival of these seagrass meadows (which themselves require sunlight for growth).

A video transect of the choked seagrass is available at https://youtu.be/ckdgbl2GPuE

Figure 4. Anchor damage was evident on the besser block fence of the southern reef (#18). Given the increased size and weight of the fence modules used for the December 2018 deployments, this damage must have been done by a large boat powering a stuck anchor off the reef after ignoring signage and advice not to anchor in the area.

Figure 5. Sedimentation of the side of the northern reef (#17) covered with a geofabric cover as required under Fisheries permit. This excessive sedimentation due to the cover is obviously extremely detrimental to the shellfish reef.

Figure 6. In contrast to Figure 5, the uncovered side of the northern reef (#17) appeared in excellent condition, demonstrating that oyster shells interlock and are quickly cemented together by invertebrate fouling organisms, making any need to cover them redundant.

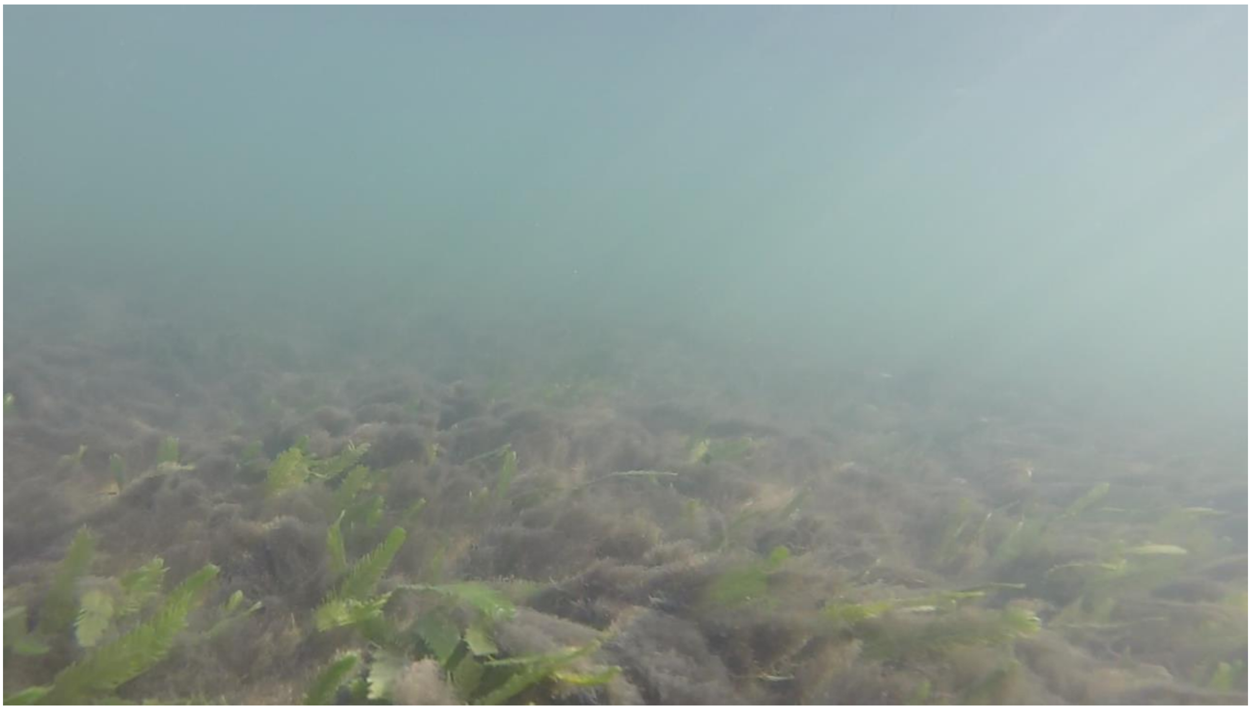

Figure 7. At the time of sampling, the seagrass beds near the Avon wreck were being smothered by a bloom of *Ectocarpus* spp. (snotweed). These brown algae blooms are now annual events that coincide with increased water clarity during the winter months, providing more evidence of the degraded, eutrophic condition of Pumicestone Passage.

Discussion

Results from these samples confirmed that natural rock oyster spatfall (*Saccostrea* spp., *Ostrea*, spp., *Dendostrea* spp. and *Crassostrea* spp., see Ramos Gonzalez et al. 2019) continues to occur subtidally in the restoration area at rates averaging around 60-70 spat per 100 shells per spawning season. Table 3 shows how juvenile oysters recruited to patch reefs #17 and #18 continue to survive and grow in size over time, and comparison with data from 18 month old oyster shells deployed in December 2017 in crate reef #1 shows that spat recruitment and survival can occur over multiple years (Diggles et al. 2018, 2019, present report). This is likely to have occurred due to favourable site selection for this trial and correct design of the patch reefs and cage reefs which ensure that 3 dimensional shell piles of greater than 50 cm height above the surrounding bottom have been maintained in an area with relatively high current flow, as this combination of high relief and current flow provides protection from sedimentation (as has been previously recorded for successful subtidal shellfish reef restoration projects in other locations, see Schulte et al. 2009, Colden et al. 2017). These are the sorts of metrics that are necessary in order to achieve successful shellfish reef restoration (Baggett et al. 2014, 2015).

It is hypothesised that the revised design of the taller, more robust fence modules and the larger size of the experimental reefs in the December 2018 deployment have, reduced (but not eliminated) the detrimental effects of anchor damage, such that we have managed to replicate the spat recruitment performance observed on the crate reefs, but it still appears that spat survival remains slightly higher on the crate reefs. This may be a function of reduced predation of oyster spat on shells in crate reefs. Video observations have found that the natural shape of patch reefs makes the top layer of shells more readily available to foraging fish, while in comparison the shells contained in crate reefs tend to be less accessible to fish due to the constraints of the shape of the cages and the small size of the wire mesh.

An incidental finding on the morning of sampling was the fact that nearby seagrass meadows just south and west of the Avon wreck were being smothered by profuse brown algae (*Ectocarpus* spp.) blooms. Blooms of snotweed now seem to be an annual event in Pumicestone Passage (Diggles 2017) and their emergence coincides with increased water clarity during the winter months. The clear water allows sunlight penetration to the bottom where the eutrophic conditions of the Pumicestone Passage stimulates abundant algal growth, which smothers the seagrass strands reducing its functional surface area and thus its suitability as fish habitat. These algal blooms are thus a significant threat to fisheries productivity and ultimately the survival of these seagrass meadows, given that the shading of the algae reduced sunlight availability needed for seagrass growth. It is notable that shellfish reef restoration can benefit seagrass conservation and recovery through increased filtration of seawater (improving water clarity and light penetration), as well as through increased nutrient uptake (Newell et al. 2004).

As was previously recorded for the December 2017 deployments (Diggles et al. 2018), the oyster shells on both of the reefs deployed in December 2018 were quickly colonised by prolific epibiont growths of various invertebrates including, amongst others, corralline algae, bryozoans, hydroids, solitary and colonial tunicates, and soft corals (Diggles et al. 2019). These epibionts have now survived over 6 months and proliferated further (Table 2), not only providing a massive increase in biodiversity, but also a significant food source for fishes which is likely to lead to increased fisheries productivity.

Of course, these epibionts also combine with natural oyster shell processes to help cement the loose shells together (Burkett et al. 2010) into a monolithic reef formation (Diggles et al. 2018). Indeed, we now have 1.5 years of empirical evidence from oyster reef trials in Pumicestone Passage that demonstrates that live oysters deployed over the top of experimental shell reefs in both 2017 and 2018 remained exactly where we put them, bound together by natural processes. This natural reef consolidation process negates any need to cover these reefs with coir netting or other mesh to "adequately contain" live shells that may be used to enhance the reefs. Indeed, after 6 months observations of reef #17 and comparisons between it and reef #18, we can confirm beyond doubt that covering shellfish reefs with artificial netting also promotes sedimentation that will smother the covered area of the reef. Thus, coir netting is not required or desirable for future reef restoration efforts.

Besides the detrimental impact of the coir netting over reef #17, the invertebrate monitoring results outlined in the present report and in the earlier report of Diggles et al (2019) are very encouraging. Indeed, evidence of spat recruitment and survival over successive years suggests that oyster reef restoration is feasible in Pumicestone Passage, and potentially also wider Moreton Bay. We will follow up these results with additional invertebrate sampling periods at 9 and 12 month intervals, supplemented by opportunistic sampling of reefs deployed in December 2017, so that the ongoing progress of reestablishment of these reefs can be better understood.

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Project partners

The various partners involved with this project are listed below. Many thanks to all partners together with Bribie's oyster gardeners and the broader community for their efforts and support as we continue our journey towards restoration of the lost shellfish reefs in Pumicestone Passage and Moreton Bay.

Joondoburri Land Trust

Sebastiani Oyster Farm

Pumicestone Passage Fish Restocking Assoc.

Kabi Kabi First Nation