Pumicestone Passage Shellfish Reef Habitat Restoration Project – December 2018 deployment

9 Month Invertebrate Monitoring

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Summary

Samples of oyster shells were obtained from two experimental subtidal oyster patch reefs deployed 9 months ago as part of the Pumicestone Shellfish Habitat Restoration Trial. Samples of 100 oyster shells were examined for evidence of natural spatfall from rock oysters and other bivalves (honeycomb oyster, glory scallop) and colonization by other invertebrates. Results confirmed that survival rates of naturally recruiting subtidal rock oyster spat on the larger 9 month old reefs continue to be high (c. 86%). The southern patch reef recorded 86 spat per 100 shells (86% survival, mean size 18.9 mm, range 8-40 mm), while the northern patch reef recorded 66 spat per 100 shells (86.6% survival, mean size of 25.8 mm, range 10-72 mm). Evidence of earlier 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. Both northern and southern patch reefs were being frequented by at least 7 species of finfish, as shown by videos of the south reef (available at https://youtu.be/UZoT9tMstkc), and north reef (https://youtu.be/rcM-GSmVrW0). Samples of 100 shells were also obtained from a crate module (cage) and a 2 meter diameter patch reef 21 months after their deployment. Total spatfall per 100 shells for the cage module was nearly double that of the 9 month old reefs (136 spat per 100 shells) with high survival (85%) and mean size 20.8 mm (range 10-52 mm), providing evidence of spat recruitment and survival over 2 summer seasons. In contrast, only 43 spat per 100 shells with low survival (20.9%) was evident on the 2 meter diameter patch reef, which was heavily damaged by anchors and knocked nearly flat over 12 months ago. Again, shells sampled from all reef types displayed prolific colonisation by invertebrate epibionts which cement the shells into a monolithic reef formation. Evidence of spat recruitment and survival over successive years in shells >20 cm above the bottom 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). Fish monitoring studies have shown despite heavy fishing effort, harvestable fish abundance had increased to be 128% higher on the reef restoration site compared to control sites, and total fish abundance had increased to 268% when compared to baseline data from the area (Gilby et al. 2018, 2019). 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). These biodiversity and invertebrate abundance improvements are to be expected given the large surface area and internal void areas of the shell reefs. The present study is the third 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). For earlier results from the first two sampling periods, see Diggles et al. (2019a, 2019b).

2.0 Method

During the low tide on 11 September 2019, divers undertook sampling of two 9 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 locations and types of experimental oyster reefs examined at 9 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 m^3 dead and 1.5 m^3 live shells with coir mesh cover, surrounded by 45 besser fence modules	66	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 m^3dead shells, surrounded by 55 besser fence modules	86	Good, some anchor damage
Total				Mean spatfall per 100 shells	76	

Due to time constraints because of the afternoon low tide, this monitoring event consisted of a single sample of 100 oyster shells from each reef (n = 2 sites per reef) which 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 also taken using an underwater camera (GoPro Hero3+) hand held by divers. In addition, an opportunistic sample of 100 oyster shells was obtained from crate module #1 (a wire cage reef filled with dead oyster shells), around 21 months after its deployment in December 2017, and a sample of 100 shells was also obtained from a 2 meter diameter patch reef #16 (a patch reef topped with live oysters) 21 months after its deployment and over 12 months after it was flattened by anchor damage. As for previous samplings, water quality data was obtained using a YSI85 DO/Temp/salinity/conductivity probe and a secchi disk. Video footage of the BESE reefs and patch reefs was also taken by an underwater drone on 14 September 2019 to inspect reef condition.

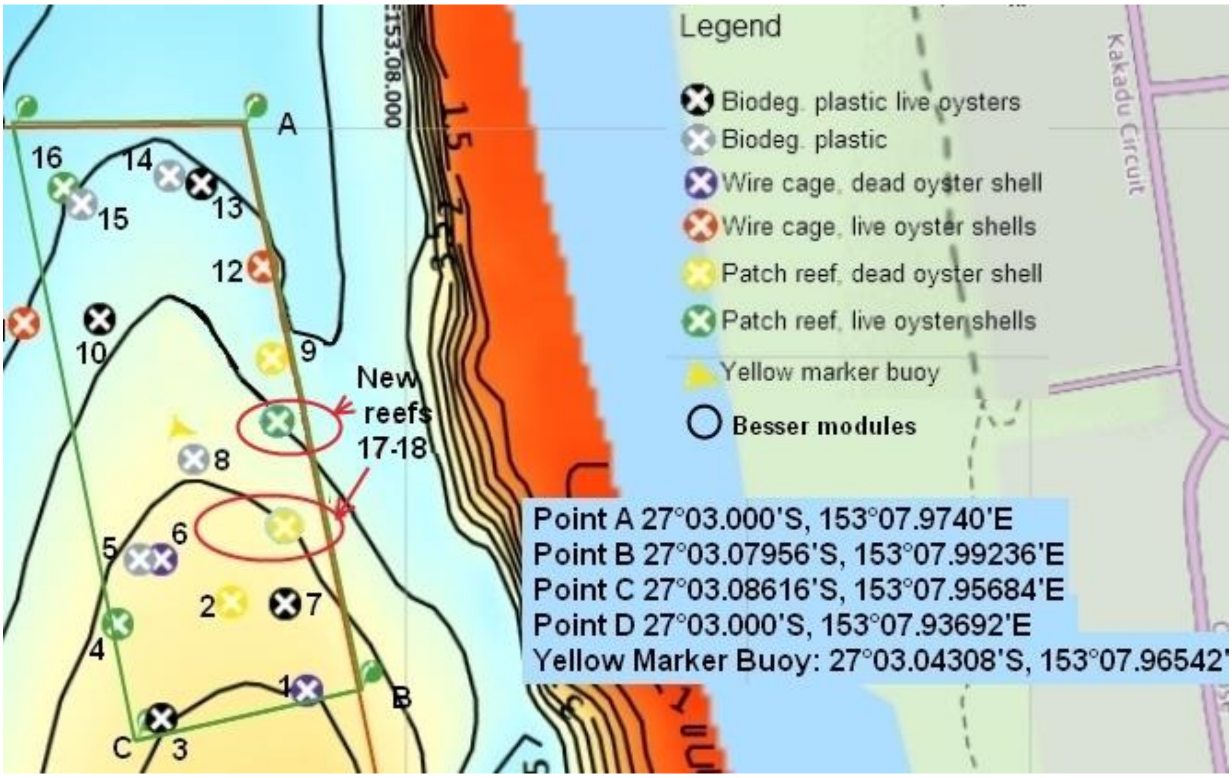

Figure 2. Detailed map of the project area showing bathymetry and layout of the new experimental reef modules #17 (north) and #18 (south) as well as location of crate reef #1 and patch reef #16. Description of reefs as per Table 1.

3.0 Results

3.1 Water quality

Water quality data obtained on the day (Temperature 17.6°C, salinity 37.5 ppt, DO 7.4 mg/L (96% saturation), secchi depth c. 2.5 meters) were typical of September in Pumicestone Passage except visibility was poor due to resuspended sediment and benthic algae (snotweed) in the water from strong (25 knot) south east winds from the previous few days. Conditions remain suitable for oyster survival and growth, the latter albeit at a reduced rate compared to the summer months due to the low water temperature.

3.2 Rock oyster spatfall

Data from these samples found the northern patch reef (#17) had 66 spat per 100 shells (Table 2), which was within the range of previous samples taken from that reef 3 months earlier (60-83, mean 71.5 spat per 100 shells, see Table 3). In contrast, the number of spat counted from the sample from the southern patch reef (#18) was slightly higher (86 spat per 100 shells, see Table 2), than previous samples (range 62-66, mean 64 spat/100 shells) taken from this reef 3 months ago (Table 3). Based on visual identification of spat sampled, there was no evidence of additional rock oyster (*Saccostrea* spp.) spatfall over winter. However, there was evidence of a small amount of recent honeycomb oyster (*Hyotissa* spp.) spatfall, particularly on the southern patch reef (#18), since the previous quarterly sample in June. Sampled shells all had significant invertebrate recruitment evident (Figures 3, 4)

Growth data showed very little growth occurred during the winter months, which would be expected given the low water temperature. The mean size of spat sampled from the northern patch reef was 25.8 mm (range 10-72 mm) (Table 2), which was similar to the mean size recorded 3 months earlier (26.7 mm, range 11-75 mm, see Table 3). The mean size of spat sampled from the southern patch reef was 18.9 mm (range 8-40 mm) (Table 2), which was also similar to the mean size recorded from that reef 3 months earlier (19.5 mm, range 8-38 mm, see Table 3). Again, the larger mean size of the spat on the northern reef was probably due to sampling of some of 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 9 months).

Examination of the proportion of dead spat found that survival rates of the naturally recruiting rock oyster spat continued to be good (86.4% survival on the northern reef, down slightly from the previous 93% for samples taken 3 months earlier, and 86% on the southern reef, up from the previous 80.5% survival from samples taken 3 months earlier) (Tables 2, 3). Samples of 100 shells were also obtained from crate module (cage) reef #1 and the 2 meter diameter patch reef #16 around 21 months after their deployment. Total spatfall per 100 shells from cage reef #1 (135 spat per 100 shells) remained around double that recorded from reefs #17 and #18 with survival around 85% and mean size 20.8 mm (range 10-52 mm) (Table 4).

Table 2. Details of rock oyster spatfall and other bivalves and invertebrates found in samples of 100 shells obtained from the 9 month old patch reefs.

Reef Number	Reef type	Spatfall /100 shells	Mean (range) spat size (mm)	Spat survival
17	Patch reef, c. 6.5 meters dia. with coir mesh cover	66	Overall 25.8 (10-72) Alive 25.7 (10-72) Dead 26.4 (18-42)	86.4%
18	Patch reef, c. 7.5 meters dia.	86	Overall 18.9 (8-40) Alive 19.6 (8-40) Dead 15.7 (8-22)	86.0%

Table 3. Summary table showing changes in spatfall numbers, growth and survival over 9 months for two approx. 7 meter diameter experimental shellfish reefs in Pumicestone Passage deployed in December 2018. * = Half of sample taken from under coir mesh cover. - = data not yet available.

Sampling Date post-deployment	December 2018 Deployment – North Reef #17 (dead and live shell)			December 2018 Deployment – South Reef # 18 (dead shell only)		
	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	66	86.4 %	25.8 (10-72)	86	86.0 %	18.9 (8-40)
12 months	-	-	-	-	-	-

Table 4. Summary table showing changes in spatfall numbers, growth and survival over 21 months for two experimental shellfish reefs (cage reef #1 and patch reef #16) deployed in Pumicestone Passage in December 2017. - = data not available.

Sampling Date post-deployment	December 2017 Deployment – Cage Reef #1 (dead shell only, wire cover)			December 2017 Deployment – Patch Reef #16 (dead and live shell)		
	Mean # spat/ 100 shells	% survival	Mean size (mm)(range)	Mean # spat/ 100 shells	% survival	Mean size (mm)(range)
3 months	-	-	-	-	-	-
6 months	-	-	-	-	-	-
9 months	79	95%	10.55 (5-25)	34	97%	35.57 (6-60)
12 months	-	-	-	-	-	-
18 months	118	95.7%	20.4 (10-50)	-	-	-
21 months	135	85.9%	20.8 (10-52)	43	20.9%	22.6 (15-48)

In contrast only 43 spat were counted from the 100 shells collected from the 2 meter diameter patch reef #16, and survival of those spat was relatively low (20.9%) (Table 4). Divers observed that this reef has not recovered from being knocked nearly flat by anchor damage over 12 months ago, (see Figure 10 and Appendix 1, page 26 of Diggles et al. 2018). Indeed, due to its small initial size and anchor damage, patch reef #16 has been reduced to less than 20 cm height above the surrounding substrate which has made it prone to sedimentation around the outer edges, almost eliminating spat recruitment.

Table 5. 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	https://youtu.be/rcM-GSmVrW0
December 2018 Deployment South Reef # 18 (dead shell only)	https://youtu.be/pBC97OtMCis	https://youtu.be/om8NH7_8lO4	https://youtu.be/UZoT9tMstkc

3.3 *Reef condition – Gopro and drone footage of reef units*

Diver inspection again found evidence of the earlier anchor damage on the fence modules surrounding the southern patch reef (#18) which was first noted 3 months ago (see Figure 4 in Diggles et al. 2019b). The larger besser fence modules nevertheless are still providing adequate protection and underwater video of this reef, despite poor visibility, found at least 7 species of finfish including silver biddy, whiptail, moses perch, happy moments, Gunther's wrasse, yellowfin bream and cardinalfish (video available at https://youtu.be/UZoT9tMstkc). Diver inspection of the northern patch reef (#17) found further degradation of the coir mesh cover. Underwater video of this reef found it was being frequented by at least 9 species of fish, including silver biddy, whiptail, moses perch, happy moments, Gunther's wrasse, blacksaddle goatfish, grass tuskfish, stripey and crested morwong (video available at https://youtu.be/rcM-GSmVrW0) A summary of the underwater videos documenting the condition of these reefs obtained by divers during all invertebrate sampling trips to date is contained in Table 5. More details of the types of fishes observed to be associating with these reefs can be found in Table 6. Underwater drone footage showed heavy anchor damage which has flattened the smaller patch reefs deployed in 2017 (see https://youtu.be/N1ZKITKE7SA), however the BESE reefs deployed in 2017 and larger patch reefs deployed in 2018 appeared in good condition.

Table 6. Species of fish observed associating with patch reefs #17 and #18 in 15 minute videos taken on 11 September 2019 from a camera oriented to face towards the reef. Poor visibility on the day made it difficult to see fish more than 2 meters away from the camera.

Fish name	Latin name	Approx # views	Activity
Reef #17 (North Reef)			
Gunthers wrasse	*Pseudolabrus guentheri*	>50	grazing on reef
moses perch	*Lutjanus russelli*	10-20	swim by
silver biddy	*Gerres subfasciatus*	10-20	grazing on reef
happy moment	*Siganus fuscescens*	10-20	swim by
whiptail	*Pentapodus paradiseus*	10-20	swim by
blacksaddle goatfish	*Parupeneus spilurus*	6-10	grazing on reef
grass tuskfish	*Choerodon cephalotes*	3-5	swim by
crested morwong	*Cheilodactylus vestitus*	1-2	swim by
stripey	*Microcanthus strigatus*	1-2	swim by
Reef #18 (South Reef)			
Gunthers wrasse	*Pseudolabrus guentheri*	>50	grazing on reef
whiptail	*Pentapodus paradiseus*	10-20	swim by
yellowfin bream	*Acanthopagrus australis*	6-10	swim by
moses perch	*Lutjanus russelli*	6-10	swim by
silver biddy	*Gerres subfasciatus*	1-2	grazing on reef
happy moment	*Siganus fuscescens*	1-2	swim by
cardinalfish	Family Apogonidae	1-2	grazing on reef

Figure 3. Photo of typical invertebrate recruitment cementing oyster shells together after 9 months on the southern reef (#18). Multiple oyster spat (arrows), various encrusting corraline algae, colonial tunicates and a snapping shrimp (arrowhead) are evident.

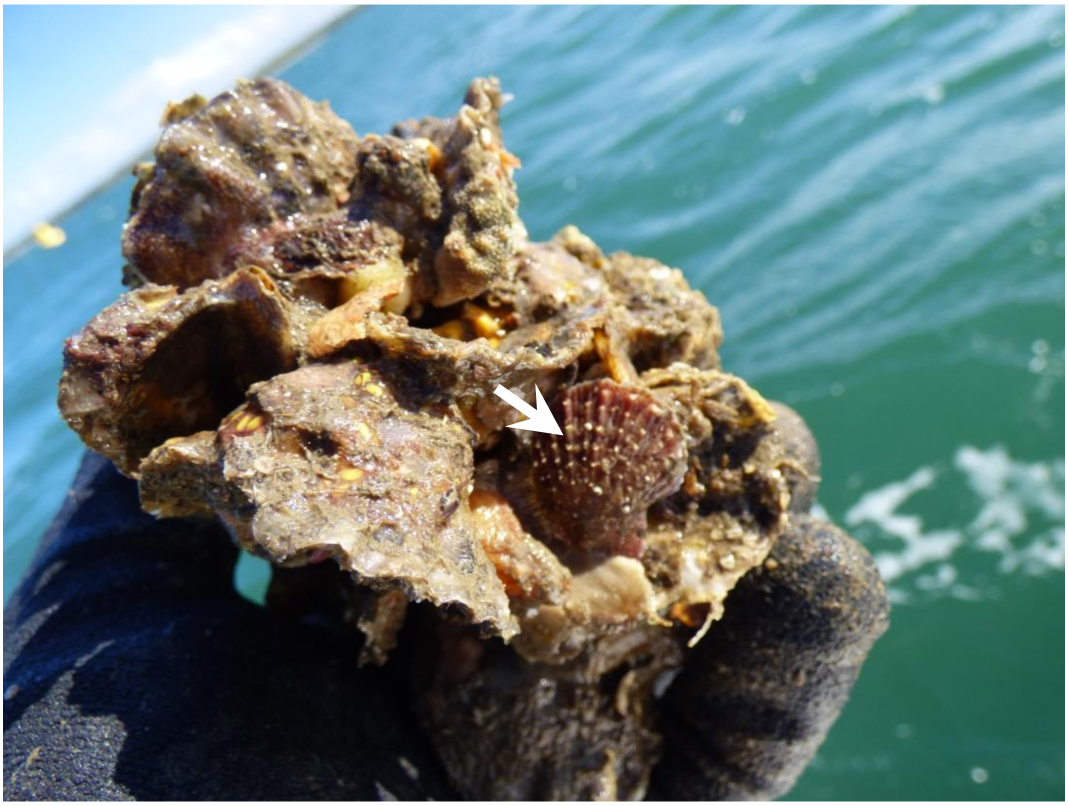

Figure 4. A clump of oyster shells sampled from the northern reef (#17), showing them cemented together by corraline algae and colonial tunicates. A recruited glory scallop is also evident (arrow).

Figure 5. Photo taken from a video of the southern reef (#18), showing poor visibility due to resuspended sediment and benthic algae (snotweed) in the water. A Gunthers wrasse (white arrow) and moses perch (black arrow) are evident in the foreground.

Figure 6. Photo taken from a video of the northern reef (#17), showing poor visibility due to resuspended sediment and benthic algae (snotweed) in the water. A Gunthers wrasse (white arrow) and whiptail (black arrow) are evident in the foreground.

Figure 7. Photo taken from an underwater drone video showing poor condition of a patch reef deployed in 2017 which has had numerous besser fence blocks removed (arrow) and the shell knocked flat by anchor damage.

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) does not occur in the restoration area during the winter months, as was previously found by Diggles (2017). However, there was evidence of a small amount of recent honeycomb oyster (*Hyotissa* spp.) spatfall, particularly on the southern patch reef (#18), since the previous quarterly survey. The virtually static mean size of the recruited spat (see Table 3) shows how juvenile oysters recruited to patch reefs #17 and #18 basically stop growing during the winter months, however survival on these reefs still remains high (c. 86%). Furthermore, the data from crate reef #1 shows that spat recruitment and survival can occur over multiple years (Diggles et al. 2018, 2019b, present report). This is likely to have occurred due to favourable site selection for this trial and correct design of the larger 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, with the long axis of the reef perpendicular to the current flow as this combination of high relief and perpendicular orientation to prevailing currents maximises 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. 2016, 2017). While sedimentation may still be problematic around the edges of high relief reefs (particularly the northern reef#17 which was covered with geofabric), much of this is likely to be due to artifactual "edge effects" (Colden et al. 2016) due to the very small size of the experimental reefs. Based on previously published scientific literature, scaling up the size of these reefs while retaining shell heights >50 cm are the primary design metrics that are necessary in order to achieve successful shellfish reef restoration (Baggett et al. 2014, 2015).

In contrast, the data from the 2 meter diameter patch reef #16 deployed in December 2017 found that recruitment and survival of spat was relatively low (20.9%) (Table 4). Divers observed that this reef has not recovered from being knocked nearly flat by anchor damage over 12 months ago, (see Figure 10 and Appendix 1, page 26 of Diggles et al. 2018). Indeed, due to its small initial size and anchor damage, patch reef #16 has been reduced to less than 20 cm height above the surrounding substrate, which has made it prone to sedimentation around the outer edges, almost eliminating spat recruitment. These results are completely consistent with previous studies from overseas which found that restored reefs less than 30 cm high tend not to persist long term, due to the increased sedimentation rates and eutrophication in todays anthropogenically modified estuaries (see Schulte et al. 2009, Colden et al. 2016, 2017). The poor condition of reef #16 after 9 months was one of the reasons why the diameter and height of reefs #17 and #18 was increased for the 2018 deployment (Diggles et al. 2018).

The fact that the number of spat per shell on crate reef #1 doubled during its second summer of deployment, while recruitment hardly occurred on reef #16, provides further evidence of subtidal spat recruitment and survival over 2 consecutive summer seasons is possible on shellfish reefs in Pumicestone Passage which can retain heights of 50 cm or more. This suggests that the shells deployed in reefs #17 and #18 can be expected to also collect more spat this summer, provided these reefs remain 50 cm or more above the surrounding substrate (i.e. as originally designed without major anchor damage).

During this sampling period and in previous months the authors have witnessed first hand several boats attempting to anchor directly onto the experimental reefs. The revised design of the taller, more robust besser block fence modules deployed in December 2018 have, reduced, but apparently not eliminated, the detrimental effects of anchor damage. Given the heavy fishing effort that is being expended over the restoration site (BK Diggles, personal observations), and the lack of appropriate signage advising boaters not to anchor in the area, it is likely that dozens of anchoring events are occurring over these experimental reefs every week. Anchor damage, rather than lack of recruitment of oysters, is therefore likely to be the major threat to the longevity of restored subtidal shellfish reefs in Pumicestone Passage. Given that signage at boat ramps and educational/awareness campaigns in the local media and community groups have not worked to reduce or eliminate anchoring damage during this trial, the high threat from anchor damage may be reduced by:

- proper signage on the marker buoy advising boaters not to anchor nearby; and/or
- addition of 4 smaller marker buoys at the 4 corners of the area to help boaters to line up the edges of the restoration area so they can avoid it; and/or
- provision of permanent anchor buoys which boaters can tie onto in lieu of using anchors that will damage the reefs.

An incidental finding this sampling period was the large number of small tufts of brown algae (*Ectocarpus* spp., or snotweed) drifting in the water column, which combined with fine sediment resuspended from recent strong winds from the previous few days. As mentioned in our previous report from June 2019, 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 hard reef as well as seagrasses. 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 has been noted in previous sampling periods, the oyster shells deployed 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. 2019a, 2019b). These epibionts have now survived over 9 months and not only provide 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 nearly 2 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 remain exactly where we put them, quickly 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, such that coir netting is not required or desirable for future reef restoration efforts.

The evidence of spat recruitment and survival over successive years in this and previous reports 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 in December 2019 so that the ongoing progress of re-establishment 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