Pumicestone Passage Shellfish Reef Habitat Restoration Project – December 2018 deployment

12 Month Invertebrate Monitoring

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Summary

Samples of oyster shells were obtained from two experimental subtidal oyster patch reefs deployed 12 months ago as part of the Pumicestone Shellfish Habitat Restoration Trial. Two samples of 100 oyster shells from each reef (n = 200 per reef) were examined for evidence of natural spatfall from rock oysters (*Ostrea*, *Crassostrea*, *Dendostrea*, and *Saccostrea* spp.) and other bivalves (pearl oysters, honeycomb oyster, glory scallop) and colonization by other invertebrates. Twelve month survival for naturally recruiting subtidal rock oyster spat was 75.4-76%. The southern patch reef averaged 125 spat per 100 shells (76% survival, mean size 18.5 mm, range 6-48 mm), while the northern patch reef was originally covered by a geofabric mesh and was affected by sand and silt, averaging only 59 spat per 100 shells (75.4% survival, mean size of 20.2 mm, range 6-55 mm). Both the northern and southern patch reefs were frequented by 8 to 12 species of finfish, as shown by videos of the south reef (available at https://youtu.be/AJiym-mGQrA), and north reef (https://youtu.be/3s7dqWXSRyE). Samples of 100 shells were also obtained from a crate module (cage) and a 2 meter diameter patch reef 24 months after their deployment. Total spatfall per 100 shells for the cage module had increased from 135 spat per 100 shells after 21 months to 154 spat per 100 shells, showing recruitment continued to occur between 21 and 24 months post-deployment (with 82% survival and mean size 19.1 mm (range 9-50 mm)). In contrast, only 31 spat per 100 shells with low survival (19.4%) was evident on the 2 meter diameter patch reef, which is showing ongoing degradation after being heavily damaged by anchors and knocked nearly flat over 12 months ago. Again, shells sampled from all reef types displayed colonisation by invertebrate epibionts which cement the shells into a monolithic reef formation. Evidence of oyster spat recruitment and survival over successive years in shells piled at least 50 cm above the bottom in the absence of geofabric mesh 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, Thurstan et al. 2020). 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 eutrophication and other ecological processes associated with catchment development (Diggles 2013). Realization of the 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, McLeod et al. 2019a, 2019b), 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 (McLeod et al. 2019b). The present study is the fourth 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 three sampling periods, see Diggles et al. (2019a, b, c).

2.0 Method

During the low tide on 22 December 2019, divers undertook sampling of two 12 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 (Reef #18, 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 (reef #17, 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 12 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	59	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^3 dead shells, surrounded by 55 besser fence modules	125	Good, some anchor damage
Total				Mean spatfall per 100 shells		

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 also taken using an underwater camera (GoPro Hero3+) hand held by divers. In addition, samples of 100 oyster shells was obtained from crate module #1 (a wire cage reef filled with dead oyster shells) 24 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) 24 months after its deployment and over 12 months after it was flattened by anchor damage. The locations of reefs #19 (27°03.065'S, 153°07.971'E) and #20 (27°03.028'S, 153°07.961'E), which were larger (9 and 7 meters diameter, respectively) patch reefs deployed on 6 and 7 December 2019, were also noted. As for previous samplings, water quality data was obtained using a YSI85 DO/Temp/salinity/conductivity probe and a secchi disk.

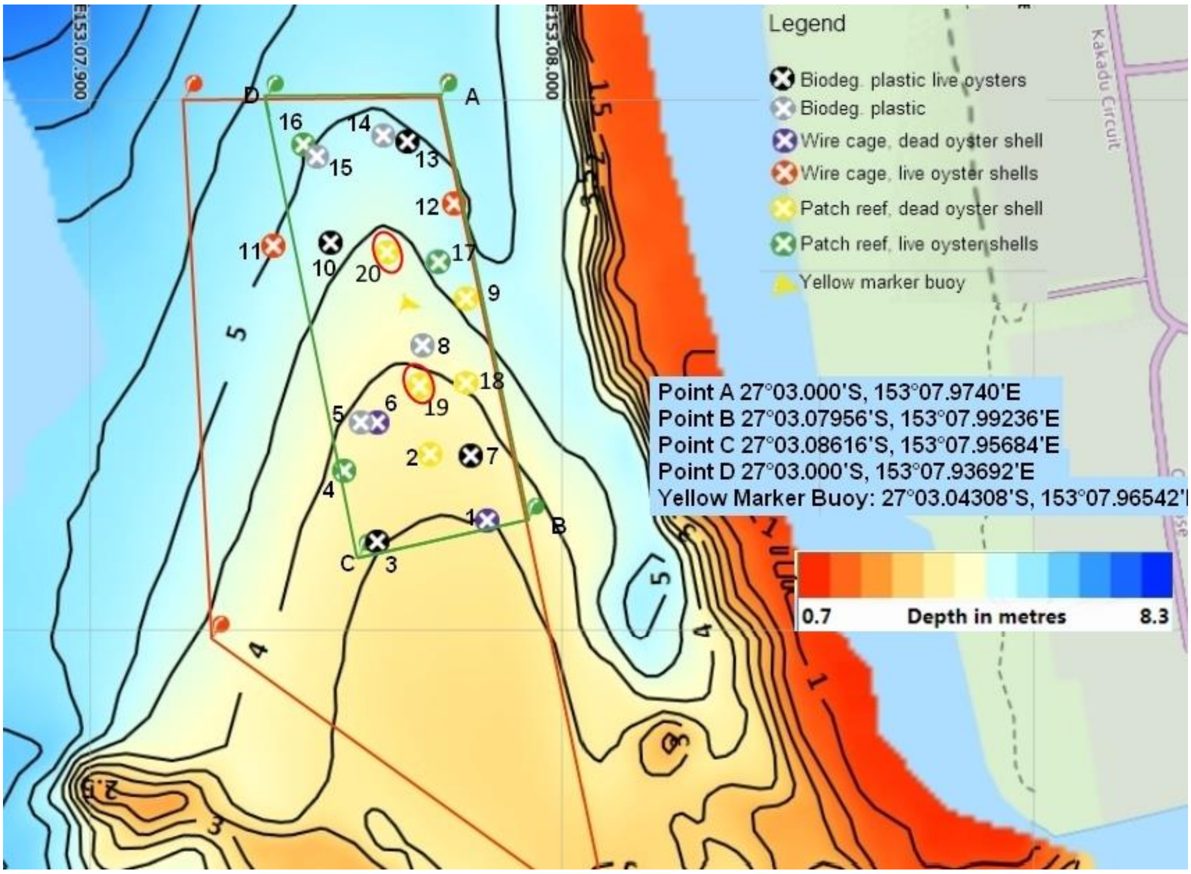

Figure 2. Detailed map of the project area showing bathymetry and positions of the experimental reef modules from the 2017 deployment (crate reef #1 and patch reef #16), the 2018 deployment (#17 north and #18 south) as well as reefs #19 and #20 from the December 2019 deployment. Description of reefs as per Table 1.

3.0 Results

3.1 Water quality

Water quality data (Temperature 27.7°C, salinity 36.3 ppt, DO 5.9 mg/L (93% saturation), secchi depth c. 2 meters) were typical of December in Pumicestone Passage indicating conditions remained suitable for oyster survival and growth. Underwater observations showed poor visibility due to resuspended sediment and filamentous algal fragments in the water, especially near the bottom (see reef monitoring videos).

3.2 Rock oyster spatfall

Data from these samples found the northern patch reef (#17) had a mean 59 spat per 100 shells (Table 2), which was similar to, but slightly less than previous samples taken from the same reef after 6 and 9 months (Table 3). This suggests that sedimentation from the geofabric cover is still affecting oyster recruitment and survival. In contrast, the number of spat counted from the sample from the southern patch reef (#18) continued to increase (now 125 spat per 100 shells, see Table 2), indicating further recruitment of not only honeycomb oyster (*Hyotissa* spp.) (which was first noted in the 9 month sampling), but also early season *Saccostrea*/*Crassostrea* recruitment (Table 3). Shells sampled from reef #18 continued to display significant recruitment of other invertebrates including tunicates, colonial tunicates and coralline algae (Figure 5)

Growth data for recruits to both reefs showed a slight reduction in average size compared to the previous two sampling periods. The mean size of spat sampled from the northern patch reef was 20.2 mm (range 6-55 mm) (Table 2), which was less than recorded 3 months earlier (25.8 mm, range 10-72 mm, see Table 3). Some of this difference was probably due to divers not sampling any of the live oysters that were placed on this reef when it was built (i.e. the previous 6 and 9 month samples from this reef included oysters up to 72-75 mm that were placed on this reef to try to boost recruitment). The mean size of spat sampled from the southern patch reef was 18.5 mm (range 6-48 mm) (Table 2), which was slightly less than the mean size recorded from that reef 3 months earlier (18.9 mm, range 8-40 mm, see Table 3) and was probably a result of the continued recruitment of new (smaller) spat in the previous 3 months.

Examination of the proportion of dead spat found that survival rates of the naturally recruiting rock oyster spat was lower than previous samples (75.4% survival on the northern reef, and 76% on the southern reef) (Tables 2, 3) which possibly reflects continued natural mortality (e.g. due to predation by fish). Samples of 100 shells were also obtained from crate module (cage) reef #1 and the 2 meter diameter patch reef #16 at 24 months post-deployment. Total spatfall per 100 shells from cage reef #1 had increased even further to (154 spat per 100 shells), with survival 81.8% and a slightly reduced mean size of 19.1 mm (range 9-50 mm) (Table 4), suggesting further recruitment had occurred.

Table 2. Details of rock oyster spatfall and other bivalves and invertebrates found in samples of 100 shells obtained from the 12 month old patch reefs #17 and #18.

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	59	Overall 20.2 (6-55) Alive 19.1 (6-55) Dead 23.3 (10-35)	75.4%
18	Patch reef, c. 7.5 meters dia.	125	Overall 18.5 (6-48) Alive 17.7 (6-43) Dead 20.9 (10-48)	76.0%

Table 3. Summary table showing changes in spatfall numbers, growth and survival over the first 12 months for two approx. 7 meter diameter experimental shellfish reefs deployed in December 2018 in Pumicestone Passage. * = Half of sample taken from under coir mesh cover.

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	59 (50-68)	75.4 %	20.2 (6-55)	125 (96-154)	76 %	18.5 (6-48)

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)
24 months	154	81.8%	19.1 (9-50)	31	19.4%	22.4 (9-55)

The damaged 2 meter diameter patch reef #16, on the other hand, has shown virtually no recruitment since being knocked nearly flat by anchor damage over 12 months ago (see Appendix 1 on page 26 of Diggles et al. 2018), and indeed a reduction in spat per 100 shells was noted, from 43 per 100 shells after 21 months, to 31 spat per 100 shells after 24 months, while survival of those spat continued to remain low (19.4%) (Table 4, Figure 3). As mentioned in previous reports, divers have noted that 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, which appears to have eliminated spat recruitment.

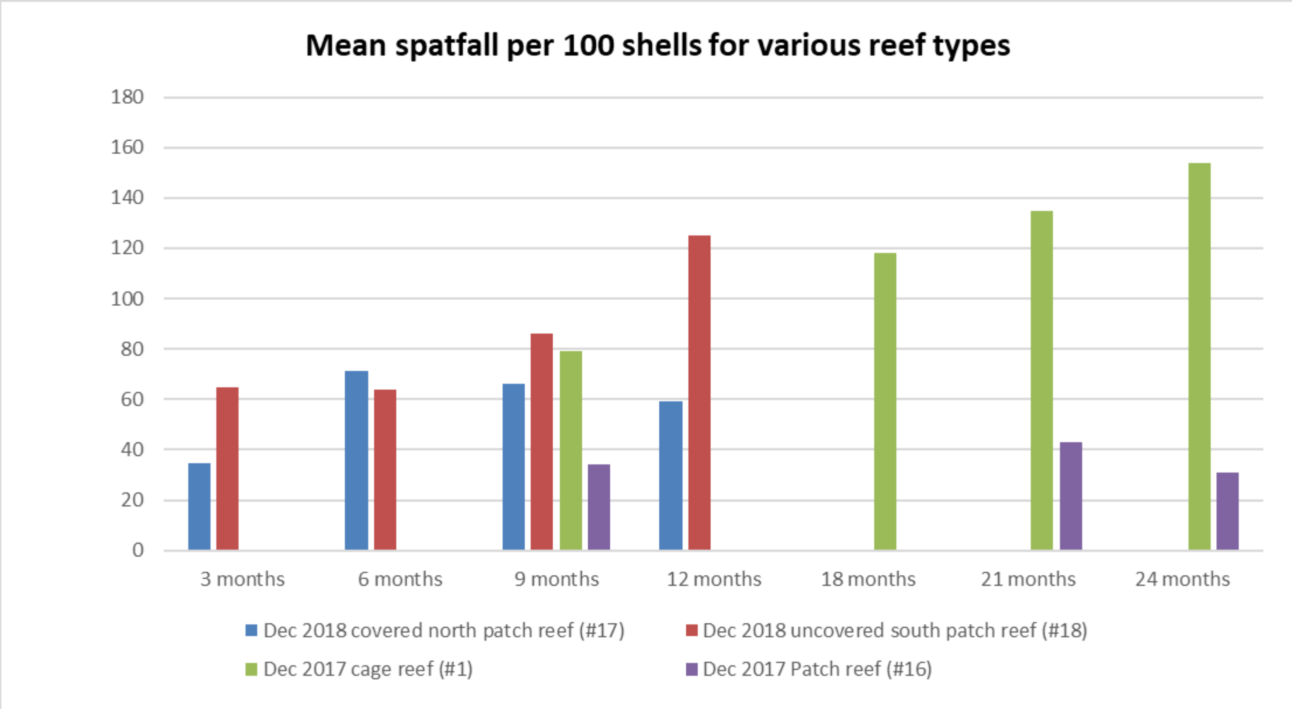

Figure 3. Graphical representation of changes in spatfall numbers over 12 months (patch reefs #19 and #20, December 2018 deployment) and 24 months (cage reef #1 and patch reef #16 deployed in December 2017) for trial reefs deployed in Pumicestone Passage. The data for reefs #1 and #18 suggest that recruitment is likely to be ongoing year-on-year when oyster shells are not covered by geofabric mesh and maintained at least 50 cm above the surrounding substrate.

Figure 4. Photo of a recreational vessel that was found anchored on reef #18 around the low tide on 22 December 2019. The crew stated their anchor dragged slightly until it took hold, and they were unaware of the restoration project due to lack of signage.

Figure 5. Examples of rock oyster spatfall (arrows) and other invertebrate recruitment (corraline algae, barnacles, tunicates) for oyster shells taken from reef #18 after 12 months deployment in Pumicestone Passage.

3.3 Reef condition – Gopro footage of reef units

A recreational vessel was found anchored on the southern patch reef #18 (Figure 4) and were asked to remove their anchor and move prior to us being able to mark the reef for diving. Sure enough, diver inspection again found evidence of more anchor damage on this reef, continuing the trend that was first noted 9 months ago (see Figure 4 in Diggles et al. 2019b). The larger besser fence modules nevertheless are still providing some protection to the edges of the reef, and underwater video of this reef, despite poor visibility, found it was frequented by at least 12 species of finfish including whiptail, happy moments, Gunther's wrasse, yellowfin bream, cardinalfish, yellowfin pike, Gunthers wrasse, fan bellied leatherjacket, snapper, crested morwong, stripeys and goatfish (Figures 6, 7, and a 15 minute video available at https://youtu.be/AJiym-mGQrA). There were notably large numbers of several fish species evident on this reef at the time the cameras were deployed, particularly whiptail, Gunther's wrasse, cardinalfish, yellowtail pike and yellowfin bream (Table 5).

Diver inspection of the northern patch reef (#17) found further degradation and sedimentation associated with the coir mesh cover. Underwater video of this reef found it was being frequented by fewer species and lower numbers of fish compared to reef #18. At least 8 species of fish were observed, including cardinalfish, Gunther's wrasse, whiptail, happy moments, blacksaddle goatfish, grass tuskfish, crested morwong and yellowfin bream (Figure 8, 13 minute video available at https://youtu.be/3s7dqWXSRyE) More details of the types of fishes observed to be associating with these reefs can be found in Table 5. A summary of all of the underwater videos documenting the condition of these reefs obtained by divers during invertebrate sampling trips to date is contained in Table 6.

Table 5. Species of fish observed associating with patch reefs #17 and #18 in 13-15 minute videos taken on 22 December 2019 from a camera oriented to face towards the reef. Poor visibility again 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)			
cardinalfish	Family Apogonidae	>50	swim by and grazing
Gunthers wrasse	*Pseudolabrus guentheri*	>50	swim by and grazing
happy moment	*Siganus fuscescens*	10-20	grazing on reef
whiptail	*Pentapodus paradiseus*	10-20	swim by
blacksaddle goatfish	*Parupeneus spilurus*	6-10	grazing on reef
crested morwong	*Cheilodactylus vestitus*	3-5	swim by
grass tuskfish	*Choerodon cephalotes*	1-2	swim by
yellowfin bream	*Acanthopagrus australis*	1-2	swim by
Reef #18 (South Reef)			
whiptail	*Pentapodus paradiseus*	>50	swim by and grazing
cardinalfish	Family Apogonidae	30-50	swim by and grazing
Gunthers wrasse	*Pseudolabrus guentheri*	30-50	swim by and grazing
yellowfin bream	*Acanthopagrus australis*	30-50	swim by and grazing
yellowtail pike	*Sphyraena obtusata*	20-30	swim by
stripey	*Microcanthus strigatus*	20-30	swim by
blacksaddle goatfish	*Parupeneus spilurus*	20-30	grazing on reef
grass tuskfish	*Choerodon cephalotes*	10-20	swim by
fan bellied leatherjacket	*Monacanthus chinensis*	10-20	swim by
happy moment	*Siganus fuscescens*	10-20	swim by
crested morwong	*Cheilodactylus vestitus*	1-2	grazing on reef
snapper	*Pagrus auratus*	1-2	swim by

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	12 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	https://youtu.be/3s7dqWXSRyE
December 2018 Deployment South Reef # 18 (dead shell only)	https://youtu.be/pBC97OtMCis	https://youtu.be/om8NH7_8lO4	https://youtu.be/UZoT9tMstkc	https://youtu.be/AJiym-mGQrA

Figure 6. Photo from a video of the southern reef (#18) on 22 December 2019 showing a school of yellowfin bream together with a whiptail (arrowed). The 15 minute video showed the reef was being frequented by at least 12 species of finfish (video available at https://youtu.be/AJiym-mGQrA).

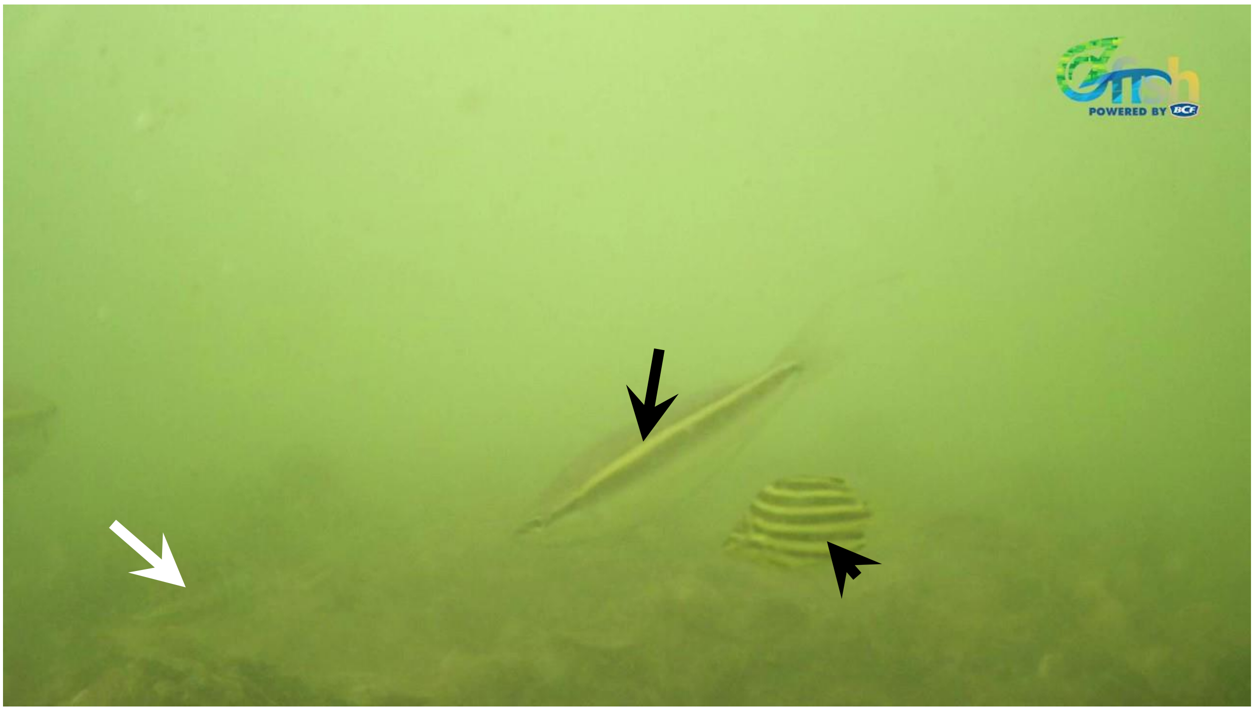

Figure 7. Photo from a video of the southern reef (#18), showing poor visibility due to resuspended sediment and filamentous algae in the water. A whiptail (black arrow), Gunthers wrasse (white arrow) and stripey (black arrowhead) are evident.

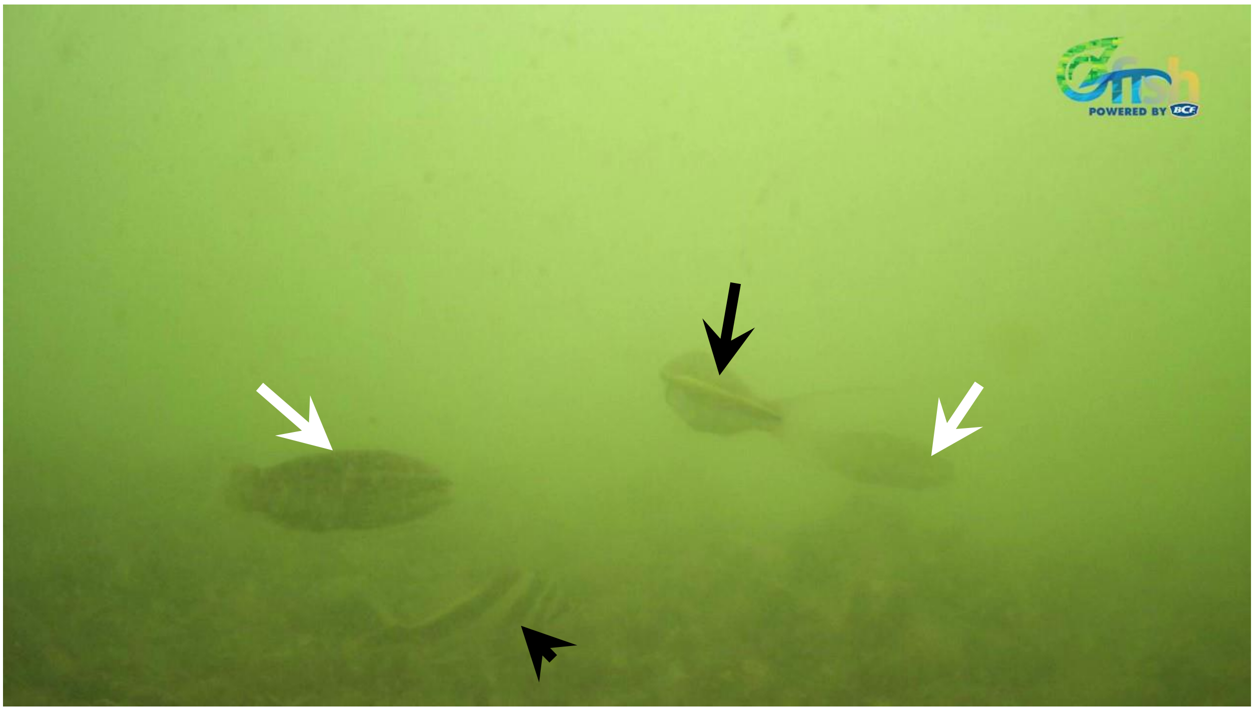

Figure 8. Photo taken from a video of the northern reef (#17), showing very poor visibility due to resuspended sediment and filamentous algae in the water. Gunthers wrasse (white arrows), crested morwong (arrowhead) and whiptail (black arrow) are evident in the foreground.

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) and honeycomb oyster (*Hyotissa* spp.) spatfall has continued to occur on the southern patch reef (#18), since the previous quarterly survey in September 2019. The slightly smaller mean size of the counted spat (see Table 3) indicates some new recruits have successfully settled, however overall survival of recruited spat was slightly lower (c. 76%) than 3 months earlier (c. 86 %), which may be a sign of natural mortality due to such factors as ongoing predation by fishes. Nevertheless, the data from patch reef #18 showed encouraging recruitment that approximated that which has been observed for crate reef #1 (which has demonstrated that recruitment and survival of spat can occur over multiple years, see (Diggles et al. 2018, 2019b, 2019c, 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). It will thus be interesting to observe the performance of patch reefs #19 (9-10 meters diameter) #20 (7 meters diameter) which were deployed on 6 and 7 December 2019. These two reefs were oriented longitudinally with the current, with reef #19 being around 30% larger than both reef #20 and the two reefs deployed in 2018 (#17 and #18 were both approximately 7 meters diameter). A-*priori* expectations would be that reef #19 will perform better than reef #20 due to its larger size, but due to its longitudinal orientation, whether reef #19 performs better than the transversely oriented (but smaller) reef #18 located nearby remains to be determined.

In contrast, the data from the 2 meter diameter patch reef #16 deployed in December 2017 found that recruitment and survival of spat on this smaller reef is on a decreasing trajectory (Table 4). Divers again observed that this reef has not recovered from being knocked nearly flat (<20 cm high) by anchor damage over 12 months ago, (see Figure 10 and Appendix 1, page 26 of Diggles et al. 2018), and the data collected here suggests that this reef will not be able to persist long term. The small initial size of patch reef #16 together with being knocked flat has made it prone to sedimentation, which the data shows has virtually eliminated spat recruitment. While sedimentation may still be problematic around the edges of some of our high relief (>50 cm high) 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. The data collected this quarter thus again confirmed previously published scientific literature which shows that retaining shell heights >50 cm above the surrounding substrate is a critical design metric required to achieve persistent long term shellfish reef restoration (Schulte et al. 2009, Baggett et al. 2014, 2015, Colden et al. 2016, 2017).

The fact that the number of spat per shell on crate reef #1 doubled during its second summer of deployment and continues to increase, provides evidence that restored shellfish reefs which can retain heights of 50 cm or more are likely to persist and survive for over 2 years in Pumicestone Passage. These data suggest that reef #18 is also on an upwards trajectory with its shells likely to collect more spat this summer, however the fate of reef #17 is uncertain, due to it suffering from sedimentation associated with the geofabric cover.

During this sampling period and in previous months the authors have witnessed first hand several boats attempting to anchor directly onto the experimental reefs (e.g. Figure 4). The revised design of the taller, more robust besser block fence modules deployed in December 2018 have reduced, but 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.

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, b, c). These epibionts have now survived at least 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 as shown by McLeod et al. (2019b) for other natural Sydney rock oyster reefs on soft sediments. 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 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.

These data are encouraging as 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, provided that oyster shells are maintained at least 50 cm above the surrounding substrate and not covered by geofabric mesh. It is therefore hoped that the many legislative barriers that currently prevent shellfish reef restoration in Moreton Bay are quickly overcome, so that restoration of these severely degraded, but highly productive ecosystems (McLeod et al. 2019a, 2019b) and their valuable ecosystem services (e.g. Newell and Koch 2004) can commence. As far as management of Moreton Bay is concerned, large scale shellfish reef restoration is likely to be a critical stepping stone towards reversal of the ongoing decline of the Moreton Bay marine ecosystem, as well as a chance to regain lost indigenous cultural heritage (Thurstan et al. 2020), whilst offsetting to some extent nutrient loading and the many other impacts of relentless anthropogenic development in the adjacent catchment.

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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, OzFish volunteers 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