The influence of finfish aquaculture on ~~demersal~~ benthic fish and crustacean assemblages in Fitzgerald Bay, South Australia

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Abstract

The influence of sea-cage aquaculture on wildfish assemblages has received little attention outside of Europe. Sea-cage aquaculture of finfish is a major focus in South Australia, and while the main species farmed is southern bluefin tuna (*Thunnus maccoyii*), there is also an important yellowtail kingfish (*Seriola lalandi*) industry. Yellowtail kingfish aquaculture did not appear to have any local or regional effects on ~~demersal~~ benthic fish and crustacean assemblages ~~(primarily fish, but also some crustaceans)~~ surveyed by downward pointing baited remote underwater video (BRUV) in Fitzgerald Bay. ~~We did, however, detect small scale spatial variations in assemblages within the bay. The type of bait used strongly influenced the assemblage recorded, with S~~Significantly greater numbers of fish were attracted to deployments where sardines were used as the bait to compared to those with no bait. The pelleted feed used by the aquaculture industry was just as attractive as sardine bait~~s~~ at one site, and intermediate between sardines and no bait at the other. There was significant temporal variability in assemblages at both farm sites and one control site over the 9 weeks of the study~~, suggesting that natural seasonal variations were more important than feed inputs associated with aquaculture in structuring the surveyed assemblages, although while the second control site was temporally stable (over the 9 weeks of the study)~~. Overall, the results suggested that aquaculture was having little if any impact on the abundance and assemblage structure of ~~the demersal macrofauna~~benthic fish and crustaceans in Fitzgerald Bay.

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Introduction

While global production figures are uncertain, it is clear that sea-cage aquaculture of finfish has expanded substantially in recent decades, due to increasing demand for seafood and largely steady production from wild capture fisheries (Halwart et al. 2007). As a consequence, there has been increased attention on its environmental effects. A range of biological and chemical aspects have been studied, including impacts associated with water column eutrophication, the benthic environment and assemblages, trophic structure and diseases~~/~~ or parasites (e.g. Bayle-Sempere et al. 2013; Fernandes & Tanner 2008; Kalantzi & Karakassis 2006; Krkosek et al. 2007; Sara 2007a; Sara 2007b; Tanner & Fernandes 2010). More recently, there has also been an increasing focus on the effects on wildfish assemblages in and around aquaculture lease areas (e.g. Dempster et al. 2002; Dempster et al. 2011; Fernandez-Jover et al. 2011; Ozgul & Angel 2013; Uglem et al. 2014), although the major focus of this work has been in Europe, and especially the Mediterranean. Whether the conclusions derived from these studies are applicable across a broader geographic range is unclear. In Australia, a small amount of work has been done around a snapper farm, which showed an increased abundance and biomass of wildfish compared to controls (Dempster et al. 2004), but the issue has received little detailed investigation.

The largely attractive effect of sea-cages that has been documented is assumed to be due to a combination of factors; habitat provision (Papoutsoglou et al. 1996), increased food availability (Pearson & Black 2001; Uglem et al. 2014), and possibly chemical attraction to farmed stock (Dempster et al. 2002). Two years after abandonment, wildfish abundance around cages at a fish farm in the Canary Islands had decreased 25-fold, although was still double that at controls, indicating that at least at this site, food availability is the primary driver of changes, with habitat provision only playing a small role (Tuya et al. 2006). The aggregation of wild fish has further environmental and ecological consequences that are poorly understood and vary between locations. Flow-on effects can include waste mitigation (Dempster et al. 2009; Felsing et al. 2005; Papoutsoglou et al. 1996), disease~~/~~ or parasite transfer (Krkosek et al. 2007), changes in local assemblage composition (Machias et al. 2005; Ozgul & Angel 2013), and altered body condition and reproductive output (Dempster et al. 2011; Fernandez-Jover et al. 2011). If fishing is prohibited, aquaculture sites could function as marine protected areas (Dempster et al. 2002), and enhance local stocks by both increasing reproductive output (Edgar et al. 2014; Pelc et al. 2010) and providing emigrants to the surrounding environment (Roberts et al. 2001; Russ & Alcala 2011). Alternatively, aquaculture leases may act as ecological traps (Gates & Gysel 1978; Gilroy & Sutherland 2007) if access to large quantities of aquaculture feed and faeces leads to decreases in condition and reproductive output, although this appears not to be the case in Norway (Dempster et al. 2011). Where legislative protection from fishing is not afforded, aggregations around sea-cages may be easy targets for fishermen, which may exacerbate the over-exploitation of stocks (Dempster et al. 2004).

Here, we assess whether finfish aquaculture has affected the ~~demersal macrofaunal~~benthic fish and crustacean assemblages in Fitzgerald Bay, South Australia. The ~~demersal~~ benthic assemblages were sampled by baited remote underwater video (BRUV) and compared on a local scale (between sites - aquaculture vs no aquaculture) within Fitzgerald Bay, regional scale (with other nearby locations that do not contain finfish aquaculture) and over time to detect any differences attributable to aquaculture. We also test the influence of bait, and bait type, on the assemblages detected using BRUVs. While BRUV surveys typically target fish, they also allow other mobile ~~macro~~fauna, such as decapod crustaceans, to be enumerated, and so we include both of these components of the benthic~~demersal~~ fauna.

Commented [MJC2]: Where exactly and by what sampling method?

Commented [MJC3]: Were cages and nets still in place but no farm fish?

Commented [MJC4]: How conclude this as farm fish also absent and was their data on amount of excess food? And evidence wild fish were feeding on it?

Commented [MJC5]: Awkward, do you mean wild fish may eat food falling through nets and thus reduce benthic impacts of lost feed?

Commented [MJC6]: I think omit as this is not relevant. Almost all MPA allow fishing too.

Commented [MJC7]: This is misleading. Few finfish farms contain fish of same parentage as wild fish. All salmonids have been selectively bred for decades, and most others have some form of selective breeding and/or based on small broodstock in a hatchery.

Commented [MJC8]: Really? Of what, wildfish? Benthos? Farm fish?

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During recent decades there has been a gradual shift towards the use of remote techniques to sample environments that are not accessible with traditional diver-conducted surveys, and now these methods are also being used in areas that were formerly sampled exclusively by divers (e.g. Lowry et al. 2012; Willis et al. 2000). The advantages of remote techniques stem from the fact that they are not subject to the limitations imposed upon divers by factors such as depth, temperature, time and safety requirements. The latter is of particular concern in this study, due to the frequent presence of great white sharks (*Carcharodon carcharias)* in the region. Many non-destructive remote techniques are ideally suited to sea-cage aquaculture and provide several inherent advantages over traditional diver surveys, as well as the universal benefits of remote techniques mentioned above. Non-destructive remote methods avoid the behavioural modifications induced in fish by the presence of divers (e.g. Cole et al. 2007; Watson et al. 2005), do not harm the species or the habitat sampled, and can provide information on the habitat and species behaviour (Harvey et al. 2013; Watson et al. 2005). Irrespective of technique, however, all surveys have their own biases that vary with habitat, environmental conditions and species being targeted. BRUV has become the standard non-destructive remote technique used for surveying demersal fish assemblages (McLean et al. 2011; Stobart et al. 2007; Unsworth et al. 2014), and is now also being used for pelagic assemblages (Santana-Garcon et al. 2014). ~~Some form of SCUBA based visual census has been more typically employed to investigate fish assemblages around aquaculture cages, however.~~

Methods

Study area

Fitzgerald Bay is located in northern Spencer Gulf, South Australia (Fig. 1). Sea-cage aquaculture ~~has been~~was undertaken within the bay continuously ~~since~~ from 1999 to 2010, initially producing snapper (~~*Pagrus*~~ *Chrysophrys* *auratus*) but since the early 2000's exclusively producing yellowtail kingfish (*Seriola lalandi*). At the time of this study in 2004, there were five 20 hectare lease sites (farms) in Fitzgerald Bay, four of which contained stock (all kingfish), with a combined annual production of approximately 620 tonnes. Production increased to ~2000 tonnes per annum shortly after this study, but then declined steeply due to husbandry issues, and- after 2010, it was relocated further south in Spencer Gulf. The farms containing fish were distributed along a channel that runs through Fitzgerald Bay, to the west of an offshore sandbank. The channel ranges in depth from 10-23 m and experiences substantial tidal flows (up to 39 cm sec^{-1}, (Parsons Brinckerhoff & SARDI 2003)). Current direction is approximately north-south along the channel, alternating every six hours in a semi-diurnal pattern. The two farms chosen for the study were located at either end of the channel, to allow for the selection of suitable control sites (Fig. 1). ~~The benthic habitat is variable throughout the bay apart from a continuous narrow coastal fringe of seagrass in shallower depths (less than 6 to 8 m: Hone et al. 1996; Shepherd 1974).~~ Control sites were selected to be as similar as possible to each lease in terms of geographic location and water depth, and were at least one kilometre from any farm to ~~avoid~~ minimise as much as possible impacts associated with aquaculture development. The ~~benthic habitat is variable throughout the bay apart from~~southern lease and control sites were dominated by coarse substrate with numerous macroalgae and sponges, while the northern sites had finer and mostly bare sediment, and there is -a continuous narrow coastal fringe of seagrass in shallower depths (less than 6 to 8 m: Hone et al. 1996; Shepherd 1974). Further details on the site and production cycle can be found in Tanner & Fernandes (2010).

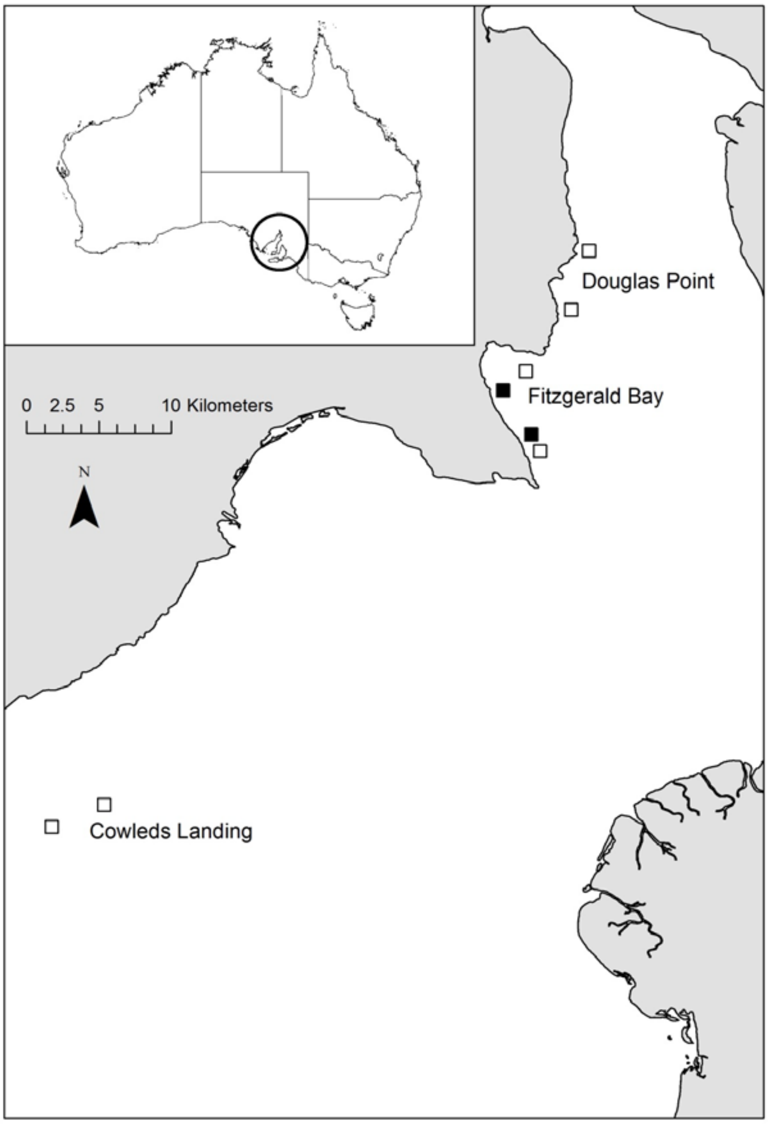

Figure 1: Map showing the location of study sites within Spencer Gulf (black boxes = lease sites, open boxes = control sites). Inset shows location of Spencer Gulf.

BRUV deployment

Benthic BRUV was chosen as the survey technique. All sampling was undertaken during daylight hours (0800 – 1700) using two BRUVs. Farm site deployments were made within 5 m of a sea-cage, and at least an hour after the single daily feeding had ceased at that cage . ~~(~~F~~f~~eeding usually commenced early in the morning, but it could take several hours to complete feeding all the cages on a lease~~)~~. Control sites were divided into 5 by 5 grids (i.e. 25 cells), cells were randomly chosen and BRUVs were deployed at their midpoint. Successive BRUV deployments were usually made 2-10 minutes apart, separated by a minimum distance of 200 m, but as much as several kilometres depending upon the weather conditions. Once set, the boat was moved >200 m away from the BRUVs and the motors turned off until retrieval.

Two Amphibico Dive Buddy housings were used with the BRUVs; one containing a Sony Digital Handycam DCR-TRV20E, the other a Sony Network Handycam DCR-TRV950E. Cameras were mounted vertically with a distance of 1 m between the lens and the seafloor. Deployment lengths of 30 minutes were chosen based on the early arrival times and low species numbers detected in the pilot study. The ~~(~~maximum number of species (1-4) usually occurred before 20 minutes recording time had elapsed~~)~~. A single small (~400 g) pack of frozen brined sardines (*Sardinops sagax*) was used as bait for each deployment. Prior to placement in a bait basket, sardines were thawed and crushed to maximise the bait plume.

BRUVs are considered as passive sampling tools, and do not require any ethics or other approvals in the jurisdiction in which this study was undertaken.

Video analysis

Video footage was viewed with a real-time counter, and analysis commenced from the moment that the BRUV settled on the seafloor. Relative abundance estimates of all mobile ~~macro~~fauna were made by recording the maximum number of individuals of a single taxon visible within one frame of footage (MaxN, Ellis & Demartini 1995). MaxN is a conservative measure of relative abundance because it usually underestimates the true numbers of each species visiting the bait (Cappo et al. 2004). Using MaxN avoids the problem of recounting the same individual on separate visits to the bait, and has been found to give an accurate estimate of "true" density (Willis et al. 2000). Due to difficulties with identifying small cryptobenthic fish species from the dorsal view recorded by the BRUVs, these species were grouped into a "benthic" category. The presence of two distinct cohorts of snapper (~~*Pagrus*~~ *Chrysophrys auratus*) in the surveys allowed separation of the classes for statistical analysis (juvenile <38 cm, adult >38 cm). Some blue swimmer crabs (*Portunus armatus)* were easily distinguished from others (e.g. male~~/~~ or female, missing claw, markings) and thus each new arrival in the FOV was included in the MaxN count regardless of whether they were all present in one frame of footage.

Statistical analyses

Non-parametric permutational multivariate analysis of variance (PERMANOVA, Anderson 2001) was used to test for differences in assemblage composition between treatments. The Bray-Curtis similarity was used for all analyses, with 9999 permutations of residuals under a reduced model. All data were 4th root transformed to down weight the influence of highly abundant species. Pair-wise *a posteriori* comparisons were made for factors that were found to have a significant effect when required. To visualise the similarities between samples, non-metric multi-dimensional scaling (nMDS) ordination plots were used. A similar approach was taken to analyse Total MaxN (i.e. the sum of MaxN across taxa), except that

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Commented [MJC11]: Why? Was this abundance not true? What were results if the data were not down weigthed?

resemblances were calculated using Euclidean distances and no transformation was applied. All analyses were conducted in Primer v6 with the PERMANOVA+ add-on (Clarke & Gorley 2006) ~~(PrimerE Ltd, Plymouth, UK)~~.

Local effects

To detect the local-scale effects of finfish aquaculture, BRUVs were used to survey the benthic mobile ~~macro~~fauna present on farm and control sites in Fitzgerald Bay. A three-way orthogonal sampling design was used, with Proximity to Aquaculture (farm~~/~~ vs control), Location (north~~/~~ vs south) and Tidal Phase (high~~/~~ vs low) as fixed factors, and three replicates. Sampling was undertaken in late June 2004.

Regional effects

To determine if broader-scale regional impacts of aquaculture were present, the two Fitzgerald Bay control sites were sampled once again, as were two 20 hectare sites both 28 kilometres to the north (Douglas Point) and 22 kilometres to the south (Cowleds Landing) of Fitzgerald Bay (Fig. 1). Neither of these additional locations has been used for aquaculture. Sites within each Location were positioned to match those in Fitzgerald Bay in terms of water depth, separation and site dimensions (Fig. 1). A total of 36 deployments (6 sites x 6 replicates) were conducted over three days in July 2004. Location was treated as a fixed factor, with Site nested in Location.

Bait effects

To evaluate bait efficacy and the effect that different baits ~~types~~ had on the sample composition of BRUV surveys in Fitzgerald Bay, two~~hree~~ bait treatments were assessed: crushed sardines (as per previous surveys), extruded snapper-feed? ~~aquaculture~~ pellets and a control without ~~no~~ bait. Pellets used for daily feeding by the aquaculture industry in Fitzgerald Bay (9 mm diameter, 9 mm long, 5.8% water content) were sourced directly from the aquaculture operators. The no bait treatment consisted of an empty bait basket. Sampling was undertaken throughout the day on three consecutive days in August~~/~~-September 2004. Each bait treatment was applied to each of the two farm and two control sites from the first survey (3 baits x 4 sites x 5 replicates = 60 deployments) following the protocols described under *BRUV deployment*, and in a random order. Strong tides during sampling resulted in the loss of six deployments from the southern sites. Bait Type (sardine~~/~~ vs pellet~~/~~ vs no bait), Proximity to Aquaculture (farm~~/~~ vs control), and Location (north vs ~~/~~south) were treated as fixed factors in a 3-way experimental design.

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Temporal effects

To determine whether the effects of finfish aquaculture varied over time, and to examine the temporal stability of the assemblages within Fitzgerald Bay, a temporal comparison of BRUV samples from all three surveys was undertaken. This analysis involved all data from Fitzgerald Bay where sardines were used as the bait, and thus included three factors: Proximity to Aquaculture (farm vs ~~/~~control); Time (3 ~~levels~~surveys) and Location (north vs ~~/~~south). As no data were collected from adjacent to cages for the regional comparison, there is an empty cell in this design, so the analysis was repeated without data from this comparison (i.e. with data from only 2 ~~levels for Time~~surveys). As the results were qualitatively similar, only the results for the analysis with 3 levels of Time are presented.

Results

The 114 BRUV deployments resulted in a total MaxN of 706 across 17 taxa. Over half of these individuals were carangids~~trevally~~ (*Pseudocaranx wrighti* – 381), with 121 in the 'benthic' category, 68 snapper, 63 blue swimmer crabs and 28 western king prawns (*Penaeus latisulcatus*). Full details of taxa recorded in each deployment are provided in the supplementary information.

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Local effects

No local-scale effects of aquaculture were detected The animals seen in BRUV samples were not correlated to the presence of snapper cages ~~on macrobenthic fish and crustacean assemblages~~ in Fitzgerald Bay (PERMANOVA: $F_{1,15}$=0.55, P=0.63). There was a clear difference between north and south in the bay, however (PERMANOVA: $F_{1,15}$=13.95, P<0.001), with the northern area having high numbers of the western king prawn and ~~trevally~~carangids, while the southern area was dominated by blue swimmer crabs (Fig. 2). Tidal Phase had no influence on the assemblage (PERMANOVA: $F_{1,15}$=1.22, P=0.36), and there were no interactions between any factors (all P>0.18). No factor (or interaction) had a significant effect on TotalMaxN (all P>0.16), with the mean value being 7.9 ± 1.2 (se).

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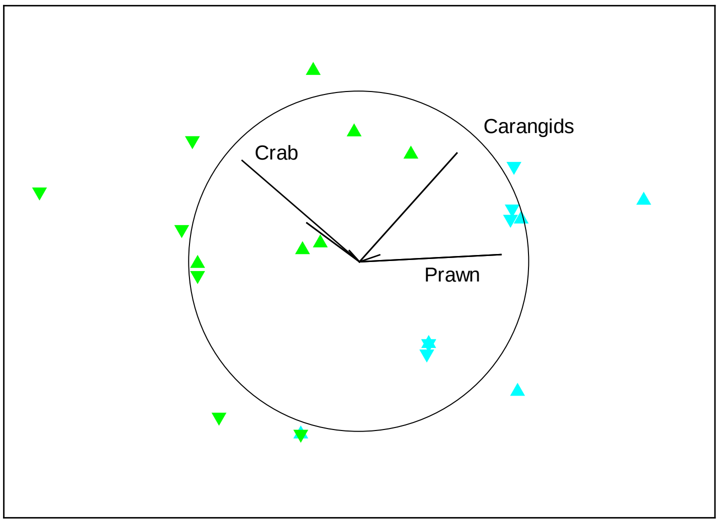

Figure 2: Non-metric multidimensional scaling plot showing the influence of Proximity to Aquaculture (▲=lease, ▼=control) and Location (blue=north, green=south) on ~~mobile macro~~benthic fish and crustacean assemblages in Fitzgerald Bay (stress = 0.14). Biplot shows correlations with key taxa (r>0.4 labelled), with the circle scaled to r=1.

Regional effects

No differences i~~n assemblage structure~~ were detected in BRUV observations between the three locations (PERMANOVA: $F_{2,3}$=0.50, P=0.93), although there were significant differences between Sites within Locations (PERMANOVA: $F_{3,30}$=6.35, P<0.001). Similar results were obtained for TotalMaxN ($F_{2,3}$=0.37, P=0.94 and $F_{3,30}$=8.6, P<0.001 for Location and Site respectively, mean ± se = 3.7 ± 0.5).

Bait effects

In the bait effects study, assemblage structure was influenced by interactions between Proximity to Aquaculture and both Bait Type and Location in bay (Table 1). Pairwise tests indicated that the south control site had a different assemblage to the other 3 sites (P<0.007). This site had high numbers of juvenile snapper and blue swimmer crabs in comparison to the other sites (Fig. 3). At the farm sites, deployments with bait differed from those without (P=0.002), but there was no difference between using sardines or aquaculture pellets (P=0.58). At the control sites, sardines differed from no bait (P=0.018), but pellets did not differ to either sardines (P=0.57) or no bait (P=0.2). Deployments with no bait attracted very few (or no) fauna (8 individuals in 16 deployments, 5 in the 'benthic' category, compared to 376 across 38 baited deployments).

TotalMaxN was significantly affected by the interaction between Proximity, Location and Bait type ($F_{2,42}$=7.03, P=0.003, Fig. 4). Pairwise tests showed deployments with pellets at the south farm site attracted ten times the abundance of ~~macrofauna~~ benthic fish and crustaceans as at the associated control site (P=0.008), and five times the abundance as on the northern farm site (P=0.009). At the north farm site, sardines attracted five times as many animals~~fauna~~ as pellets, and 150 times as many as unbaited deployments, while at the south farm site, pellets attracted three times as many as sardines, while unbaited deployments attracted no ~~macro~~fauna.

Table 1: PERMANOVA table showing effects of Proximity to Aquaculture cages, Location within Fitzgerald Bay and Bait Type on ~~mobile macro~~benthic fish and crustacean assemblages detected using BRUVs.

Source	df	SS	Pseudo-F	P(perm)
Proximity	1	4093.8	5.44	**0.0035**
Location	1	4878.6	6.48	**0.0005**
Bait	2	11220	7.45	**0.0001**
ProximityxLocation	1	2898.8	3.85	**0.0184**
ProximityxBait	2	3596.1	2.39	**0.0473**
LocationxBait	2	3351.2	2.23	0.0637
ProximityxLocationxBait	2	3173.2	2.11	0.0779
Residual	42	31615		

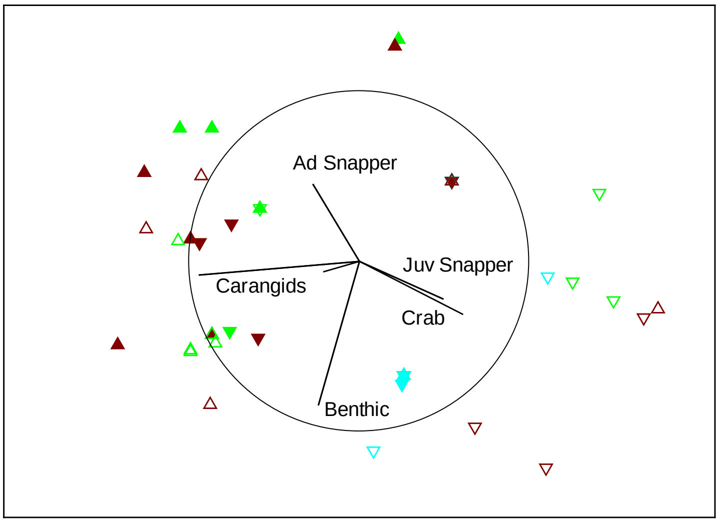

Figure 3: Non-metric multidimensional scaling plot showing differences in animals observed by BRUV ~~mobile macrobenthic fish and crustacean assemblages~~ with Proximity to Aquaculture (▲=lease, ▼=control), Location (filled=north, hollow=south) and Bait Type (green=pellets, brown=sardines, blue=none) in Fitzgerald Bay (stress=0.14). Biplot shows correlations with key taxa (r>0.4 labelled), with the circle scaled to r=1.

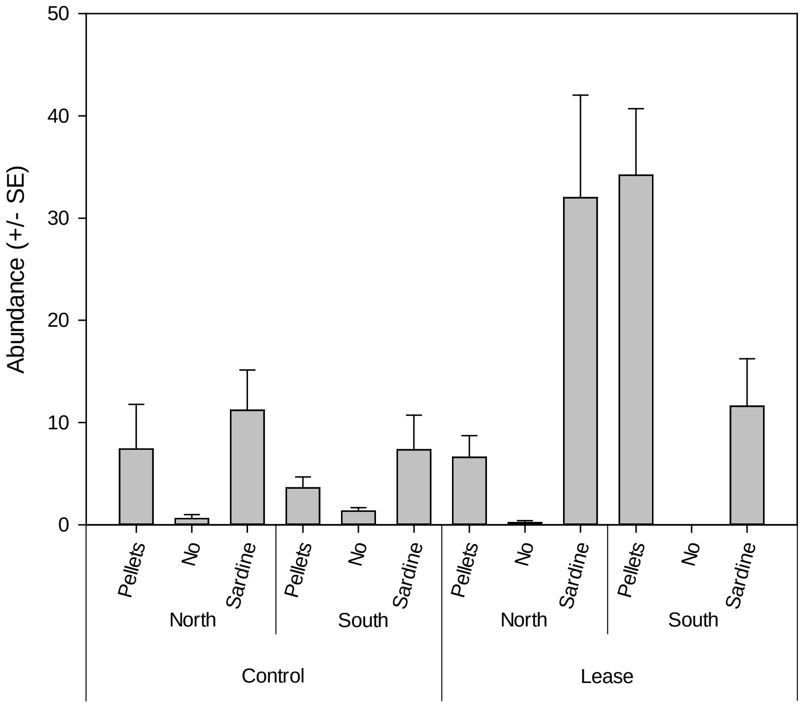

Figure 4: Influence of Proximity to Aquaculture (control vs lease), Location (north vs south) and Bait Type (pellets vs no bait, vs sardines) on total abundance of ~~wild macrofauna~~benthic fish and crustaceans detected in BRUV deployments.

Temporal effects

The temporal comparison again showed complicated interaction patterns for assemblage structure (Table 2). Pairwise tests showed temporally variable assemblages at both farm sites (south: P=0.023; north: P=0.011), and for the north control site (P≤0.011 for all pairs of Time). Western king prawns were only present in the first survey, while the final survey documented high numbers of ~~trevally~~carangids and low numbers in the 'benthic' category. In contrast, the south control site was temporally stable (P≥0.18), with consistently high numbers of blue swimmer crabs, Port Jackson sharks (*Heterodontus portusjacksoni*) and the 'benthic' category (Fig. 5).

For TotalMaxN, the interaction between Time, Proximity and Location was significant ($F_{1,44}$=4.5, P=0.031, Fig. 6). Importantly, pairwise tests showed that farm sites did not differ from control sites at each time and location. At the north farm site, there were three times as many fauna at the final census as at the first, while at the control site, the first and final census had four and six times as many fauna respectively as the intermediate census. During the intermediate survey, south control sites had more the three times the abundance as north control sites.

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Table 2: PERMANOVA table showing effects of Time, Proximity to Aquaculture cages, and Location within Fitzgerald Bay on mobile macrobenthic fish and crustacean assemblages BRUV observationsdetected using BRUVs.

Source	df	SS	Pseudo-F	P(perm)
Time	2	11597	9.55	**0.0001**
Proximity	1	1006.7	1.66	0.2284
Location	1	9867.1	16.25	**0.0001**
TimexProximity	1	832.38	1.37	0.298
TimexLocation	2	2541	2.09	0.1045
ProximityxLocation	1	3157.5	5.20	**0.0098**
TimexProximityxLocation	1	3147	5.18	**0.0069**
Residual	44	26725		

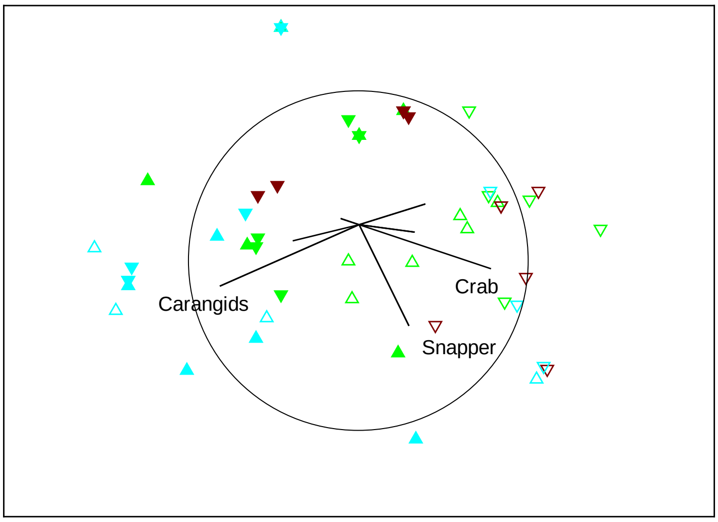

Figure 5: Non-metric multidimensional scaling plot showing differences in BRUV observations -mobile macrobenthic fish and crustacean assemblages with Time (green=Time 1, brown=Time 2, blue=Time 3), Proximity to Aquaculture (▲=lease, ▼=control) and Location (filled=north, hollow=south) in Fitzgerald Bay (stress=0.2). Biplot shows correlations with key taxa (r>0.4 labelled), with the circle scaled to r=1.

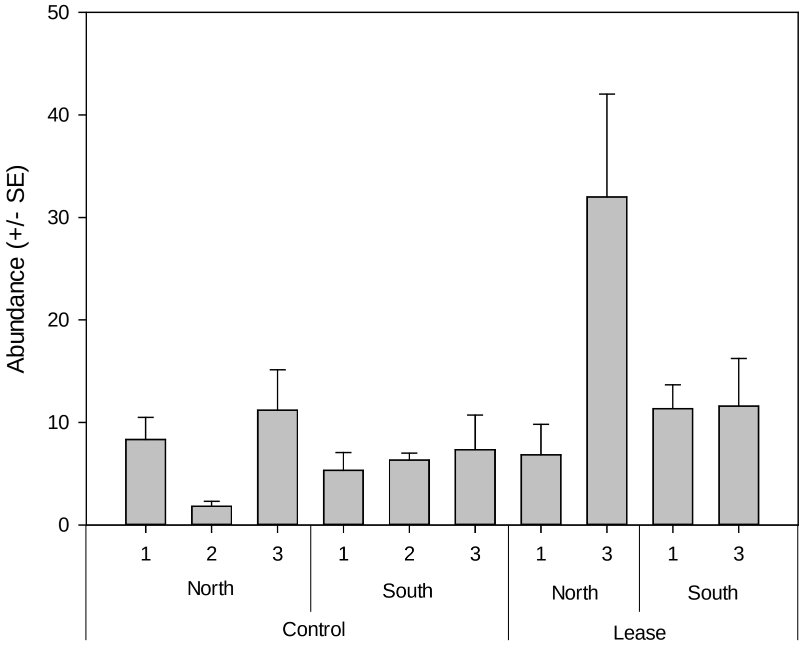

Figure 6: Influence of Proximity to Aquaculture (control vs lease), Location (north vs south) and Time (survey 1, 2 or 3) on total abundance of ~~wild macrofauna~~~~benthic fish and~~ animals ~~crustaceans~~ detected by~~in~~ BRUV~~ deployments~~.

Discussion

Effects of aquaculture

The presence of finfish aquaculture was found to have no effect on the composition of the ~~demersal macrofaunal~~benthic fish and crustaceans observed by BRUV~~ assemblages~~ in Fitzgerald Bay on a local or regional scale, although we did detect small-scale variation in assemblages unrelated to aquaculture. This finding contrasts to most studies that have examined wildfish assemblages around aquaculture cages, which have shown altered community composition, and increased abundance and biomass, as a result of aquaculture (e.g. Dempster et al. 2005; Dempster et al. 2004; Dempster et al. 2002; Dempster et al. 2009; Giannoulaki et al. 2005; Ozgul & Angel 2013; Valle et al. 2007). Machias et al. (2004, 2005) also showed regional scale increases in wildfish abundance as a result of aquaculture due primarily to an increase in predators on benthic invertebrates and small fish (ie not species likely to feed directly on aquaculture waste). This general increase in fish abundance around farms appears to be method independent, with the studies mentioned above using techniques as varied as diver surveys, trawls, remote video and acoustic surveys, although none have used baited video as we did. While these studies primarily focused on pelagic assemblages directly associated with the cages, or included both pelagic and demersal assemblages, Bacher et al. (2012) used scuba to count fish under cages ~~explicitly examined benthic~~

~~assemblages~~ at a farm in Spain and ~~also found them to differ with proximity to cages. The latter also found benthic assemblages to have~~ there were significantly ~~three times~~ more fish associated with cages at the surface, mid-water and near the seabed. ~~the abundance of mid-water and surface assemblages~~.

The lack of response to aquaculture detected here may be due to the relatively small-scale nature of the industry in Fitzgerald Bay, which was still expanding at the time of this study, and/or the wide dispersal of wastes, both of which would limit the availability of aquaculture derived food. With an annual production in Fitzgerald Bay of 620 tonnes across four farms at the time of the study, and a food conversion ratio of ~3:1 (Fernandes & Tanner 2008), feed input was ~ 1860 tonnes $year^{-1}$. This was sufficient to produce detectable effects on sediment organic carbon and porewater nutrient levels, but did not produce a clear effect on either infauna or epifauna (Tanner & Fernandes 2010). Production in Fitzgerald Bay is at the low end of the range for the studies above that have reported impacts of aquaculture on wildfish assemblages (125-3000 tonnes for those that provided details), although none of these studies report total production for a region, instead only reporting production for individual farms. Now that yellowtail kingfish production is expanding again in South Australia, there is the potential for farming to resume at Fitzgerald Bay. The data presented here, and by ~~(~~Tanner & Fernandes (2010), suggest that at similarly low levels, ~~this would be environmentally sustainable, but that~~ there would be minimal ecological impact. However, the risk of impacts would increase~~s~~ if production were to expand to typical commercially viable levels seen elsewhere in the world (i.e. several thousand tonnes per annum).

Given the substantial tidal flows through Fitzgerald Bay (up to 39.1 cm sec^{-1}, Parsons Brinckerhoff and SARDI 2003) and the seafloor clearance (5 to 15 m) of the sea-cage nets, there is ~~also~~ ample opportunity for waste dispersal to occur over a substantial area, especially for light-weight wastes (faeces). Conversely, pelleted feed sinks rapidly and is not carried far from the farm, although the accumulation of pellets underneath farms has not been seen (Tanner pers. obs.), and feed wastage appears to be limited (Fernandes & Tanner 2008). The combination of these factors may prevent sufficient waste deposition beneath the sea-cages in Fitzgerald Bay to attract resident demersal scavengers. Furthermore, during the bait effects study, pellets held in bait baskets were observed to disintegrate within the 30 minute duration of a BRUV deployment. Any pellets, therefore, that did reach the seafloor would most likely disintegrate rapidly and either be consumed by the resident demersal fauna or dispersed by the tide within a very short time. Such limited food availability would provide little direct incentive for scavengers to accumulate in the area.

If the scavengers most involved in waste mitigation in Fitzgerald Bay did not remain associated with the sea-cages for long periods, they may not have been sampled by the techniques used in this survey, as feeding times were avoided during sampling. Wild species have been observed to modify their behaviour in response to aquaculture practic~~s~~es. Sea birds follow feed boats from cage to cage and wild fish follow inter-tidal oyster farmers during infrastructure defouling (Williams pers. obs.). It is possible, therefore, that the scavengers in Fitzgerald Bay may also have modified their behaviour. Regardless of the cue (e.g. boat engines, the noise of pellets hitting the surface of the water, the feeding activity of farmed fish), the scavengers may have moved from cage to cage during feeding and thus were not observed in the BRUV deployments. Such movements are a distinct possibility for highly mobile species such as ~~trevally~~carangids, which were the most abundant species in this study. It is also possible that fish attracted by the presence of aquaculture remain tightly associated with the cages, and were not attracted to nearby BRUVs. Several attempts were

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Bait effects

While there were complex interactions in the bait effects study, deployments without bait clearly documented a different assemblage to those with bait. The low numbers of fauna documented in the former suggests that unbaited videos had no attractant effect, but rather simply recorded those animals that happened to pass through. That the use of bait increases the abundance and diversity of the fish assemblage recorded is well documented (e.g. Bernard & Goetz 2012; Hardinge et al. 2013), although a detailed analysis of feeding guilds across a range of habitats showed that this attractant effect only held for predatory and scavenging species, and not for herbivores or omnivores (Harvey et al. 2007).

Sardines and pellets appeared equally effective as bait, at least in terms of assemblage composition. While sardines are the standard bait used for BRUV deployments in Australia, previous work has also shown that other bait types can be equally as effective when it comes to documenting assemblage composition (Dorman et al. 2012; Wraith et al. 2013). However, both of these studies did find differences between bait types on univariate measures such as total abundance.

Temporal stability

Dempster et al. (2002, 2004), found that wild fish aggregations associated with sea-cages in the Mediterranean were relatively temporally stable over periods ranging from several weeks to months. Bacher et al. (2012)~~-~~ found a similar result for seabed fish~~benthic assemblages~~, but not mid-water and surface, which varied with season. The BRUV observed ~~macrofaunal benthic~~ fish and crustaceans ~~assemblages~~ in Fitzgerald Bay also varied over the course of the present study (nine weeks) at both lease sites and one of the control sites. This difference could be due to the fact that this study was essentially sampling natural communities, whereas the aggregations examined by Dempster et al. (2002, 2004) were not present prior to the establishment of aquaculture. The differences detected in the present study~~, therefore,~~ were possibly due to ~~natural~~ seasonality; ~~:~~ with species responding to the transition from early (June) to late (August~~/~~–September) winter.

While some species were detected throughout the present study (~~*Portunus* armatus~~blue swimmer crabs, ~~*Pseudocaranx* wrighti~~carangids, juvenile ~~*Pagrus* auratus~~snapper, "Benthic" category), there were several interesting temporal trends for other species. Mature ~~*Pagrus auratus*~~snapper, ~~*Penaeus* latisulcatus~~western king prawns, ~~*H.* portusjacksoni~~Port Jackson sharks and bridled leatherjackets (*Acanthaluteres~~.~~ spilomelanurus*) were recorded exclusively during one sampling period. Very low numbers counts and sporadic sightings of the latter two species prevent temporal inferences from being made from the existing data. ~~*Penaeus* latisulcatus~~Western king prawns, however, ~~was~~ were common during the first survey (June) and absent from the third survey (August~~/~~–September). Activity in this species is directly related to water temperature, with minimum activity occurring during the cooler winter months (King 1977). During August~~/~~–September, water temperatures in Fitzgerald Bay can drop down to ~13ºC (Parsons Brinckerhoff & SARDI 2003). The lower limit of activity for penaeid prawns is 10-12ºC; therefore, most were likely to have been buried in the sediment during the third survey (King 1977). The species is also migratory with individuals moving in a southerly and easterly direction as they mature (Carrick 1982) and thus likely to leave

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Fitzgerald Bay during the year. Adult *Pagrus auratus*snapper were recorded only during the second survey, which corresponds with the lead-up to their annual reproductive season in upper Spencer Gulf from October to March (Fowler & Jennings 2003).

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Conclusions

BRUV observations could not detect any effects of fFinfish aquaculture in Fitzgerald Bay. Similarly, does not appear to have affected the resident demersal assemblage of benthic fish and crustaceans, suggesting that the benthic environment within the bay is not being substantially affected by waste from the sea-cages. This conclusion is supported by a concurrent study of other components of the ecosystem in Fitzgerald Bay, which showed detectable impacts on sediment chemistry, did but not find effects on infaunal and epifaunal assemblages (Tanner & Fernandes 2010). This finding contrasts with most previous work of a similar nature, which may be explained by the relatively low stocking total aquaculture production levels in Fitzgerald Bay, and high rates of water movement.

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