Mudflat Condition Monitoring in Upper Gulf St Vincent

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Cover photograph: Mudflats with seagrass and the bivalve *Pinna bicolor* beds at incoming tide; Orlando Lam Gordillo

1. Executive Summary

This is the third mudflat monitoring survey conducted by Flinders University as part of investigations into mudflat condition for the Adelaide and Mt Lofty Ranges Natural Resources Management Board along intertidal shorelines of Upper Gulf St Vincent since 2008. The current monitoring report provides information of the macroinvertebrate communities across sites at Section Bank, Port Gawler, Middle Beach and Port Prime from surveys conducted in 2018. Surveys were conducted across the low to high tide zone at all sites using the four different sampling methods of timed searches, quadrats, sediment cores and emergence traps. Unfortunately, the emergence traps have not proved to be useable due to the high current speeds and very soft sediments in Upper Gulf St. Vincent. Further research and development on the design of emergence traps is still underway at Flinders University, with a refined and useable design available in 2019/20 as part of a current PhD project that is investigating benthic functioning in the region.

Results from the 2018 mudflat surveys identified that timed searches and sediment cores captured the most taxa. Quadrat sampling identified the most common epifauna species (e.g. mainly gastropod snails) but less rarer species, simply due to the small spatial area of each replicate. Timed searches were comparable to quadrat counts for macroinvertebrate assemblages, particularly for reliable indicator species for determining dissimilarities between sites. However, timed searches did cover a larger spatial area, thus has the ability to detect more of the rarer species. Core sampling is unique in the macroinvertebrate assemblages that are sampled (e.g. sediment infauna) and does not correlate at all with timed searches and quadrats as a mudflat sampling method. The results from the 2018 mudflat survey were comparable to the 2008 and 2012 mudflat monitoring in Upper Gulf St Vincent with high taxa diversity at Port Gawler, Middle Beach and Section Bank but a large amount of variability between sites and zones for all methods of sampling. Molluscs, Annelida and Crustacea were the major phyla that contributed most to the macroinvertebrate assemblages at all sites, which is similar to those results found in the 2012 mudflat survey. The results of the 2018 survey provide further evidence of the diversity of macrobenthic taxa that inhabit mudflats in Upper Gulf St. Vincent, but there are very idiosyncratic patterns at the site level, particularly around the Port River system and mangroves (e.g. Section Bank, Port Gawler and Middle Beach) compared to the open mudflats at Port Prime/Thompson Beach. Future monitoring should continue at the same sites, but more investigation is required at the finer spatial scale to obtain a better understanding of habitat niche and function. Overall, the survey in 2018 provides further additional evidence to the 2008 and 2012 survey; that the Upper Gulf St Vincent region is a high quality foraging habitat for shorebirds

2. Introduction

Worldwide, coastal ecosystems provide a wide range of ecosystem functions and services such as harvestable food resources, water purification, coastal protection, and habitat for foraging and shelter by multiple native and migratory species (Savage et al. 2012, Basset et al. 2013). However, anthropogenic degradation or modification of coastal habitats has intensified around the world resulting in loss of structures, functions, biodiversity and ecosystem services (Lotze et al. 2006, Moreno-Mateos et al. 2012, Costanza et al. 2014). Along the Samphire Coast in Gulf St Vincent, mudflats are widespread and an important component of the ecosystem, particularly as habitat for migratory shorebirds and juvenile fish (Connolly 1994; Jackson & Jones 1999; Purnell et al. 2015).

The Samphire Coast has recently been recognised as a region of high habitat and biodiversity value with the proclamation of the Adelaide International Bird Sanctuary (Winaityinaityi Pangkara). The region is also part of the Upper Gulf St Vincent Marine Park and is also protected by Aquatic Reserves. Yet, even with various levels of protection in place, the Samphire Coast has a number of direct and indirect environmental pressures on the region (e.g. off-road vehicles and invasive species).

Across the intertidal mudflats of the region, shorebirds use the grounds for foraging (Purnell et al. 2013). Therefore, continued monitoring of benthic communities in mudflats, as a preferred food source for shorebirds and fish species, are important for informing upon the conservation status and improvements in the region over time (Warwick & Somerfield 2015). Assessments of mudflat condition based on benthic community structure, also provides an understanding of links between habitat function and the state of the environment and ecosystem services provided by tidal wetlands along the Samphire Coast.

Previous assessments of benthic condition in mudflats along the Samphire Coast found large abundances in macroinvertebrates and very site-specific patterns of abundances, biomass and community compositions (Dittmann 2008; Dittmann et al. 2012). The most recent benthic community assessment of mudflats in the region occurred in 2011/12 and any possible changes to benthic community structure with recent conservation planning, remains unknown.

Based on previous monitoring, recommendations were given that future comparisons over time should be site specific, and include a variety of methods to fully ascertain the diversity, harvestable prey and community composition (Dittmann et al. 2012). For the 2018/19 Samphire Coast mudflat assessment, we also trialled additional methods (e.g. emergence traps) that cause less disturbance to soft-sediments, and aimed to compare those results obtained with more traditional methods used in earlier monitoring (e.g. sediment cores, quadrat counts and timed searches). This will allowed us to evaluate the effectiveness of each method and give recommendations for methods to use in future monitoring.

Thus, the aims of this project were to:

- carry out a condition monitoring of benthic communities in mudflats using different methods

- compare the current condition and food availability for shorebirds with previous monitoring
- apply additional methods in the field that can lead to a community protocol
- evaluate outcomes based on various combinations of methods
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3. Methodology

Sampling locations

Mudflat surveys were conducted in October and November 2018 at four sites along the Samphire Coast, in Gulf St Vincent. Survey sites were selected based on their distribution across the region to gain spatial representation of foraging habitats for shorebirds (Close 2008) and comparability with previous mudflat monitoring (Dittmann 2007; Dittmann et al. 2012). The sites surveyed were Section Bank (SB), Port Gawler (PG), Middle Beach (MB) and Port Prime (PP) (Figure 1). Section Bank required a small boat to gain access to the mudflat, whereas all other sites were accessed from shore.

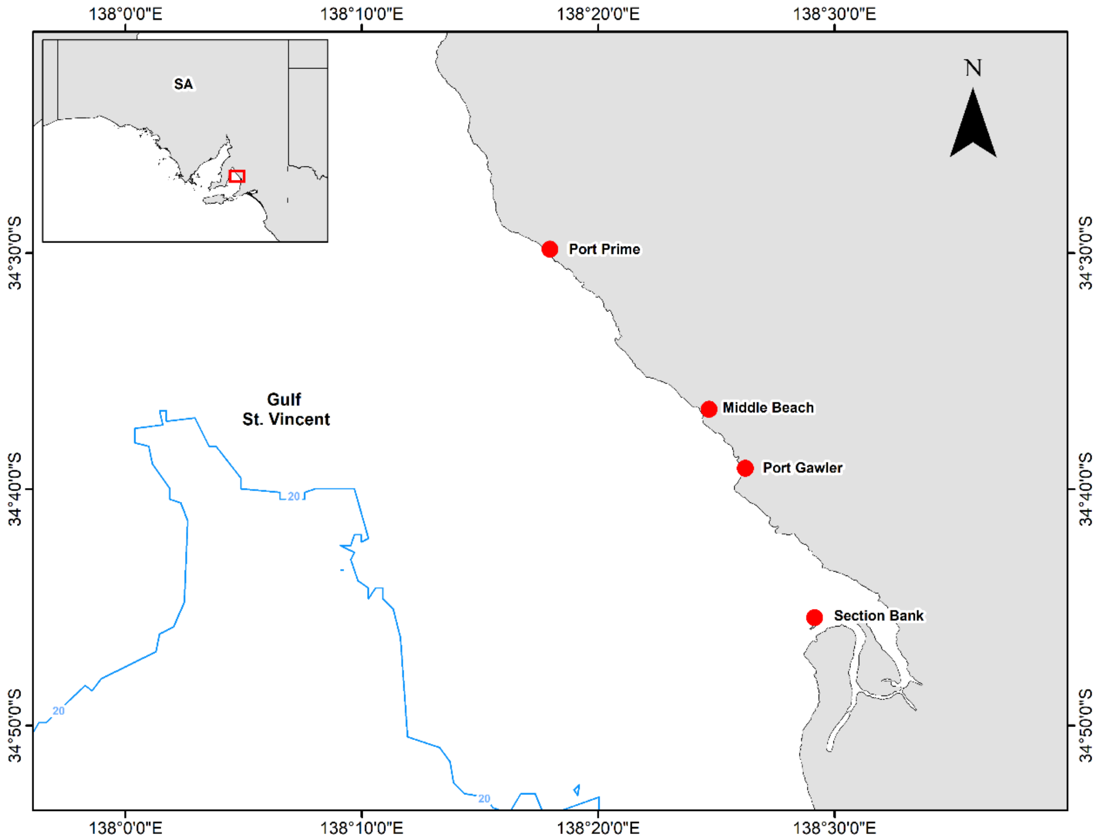


Figure 1: Location of the designated study sites in Gulf St Vincent, South Australia. PP = Port Prime/adjacent to Thompson Beach (TB), MB = Middle Beach, PG = Port Gawler, SB = Section Bank.

Different zones or strata were sampled at each site using a stratified random sampling approach (Table 1) (Kingsford and Battershill 1998). Zones were established as low, middle and high intertidal zones based on distance from shoreline, sediment properties, and presence of biogenic structures (e.g. mussel beds) as indicated in the previous mudflat monitoring surveys (Dittmann 2007; Dittmann et al. 2012). At each of the four sites, ten replicate samples per zone were taken for quadrats and sediment cores, but for timed searches only six replicates were taken per zone due to logistical constraints of the narrow low–tide time period (e.g. 4 hours). Emergence traps were only deployed in the middle and low tide zones, with ten replicates per zone.

Sampling methods

Various sampling methods were used in the mudflat surveys to assess macroinvertebrate epifauna (e.g. timed searches and quadrats) and infauna (e.g. sediment cores and emergence traps). To characterise some environmental variables, field measurements were undertaken for salinity, temperature and dissolved oxygen in the overlying and pore water. Also, sediment characteristics were qualitatively described in the field based on feel of sediment; grain size (clay, sand), colour, smell and firmness (sinking depth). Field observations were also recorded that included presence of seagrass, wrack, bird presence, or any other observations made.

Timed searches

For this rapid assessment approach, replicate ten minute searches were carried out and all species observed were identified and counted for a more comprehensive species assessment. This can include species found to be active on the sediment surface, as well as species identified when opening up the sediment with a shovel for the vertical sediment profiles. Some specimens that were difficult to identify in the field were preserved in 70 % ethanol and taken back to the Flinders University for more detailed taxonomic identification (e.g. some small crustaceans).

Quadrats

The density of snails and other organisms active on the sediment surface were assessed by haphazardly placing a quadrat (50 x 50 cm side lengths) for identification and counting of all macrofauna observed on the sediment surface (Figure 2). The type and density of burrow openings were also recorded, and while these burrows are not always occupied, the counts inform on presence of species that build burrows and contribute to bioturbation, which is an important ecological function in marine sediments (Schlacher et al. 2016).

Sediment core samples

To obtain benthic fauna living inside the sediment, samples were taken using a PVC corer (83 cm^2 surface area) to 15-20 cm sediment depth, with contents sieved through 0.5 mm mesh (Figure 2). The organisms and some coarser sediment retained on the sieve were preserved in plastic zip-lock bags of 70 % ethanol and were taken to Flinders University for further laboratory analysis (e.g. sorting, identification and counting). All sediment core samples were sorted, identified to the lowest possible taxonomic level (i.e. to Class, Family or Species in many cases). The macrofauna obtained from all samples were preserved in sealable vials of 70 % ethanol for future monitoring assessments.

Emergence traps

As a new non-invasive method to sample infauna, emergence traps were trialled in the middle and high tide zone at Port Parham and Section Bank (Figure 2) These traps make use of the growing understanding of nocturnal emergence of infauna from mudflat sediments. The traps were set up on one day at low tide, retrieved on the following low-tide during the day, and mobile infauna which had left the sediment overnight were collected into a receiving jar inside the trap (Figure 2b). Macroinvertebrate samples were removed from the traps and taken back to the Flinders University laboratory for identification and abundance counts. Efficiency of emergence traps were evaluated against the data from infauna samples obtained from core samples.

Vertical sediment profiles

The depth of the oxic layer is informative for the condition of mudflats (e.g. a deeper oxic horizon is indicative of healthier condition than anoxic mud reaching to the surface), and illustrates the depth to which benthic organisms are living inside the sediment, and whether food is thus available for shorebirds with longer or short bills. In each sampling area, the sediment was excavated with a shovel, and a ruler placed next to the sediment before photos were taken (Figure 2a). These photos provided a record over time.

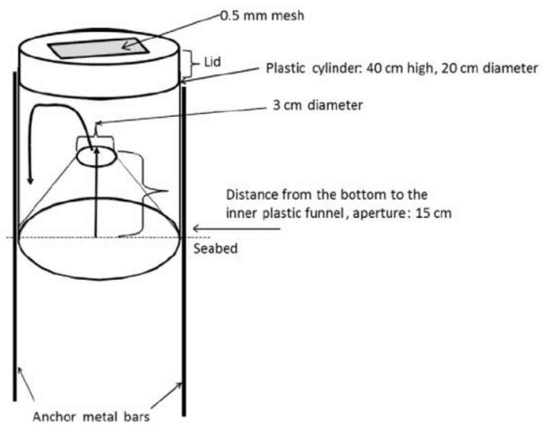
Sediment core samples, quadrats and timed searches have been used in previous monitoring (Dittmann et al. 2012), and the same procedures (apart from the sediment depth differentiation of the core samples) can be applied to allow comparisons over time.

The variables assessed from the sample sets included macroinvertebrate species richness and individual densities, and multivariate community structure.

(a)

(b)

(c)



(d)

Figure 2: Examples of the methods that were applied for the mudflat monitoring in 2018. (a) quadrats for assessing epifauna; (b) sediment coring for infauna; (c) example of an emergence trap that can be inserted in the sediment to catch benthic organisms who are actively leaving the sediment overnight (image taken from Pacheco et al. 2015), and; (d) sediment profiles showing the depth of the oxic and anoxic layer and burrows from benthic macroinvertebrates.

Data analyses

Species richness, total abundance, major phyla and key species abundance data were analysed between sites and zones for each method with PERMANOVA tests based on Euclidean Distance matrices. Macroinvertebrate community data were observed graphically using Non-Metric Multidimensional Scaling (nMDS) plots and tested using PERMANOVA based on Bray Curtis Similarity matrices. Most data were log transformed (i.e. except species richness that was left untransformed) with all analyses were conducted in PRIMER/PERMANOVA+ V7. To determine if there was any correlation between the different methods based on the macroinvertebrate community datasets, a comparison of Bray-Curtis matrices based on Spearman Ranks was conducted between the three methods (Clarke & Gorley 2015). For each method, SIMPER analyses were also conducted on datasets from each method to determine reliable indicator species that contributed to community differences between zones. For each method, data from SIMPER analyses were averaged for each site-to-site pair (e.g. six pairs) with averages including zeros from pairs that did not identify particular reliable indicator species as a mathematical mechanism to down weight averages, so that clear patterns could be identified between methods. Due to the difference in replicate numbers for timed searches (e.g. six versus 10) compared to the other two methods, the quadrat and sediment core data had five randomly selected sets of replicates from each site and zone so that correlations could be determined in pair comparisons with timed searches. The five correlation values for the quadrat and sediment cores were then averaged to get a robust correlation value.

4. Results

General Observations

Observations from the various methods across all three zones within the four sites were recorded with an overview of environmental parameters, sediment description, vegetation characteristics and bird presence (Table 1). Most sediments were fine-grain sands across the low to middle tide zones and coarse sand or shell grit in high tide zones. Sediments were very soft, with sinking depths to knee depth at Section Bank and Port Gawler. Mudflats at Section Bank consisted of seagrass patches and the bivalve, *Pinna bicolor* beds, whereas Port Gawler and Middle Beach had samphire, seagrass beds and mangroves. The mudflat at Port Prime was very different with some mussel beds, but no vegetation apart from patches of wrack dispersed throughout. Waterbirds were observed at all sites, but most abundant at Port Prime (Table 1). In comparison, shorebirds were observed at all four sites, but most abundant at Section Bank (Table 1).

Table 1: Overview of habitat characteristics for Port Prime, Port Gawler, Middle Beach and Section Bank zones in October/November 2018. Cross indicates presence of birds recorded. Tidal zones are; High (HT), Middle (MT) and Low (LT) tide.

Site	Zone	Date sampled	Salinity (ppt)	Sediment Description	Sinking depth	Vegetation characteristics	Presence of birds	
							Water birds	Shore birds
Port Prime	HT	23/10/2018	49.38	Corse sand, shell grit	<ankle	Bare mudflat with no vegetation		
	MT	23/10/2018	52.66	Corse sand, shell grit	<ankle	Bare mudflat with no vegetation		
	LT	23/10/2018	50.44	Corse sand, shell grit	<ankle	Seagrass wrack	x	x
Middle Beach	HT	24/10/2018	38.64	Coarse sand	<ankle	Bare mudflat with some seagrass wrack		
	MT	24/10/2018	40.02	Fine to coarse sand	<ankle	Seagrass bed	x	x
	LT	25/10/2018	39.24	Fine to coarse sand	<ankle	Seagrass bed	x	x
Port Gawler	HT	25/10/2018	45.04	Coarse sand	<ankle	Bare mudflat with no vegetation		
	MT	25/10/2018	41.38	Fine to coarse sand	<ankle	Seagrass bed and seagrass wrack		
	LT	25/10/2018	38.96	Fine sand	<ankle	Seagrass bed	x	x
Section Bank	HT	8/11/2018	36.03	Fine to coarse sand	Between ankle and knee	Seagrass bed	x	x
	MT	8/11/2018	35.68	Fine sand	<ankle	Bare mudflat with some seagrass wrack	x	x
	LT	8/11/2018	26.9	Fine sand	<ankle	Bare mudflat with some seagrass wrack	x	x

Macroinvertebrate taxa richness

Across the three methods and all sites, there were 74 different taxa found in mudflats of Upper Gulf St Vincent during the 2018 survey. Taxa richness of macroinvertebrates was greater using the timed search and sediment coring methods (e.g. 29 and 59 taxa respectively) versus quadrat counts (10 species) (Figure 3). Across the three methods, there was also a lower taxa richness found at Port Prime (21 taxa) compared to the other three sites (Section Bank, 41 taxa; Port Gawler, 50 taxa ; Middle Beach, 46) (Figure 3). The timed search method was useful for assessing epifauna across a larger spatial area and included various groups such as gastropod snails, crustaceans and some bivalves (e.g. mussels and the bivalve *Pinna bicolor*) (Figure 3). In comparison, the quadrat method tended to only be useful for counting gastropods, crustaceans and some of the more conspicuous bivalves such as mussels (Figure 3). The greatest diversity of a number of different phyla was found using the core method, but with a focus on annelid worms, gastropod snails, bivalves and crustaceans (Figure 3). All three methods had significant variation in taxa richness between zones and sites (Table 2).

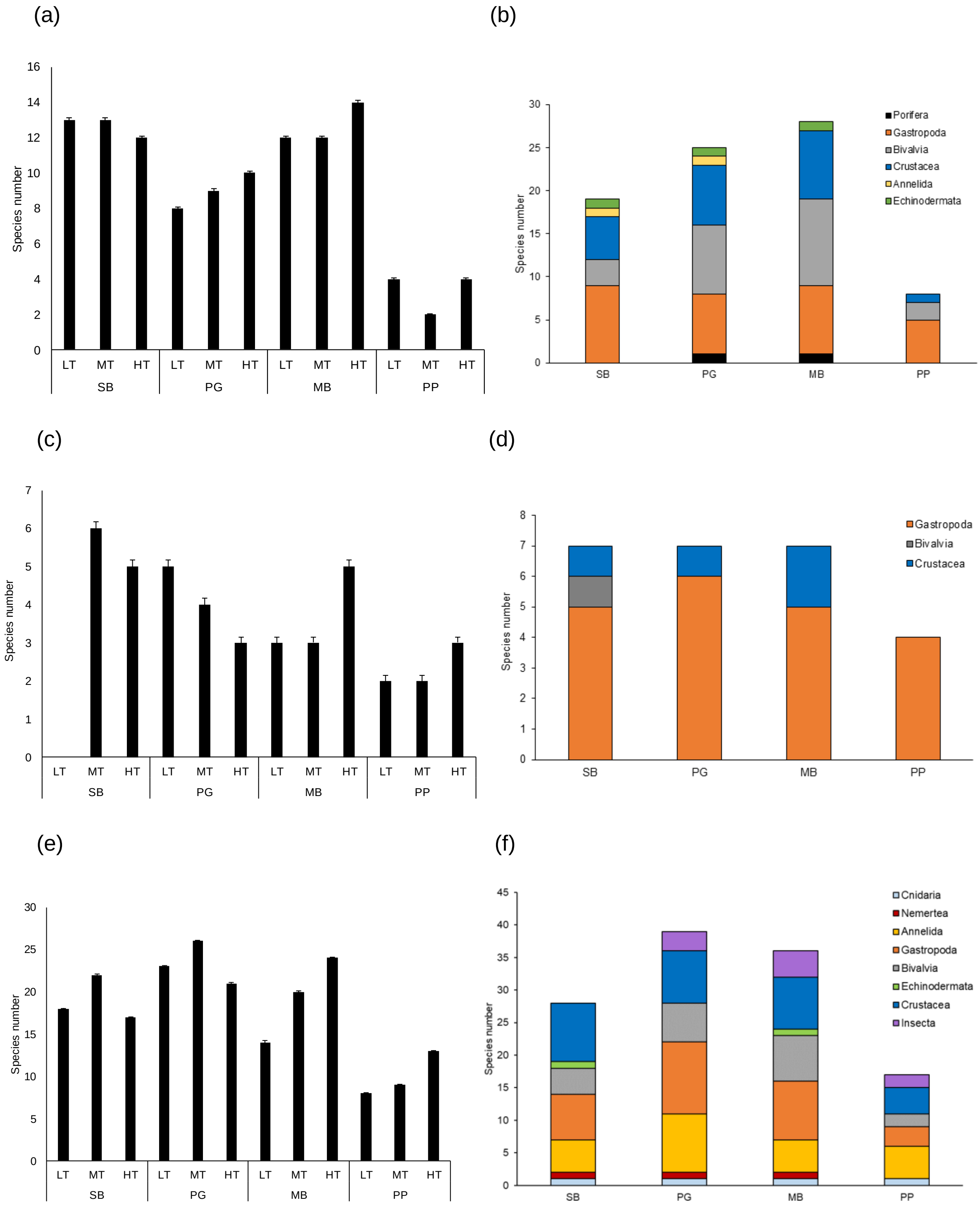


Figure 3. Total species number per site and zone (+SE), and major taxa per site from the (a,b) timed search, (c,d) quadrat, and (e,f) sediment core methods. SB= Section Bank, PG= Port Gawler, MB= Middle Beach, PP = Port Prime.

Table 2: Two-way PERMANOVA test results for macroinvertebrate species numbers between sites and zones for each of the three methods. Significant results $p < 0.05$ in bold.

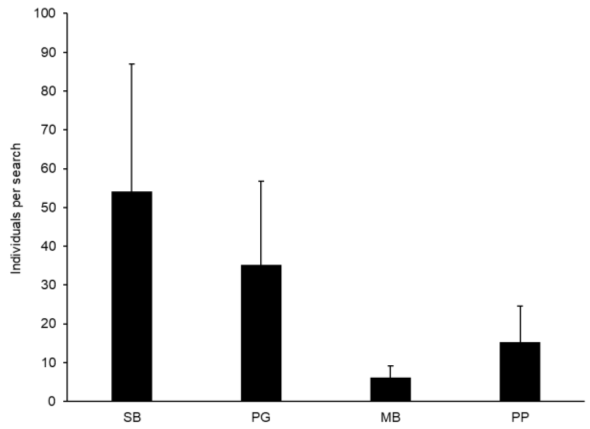
	df	Timed search P (perm)	Quadrat P (perm)	Sediment cores P (perm)
Site	3	**0.0001**	**0.0001**	**0.0001**
Zone	2	0.5196	**0.0001**	**0.0015**
Site x Zone	6	**0.0007**	**0.0001**	**0.0001**
Residual	108			

Macroinvertebrate abundances

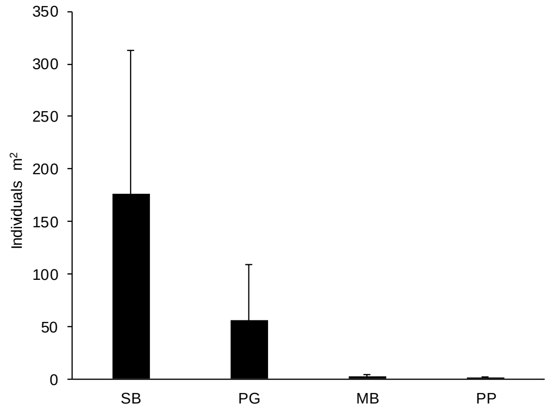
Total macroinvertebrate abundances had significant variation between sites and zones for all methods (Figure 4; Table 2). The greatest total abundances were found using the sediment core method (Figure 4).For most of the major phyla there was a significant amount of variation between sites and zones for using each method, except for annelids and bivalves in timed searches, and bivalves in quadrat counts (Figure 5 & 6, Table 3). Annelids and bivalves were not commonly found using the timed search and quadrat methods due to the burrowing behaviour of those animals and the focus on epifauna with timed searches and quadrats.

Key macroinvertebrate species were identified for each method and mainly consisted of gastropods for the timed searches and quadrat counts (Figure 7). In comparison, the sediment cores had a mix of key macroinvertebrate species that included annelid worms, bivalves, the burrowing gastropod snail *Salinator fragilis* and some smaller, but common sediment surface dwelling limpets (Figure 7). Overall, there was a lot of variation in those key macroinvertebrate species between sites and zones with significant differences identified in each of the key species for all methods, except for the limpet *Notoacmea flammea* in quadrat counts (Figure 7, Table 4).

(a)



(b)



(c)

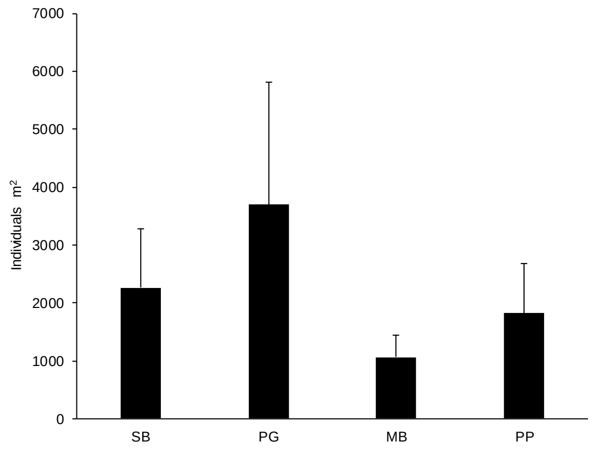


Figure 4: Total macroinvertebrate abundances for sites from (a) timed searches, (b) quadrats and (c) sediment core methods. SB= Section Bank, PG= Port Gawler, MB= Middle Beach, PP = Port Prime.

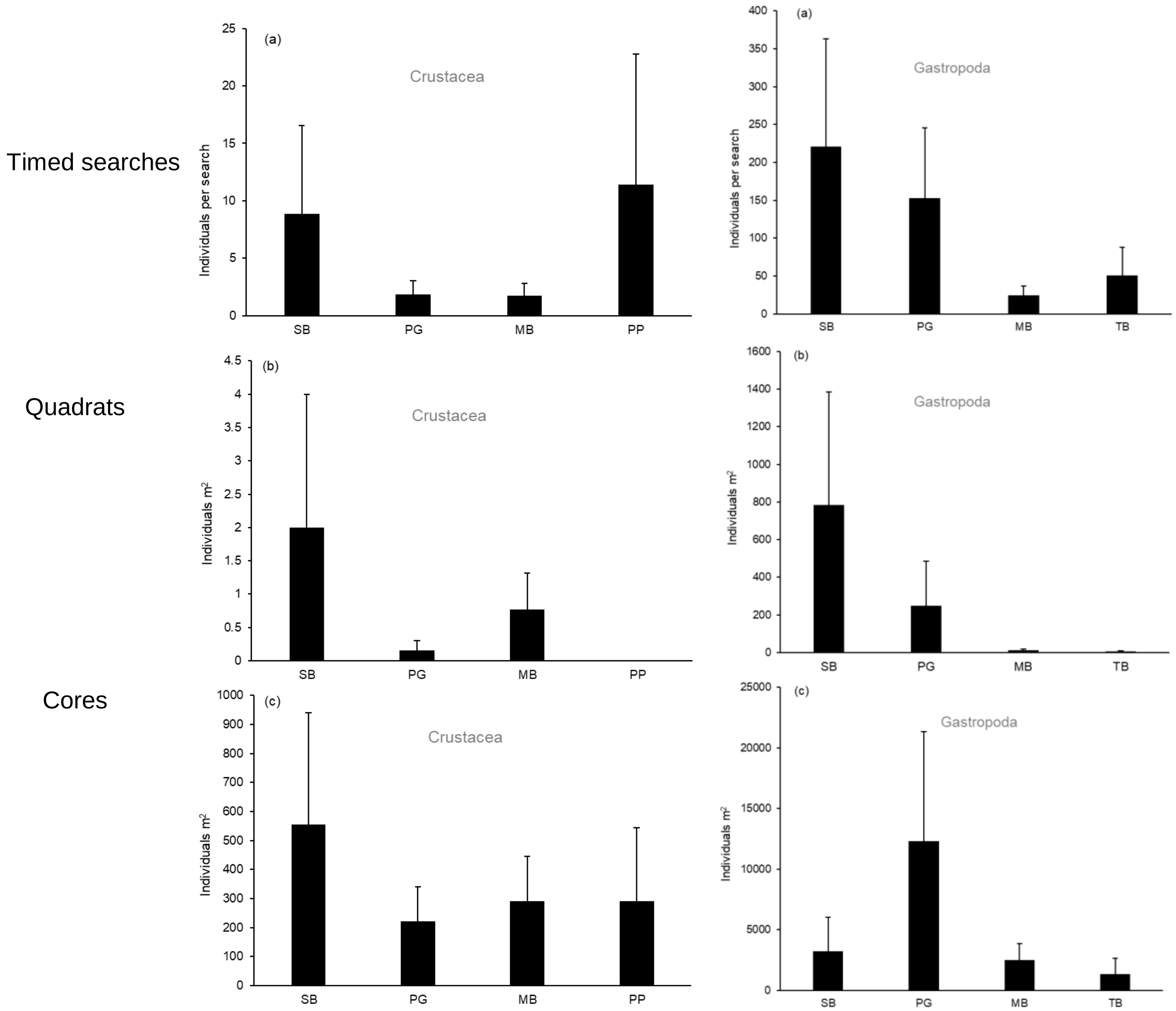


Figure 5: Abundances for major taxa from all sites using the three methods. SB= Section Bank, PG= Port Gawler, B= Middle Beach, PP = Port Prime.

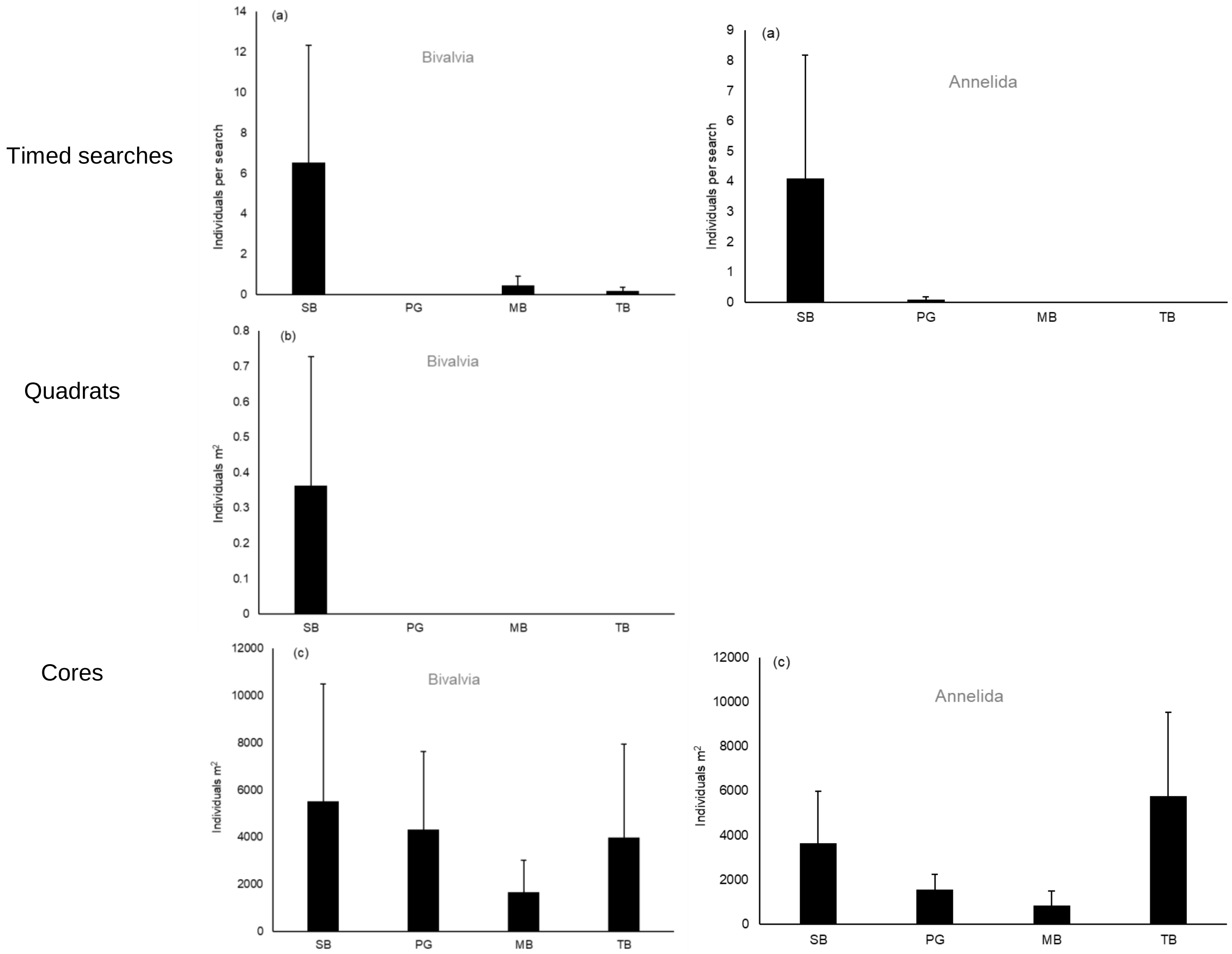


Figure 6: Abundances for key taxa from all sites using the three methods. SB= Section Bank, PG= Port Gawler, B= Middle Beach, PP = Port Prime.

Table 3: Three-way PERMANOVA test results for abundances of total macrofauna, Annelida, Crustacea, Gastropoda and Bivalvia for (a) timed searches, (b) quadrats and (c) sediment cores, between sites and zones. Significant results p <0.05 in bold. No annelid worms were found in quadrat surveys.

(a)

Timed searches	df	Total macrofauna	Annelida P (perm)	Crustacea P (perm)	Gastropoda P (perm)	Bivalvia P (perm)
Site	3	**0.0001**	**0.0003**	**0.0001**	**0.0055**	**0.0004**
Zone	2	0.0562	0.7114	**0.0007**	**0.0241**	0.9409
Site x Zone	6	**0.0001**	0.9508	**0.0001**	**0.0001**	0.7214
Residual	60					

(b)

Quadrats	df	Total macrofauna	Crustacea P (perm)	Gastropoda P (perm)	Bivalvia P (perm)
Site	3	**0.0001**	**0.0003**	**0.0001**	0.4805
Zone	2	**0.0001**	**0.0011**	**0.0001**	0.4758
Site x Zone	6	**0.0001**	**0.0001**	**0.0001**	0.487
Residual	60				

(c)

Sediment cores	df	Total macrofauna	Annelida P (perm)	Crustacea P (perm)	Gastropoda P (perm)	Bivalvia P (perm)
Site	3	**0.0001**	**0.0001**	0.0679	**0.0001**	**0.0001**
Zone	2	**0.0001**	**0.0408**	0.1604	**0.0001**	**0.0017**
Site x Zone	6	**0.0001**	**0.0001**	**0.0004**	**0.0001**	**0.017**
Residual	60					

Table 4: Three-way PERMANOVA test results for abundances of key macroinvertebrate taxa identified between sites and zones for the (a) Timed search, (b) Quadrats and, (C) Sediment core methods. Significant results p <0.05 in bold. Not all key species were found using all methods.

(a)

Timed searches	df	*Zeucumentus diemenensis* P (perm)	*Bembicium vittatum* P (perm)	*Salinator fragilis* P (perm)	*Nassarius pauperatus* P (perm)	*Patelloida* spp. P (perm)	*Notoacmea flammea* P (perm)
Site	3	**0.0002**	**0.0001**	**0.0375**	**0.0001**	**0.0056**	**0.0027**
Zone	2	**0.0004**	**0.0001**	**0.0001**	0.4422	**0.0431**	**0.0057**
S x Z	6	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0442**	**0.0238**
Residual	276						

(b)

Quadrats	df	*Zeucumentus diemenensis* P (perm)	*Bembicium vittatum* P (perm)	*Salinator fragilis* P (perm)	*Nassarius pauperatus* P (perm)	*Notoacmea flammea* P (perm)
Site	3	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.6259
Zone	2	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.7877
S x Z	6	**0.0001**	**0.0001**	**0.0001**	**0.0001**	0.5072
Residual	276					

(c)

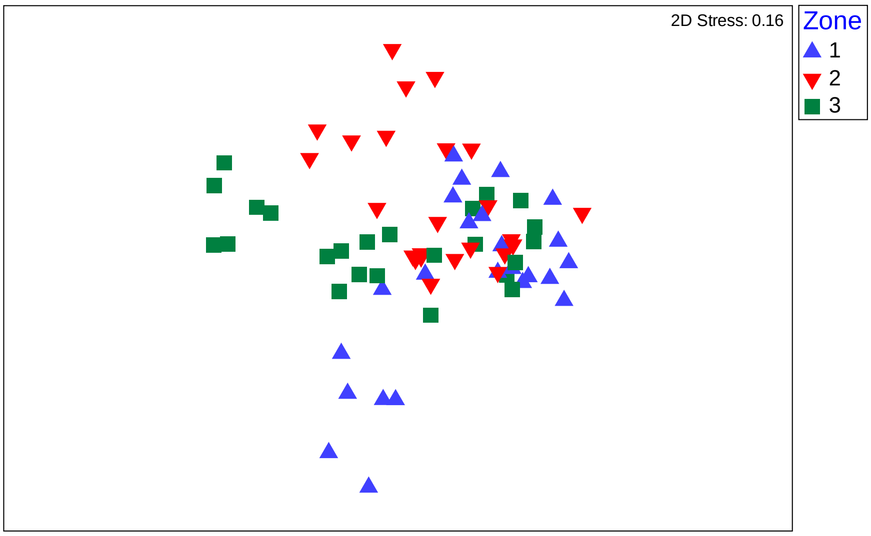
Sediment cores	df	Capitellidae P (perm)	Orbinidae P (perm)	Nereididae P (perm)	*Soletellina alba* P (perm)	*Anapella cycladea* P (perm)	*Xenostrobus inconstans* P (perm)	*Salinator fragilis* P (perm)	*Patelloida* spp. P (perm)	*Notoacmea flammea* P (perm)
Site	3	**0.0003**	**0.0001**	**0.0001**	**0.0001**	**0.0001**	**0.0187**	**0.0002**	**0.0001**	**0.0001**
Zone	2	0.4991	**0.0022**	**0.0001**	0.0908	**0.0422**	0.4241	**0.0001**	0.1651	**0.0066**
S x Z	6	**0.0047**	**0.0001**	**0.0001**	**0.0019**	**0.0276**	**0.0052**	**0.0001**	**0.0001**	**0.0001**
Residual	276									

Macroinvertebrate assemblages

Macroinvertebrate assemblages in mudflats of Upper Gulf St Vincent were not clearly defined across all sites and zones using the timed search method with a lot of overlap between clusters observed in nMDS plots (Figure 7). For the quadrat counts, clustering for zones and sites were observable but with a large amount of overlap, except for the clearly defined macroinvertebrate community structure in the low tide zone at Port Gawler, and mid-to-high tide zones at Section Bank (Figure 8). Macroinvertebrate assemblages were unclear in nMDS plots for sediment cores, with defined clustering only observable for the mid-tide zone at Port Gawler (Figure 9). Overall, for each method there was a large amount of variation in data, which was identified by the significant interactions between zones and sites for timed searches, quadrats and sediment cores (Table 5).

Timed searches

(a)



(b)

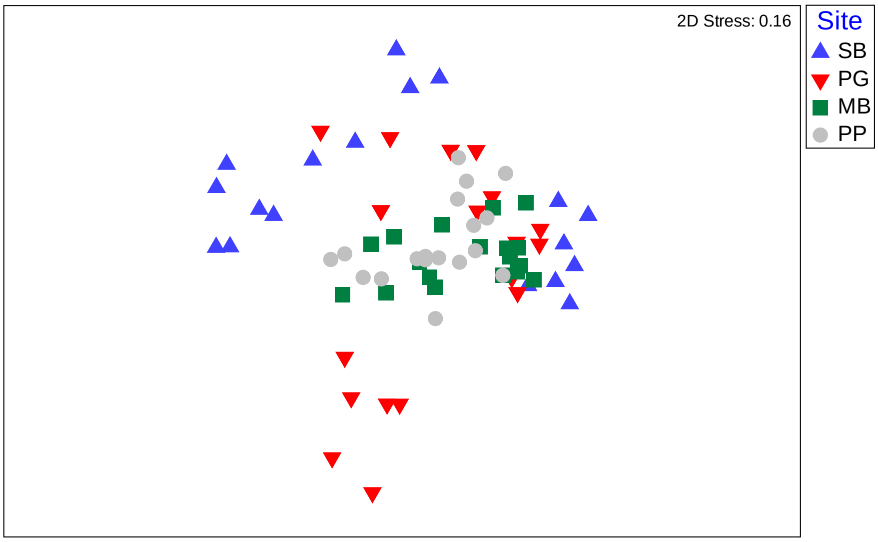
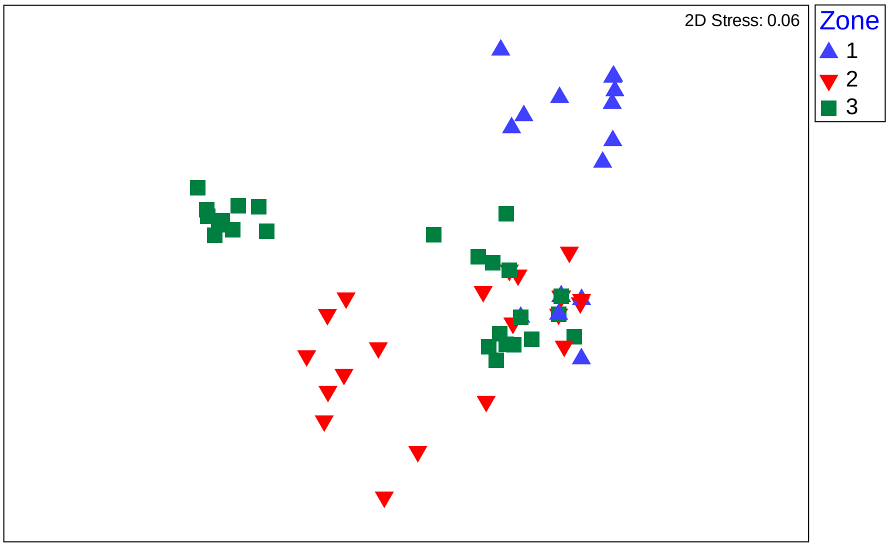


Figure 7: Community assemblage structure from Timed Searches between (a) zones and (b) sites. Non-Multi-Dimensional Scaling plots are based on Bray Curtis Similarity matrices.

Quadrats

(a)



(c)

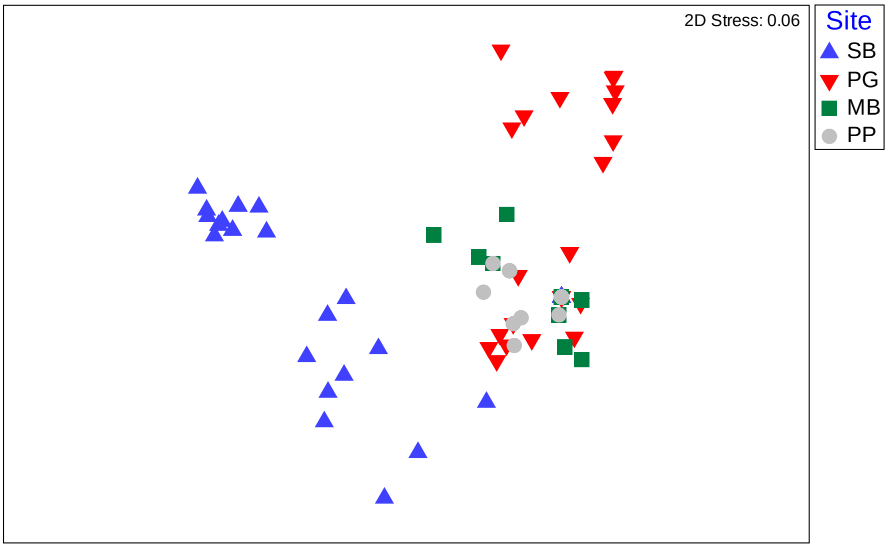
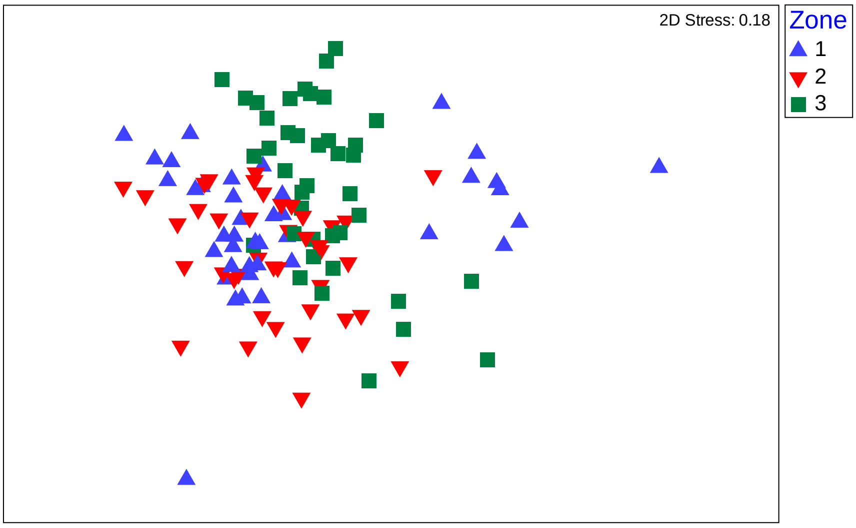


Figure 8: Community assemblage structure from Quadrat counts between (a) zones and (b) sites. Non-Multi-Dimensional Scaling plots are based on Bray Curtis Similarity matrices.

Sediment cores

(a)



(b)

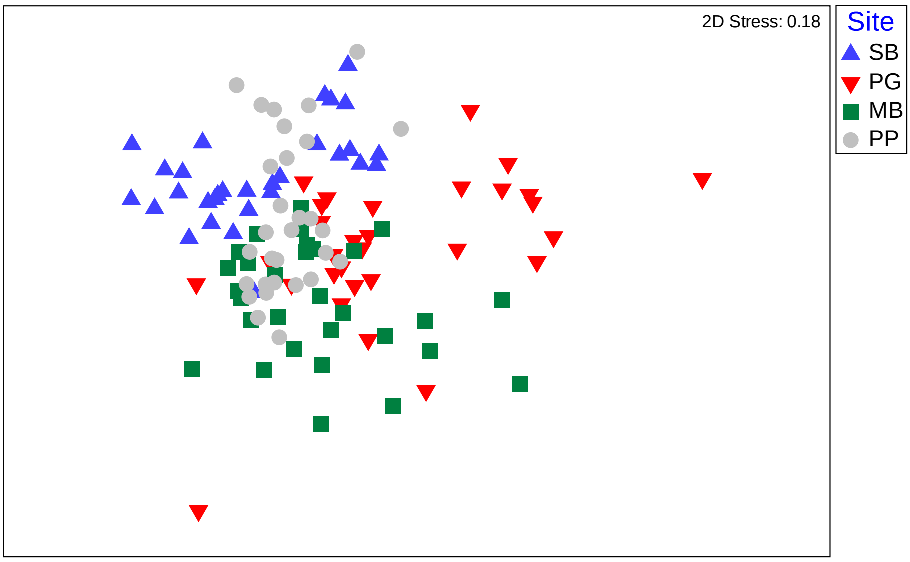


Figure 9: Community assemblage structure from Sediment Cores between (a) zones and (b) sites. Non-Multi-Dimensional Scaling plots are based on Bray Curtis Similarity matrices.

Table 5: Three-way PERMANOVA test results for macroinvertebrate community assemblages between all methods, sites and zones. Significant results p <0.05 in bold.

	df	Timed searches	Quadrats	Sediment cores
Site	3	**0.0001**	**0.0001**	**0.0001**
Zone	2	**0.0001**	**0.0001**	**0.0001**
Site x Zone	6	**0.0001**	**0.0001**	**0.0001**
Residual	276			

Comparison of methods

All three methods were compared to identify whether there were any correlations in macroinvertebrate assemblages between method pairs. The only method comparison that showed some positive correlation was between quadrat counts and timed searches as they both tended to focus on epifauna (Table 6). Both quadrat counts and timed searches showed very little correlation in macroinvertebrate assemblages with sediment cores, indicating that there are a large amount of burrowing organisms that can only be surveyed using the coring method (Table 6). SIMPER analyses of each method identified the macroinvertebrate taxa that were reliably contributing most to dissimilarities between sites. The best contributors to dissimilarities between sites for timed searches were the two gastropod snail species *Salinator fragilis* and *Zeacumantes diemenensis* followed by four other taxa that included gastropods and crustaceans (Table 7). The two gastropod snail species *S. fragilis* and *Z. diemenensis* were also the only reliable and best contributors to dissimilarities between sites for the quadrat count method (Table 7). For the sediment core method, the snail *S. fragilis* was also the best contributor to dissimilarities between sites, but there were a range of other taxa that were reliable contributors such as polychaete worms (e.g. Capitellidae) and bivalves (*Anapella cylcada*) (Table 7). The SIMPER results showed that the quadrats and timed searches had some similar taxa as reliable contributors to dissimilarities between sites, with a few more species identified for timed searches, which is indicative of the spatial area covered by each method (e.g. < 1 m^2 for quadrats, 10s of m^2 for timed searches). In comparison, sediment cores collected many taxa that were unique to that particular method as reliable contributors to dissimilarities between sites (e.g. burrowers such as polychaetes and bivalves). The one species that was consistent across all methods was the snail *S. fragilis* which is numerous across mudflats in Upper Gulf St Vincent and not only uses the sediment surface but are shallow burrowers into the sediment, hence the reason why they are commonly captured in sediment cores as well as quadrats and timed searches.

Table 6: Spearman Rank Correlation between methods for community structure based on 2nd Stage analyses of Bray-Curtis Similarity Matrices. Averages are provided for the quadrat and sediment core methods based on five randomised sample runs of 2nd Stage analyses.

Method	Timed searches	Quadrats
Timed searches		
Quadrats	0.53	
Sediment cores	0.12	0.27

Table 7: Taxa that are reliable contributors to dissimilarities from SIMPER analyses between sites for each method. Values provided are average percent contributions to dissimilarities between sites based on all six possible site versus site comparisons. Zero counts are included in average calculations to down weight data to identify rank of importance (i.e. greater value number for best contributor) for each taxa using each method as a reliable contributor species between sites. U = taxa observed using particular method but an unreliable contributor for that method. Blank cell = taxa not observed using particular method.

Key taxonomic group	Taxa	Timed searches	Quadrats	Sediment cores
Annelida	Capitellidae			8.59
	Nereididae			5.45
Crustacea	Amphipoda	U		2.19
	Flabellifera	4.50	U	
	Lophopagurus nanus	6.53	U	U
Bivalvia	*Anapella cycladea*			7.23
Gastropoda	*Austrocochlea constricta*	5.07	U	U
	Nassarius pauperatus	6.93	U	2.51
	Notoacmea spp.	U	U	5.58
	Salinator fragilis	14.06	15.10	11.88
	Zeacumantus diemenensis	14.00	14.20	U

Emergence traps

Emergence traps were trialled at Port Prime and Section Bank at low tide when mudflats were exposed to allow for installation of traps into the sediment. Unfortunately, with multiple attempts and various combinations of adapted designs to secure the traps to sediments (e.g. weights, burying in sediment, securing stake numbers and dimensions), they were ineffective at staying secured to the sediment due to large tidal flow-rates across mudflats in the region. The further design of emergence traps is an ongoing challenge being investigated by researchers at Flinders University and will be a component of a current PhD project on benthic functioning across mudflats in South Australia, including Upper Gulf St Vincent.

5. Discussion

In the 2018/19 survey, mudflats in Upper Gulf St Vincent had a diverse range of taxa present across the low to high tide zones at Section Bank, Port Gawler and Middle Beach. Port Prime had less taxa richness but high abundances of the bivalve, crustacean and polychaete worm taxa that were present. Timed searches and sediment cores collected more species overall compared to quadrat counts. The macroinvertebrate assemblages collected using timed searches and quadrats showed some correlation between them. In comparison, timed search and quadrat macroinvertebrate assemblages were not correlated with assemblages from sediment cores. Timed searches and quadrats had very similar taxa represented as strong, reliable indicators to assess dissimilarities between sites (e.g. the snails *Salinator fragilis* and *Zeacumantus diemenensis*), but timed searches had a larger pool of species as other reliable indicators as well. Compared to those other two methods, sediment cores had a very different set of reliable indicators to determine dissimilarities between sites (e.g. more polychaete worms and bivalves).

Food availability for shorebirds

The macroinvertebrate taxa available as food for shorebirds and fish varied across the Upper Gulf St Vincent region. Results from the 2018 survey align with earlier surveys in 2008 and 2012 with Section Bank and Port Gawler identified in those surveys as speciose sites and high abundances of macroinvertebrates. Middle Beach was comparable to the other two sites in the current 2018 survey for the number of taxa but with lower total macroinvertebrate abundances. There are distinct macroinvertebrate assemblages along the more open mudflats at Port Prime/Thompson Beach compared to the other three Port River or mangrove sites. Some of the idiosyncratic variability at the site level across the region may contribute to the presence or absence of particular species of foraging shorebirds. Shorebird beak and body morphology determines the feeding position of those birds within sediments and the macroinvertebrate species they feed upon, which vary according to burrow type and depth (Zwarts and Wanink 1993; Higgins and Davies 1996). Overall, further evidence from the 2012 survey builds upon the 2008 and 2012 survey; that the Upper Gulf St Vincent region is a high quality foraging habitat for shorebirds (Dittmann 2008; Dittmann et al. 2012). Yet, further understanding of foraging of particular migratory shorebirds across Upper Gulf St Vincent mudflats and preference for particular macroinvertebrate guilds at finer spatial scales would be useful in future to improve understanding of resource partitioning and shorebird feeding dynamics for the region.

Future mudflat monitoring

Future mudflat monitoring should continue in Upper Gulf St Vincent, considering the high conservation value of the region and importance as a foraging habitat for migratory shorebirds and fish. We recommend that in future the three methods of timed searches, quadrats and sediment cores are continued for consistency and to provide a reliable estimate of the various taxa that live upon and within sediments throughout the low to mid tide zone. The timed searches are providing a better estimate of some of the rarer species that are not sampled using quadrats, and the quadrats are more accurate at sampling a defined spatial area, which is important for detecting changes in the ecology over time. Core sampling is very different as a sampling method as it captures the burrowing infauna. At this stage there are no alternative methods to core sampling that may be beneficial as a replacement or complimentary method, thus sediment core sampling should continue in future mudflat monitoring as well.

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