Rocky subtidal assemblages across the Adelaide Metropolitan coast, a baseline in relation to future coastal desalination for Adelaide City: Summer 2012 final report

Final report prepared for AdelaideAqua D & C Consortium

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Summary

This report provides data against which to assess potential changes to the abundances of subtidal flora and fauna associated with desalination activities at Port Stanvac. In combination with previous surveys (Russell & Connell 2010, Russell & Connell 2011) it provides data on the flora and fauna of the sites spanning nine seasons from 2009 – 2011, plus Summer 2012 (i.e. January 2012). Temporal trends are provided (i.e. spring, summer, autumn, winter across years) among 2 sites opposite the desalination plant (i.e. 'desalination location') and 2 sites within each of 5 locations to the north and south (i.e. 'reference locations'). These data will assist with assessments of potential future change. These assessments are necessarily centred on the quantitative logic and design of 'Beyond-BACI': i.e. whether future change of mean abundance opposite Port Stanvac differs from changes of mean abundance among reference sites. This approach allows individual reference locations to differ from each other and to change through time differently from each other, but tests whether Port-Stanvac changes more (or less) than found on average. The data covered in this report represent pre-operational data as no significant discharges had been released to the Adelaide Metropolitan Coast.

The interpretations in this report are made from separate assemblage level (i.e. community and habitat) and population level analyses (i.e. species). With regard to population analyses, we focused on the most common and abundant species because these species improve the reliability of detecting environmental change through powerful statistical analysis. That is, tests that are improved by values (in this case population abundances) that are widely distributed across all spatial and temporal samples and are large (i.e. abundance is large). No species of concern were detected within these multiple surveys, including invasive species or endangered species.

Neither multivariate nor univariate estimates of variances for a range of flora and fauna showed any general tendency for Port Stanvac to be more (or less) variable than the reference locations. The reference locations were as different from each other as either was from Port-Stanvac, which was, therefore, within the range of spatial and temporal variability of that coast and time period. There was

little to no indication that the subtidal fauna and flora at Port-Stanvac showed different trajectories through time or different abundances or variations from the reference locations. Temporal patterns were noisy within each site, except for the primary subtidal habitats (i.e. canopy-forming algae) which were stable through time as were their key invertebrate consumers (*Heliocidaris erythrogramma*) and strongly site-attached fish (*Parma victoriae*). Spatial patterns of diversity and abundance were inconsistent among the 5 locations including Port Stanvac and much of this varied from season to season. Temporal patterns at Port Stanvac did not appear to behave in a manner that was consistently different to those at the reference sites. Whilst this strong spatial and temporal variability indicates that no particular reference site maybe representative of the subtidal flora and fauna at Port Stanvac, these data provide a useful basis on which to assess future changes that may be associated with desalination activities. Indeed, these spatial and temporal data provide the foundations needed for a 'Beyond-BACI' framework to reliably detecting change.

Background

The South Australian Government contracted the AdelaideAqua D & C Consortium to construct a seawater desalination plant at Port Stanvac to provide Adelaide with drinking water at a rate of 50 – 100 GL per annum. This final report, in conjunction with previous reports (Russell & Connell, 2010, 2011) provides data on ecological patterns of subtidal flora and fauna needed for assessments of future change associated with near-shore desalination activities. The activities that have potential to cause change centre on construction and maintenance of intake and outfall pipelines and structures used to draw seawater and discharge saline concentrate (above oceanic salinity levels) to the Gulf St Vincent; including the discharge *per se*. By providing an ecological baseline, this report forms part of the detailed environmental and technical investigations required by the Environmental Protection Authority (EPA).

This report is written from the viewpoint of using the contemporary patterns not only to identify the presence of invasive or rare species of concern, but to provide a quantitative analysis and framework for future assessments of ecological change at Port Stanvac. The quantitative analyses are interpreted against this intention and also against the general ecology of this site, particularly historical changes associated with human activity. These interpretations may assist the interpretations of any future work that assesses ecological change associated with the near-shore desalination activities. The data covered in this report represent pre-operational data as no significant discharges had been released to the Adelaide Metropolitan Coast.

Aims and Methods

Aims: The primary aim of this report is to provide a data describing contemporary ecological patterns of subtidal flora and fauna in relation to future studies of ecological change associated with coastal desalination at Port Stanvac. To achieve this aim, data needed to be collected across a number of seasons before the operation of the plant. The survey also needed to include reefs that will potentially be affected by activities of the desalination plant (i.e. close to the plant) and reference sites that are to be unaffected by these activities (i.e. isolated by distance from the plant). As such, the survey involved seasonal surveys (autumn, winter, spring, summer) throughout 2010, 2011 and January 2012 at replicate sites adjacent to Port Stanvac (n = 2 sites) and this replication was repeated within each of four reference locations along the coast, both north and south (i.e. n = 2 sites at each of 4 locations, for a total of 8 reference sites). Therefore, sampling in each year consisted of four quarterly surveys of benthic flora and fauna, with a total of 20 transects per season. These surveys were completed before, during and after the marine construction phase (detailed in Russell & Connell 2010, 2011).

Methods: The methods used in gathering the data in the current report were the same as those used for the initial environmental assessment (Theil & Tanner 2009) to ensure comparability, consistency and commensurability with past (e.g. EIS surveys) and future work (e.g. ongoing monitoring). The full complement of surveys includes seasonal surveys (autumn, winter, spring, summer) throughout

2009 (Russell & Connell 2010) and 2010-2011 (Russell & Connell 2011) and January 2012 (this report).

Surveys of benthic algae, invertebrates and fish were done at two shallow subtidal reefs adjacent to the Port Stanvac desalinisation plant discharge, as well as on each of four reference locations (Hallett Cove, Noarlunga, Horseshoe and Moana reefs). Two sites were surveyed at each location: Hallett Cove, Port Stanvac, Noarlunga, Horseshoe and Moana Reefs (Figure 1, Table 1). Surveys were conducted using the Reef Health survey protocols (Turner *et al*. 2007). Each site consisted of a pair of transects that were surveyed for macroalgae, benthic invertebrates, mobile invertebrates and fish. Along each transect, mobile fish were first enumerated by a SCUBA diver (50 × 5 m belt transect). Benthic invertebrates were then counted by this same diver returning along the transect (50 × 1 m belt transect). Both fish and invertebrates were identified to the lowest taxonomic resolution possible. Meanwhile, another diver identified the percentage cover of different types of algae along a 20 m transect using the line intercept transect method (LIT) and collected specimens of all algae to be identified to species.

Quantitative analyses: The sampling design, Beyond BACI, adopted the logic of Underwood (1984) ["On beyond BACI: sampling designs that might reliably detect environmental disturbances" *Ecological Applications* 4:3-15] as applied by the statistical methods of direct analysis of Anderson et al. (2008) ["PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods"]. In this current report, the factor "control versus impact" in BACI adopts an asymmetrical design because there are two "impact" sites at Port Stanvac versus two "control" sites in each of four separate locations. Our analysis specifically compares the two Port Stanvac sites to the eight reference sites; this comparison (or factor), is nominated "use" because this report compares the "use" of desalination to the alternate coastal uses. In this design, sites and locations are treated as random and sites were nested within locations. Seasons are treated as fixed and are orthogonal with 'use' and 'location' and 'site', allowing for tests of temporal consistency or inconsistencies between the two Port Stanvac sites and eight reference sites (Anderson et al. 2008). This report does not provide significance tests of "location' because asymmetrical designs in PERMANOVA do not provide the correct F and P values. This does not affect the reliability of the analyses because the important tests focus on whether Port Stanvac is different form reference sites (i.e. "use" term), or whether the temporal trajectories at Port Stanvac are different from reference sites (i.e. "use × season" term).

Results

General quantitative results

Patterns of assemblages of fish, invertebrates and algae at Port Stanvac varied through time and space in ways that were inconsistent, except for the primary habitats and two of their consumers. Temporal patterns were noisy within each site. Spatial patterns were inconsistent among the 5 locations. Temporal patterns at Port Stanvac did not appear to behave in a manner that was consistently different to those at the reference sites. Whilst this strong spatial and temporal variability indicates that no reference site is representative of the subtidal flora and fauna at Port Stanvac, these data provide a useful basis on which to assess future changes that may be associated with desalination activities.

Assemblages (communities) of fish and invertebrates and their algal habitats

Multivariate analyses detected a significant 'site(location(use)) × season' interaction ($F_{25,60}$: all $P \leq 0.01$, Table 2) for each major assemblage; algae (Fig. 2), invertebrates (Fig. 3) and fish (Fig. 4). Port Stanvac was not detected to differ from the reference sites (i.e. 'use', Table 2) or from these sites in consistent ways through time (i.e. 'use × season', Table 2) for any of these assemblages. Detection of a significant **'use × season'** interaction would be indicative of changes at the Port Stanvac sites that has a different trajectories or time-course compared to reference sites. That this interaction did not occur suggests that there is nothing special about the seasonal changes at this site relative to seasonal changes among the reference sites. Similarly, the spatial patterns at Port Stanvac were indistinguishable from the reference sites when averaged across seasons (i.e. 'use' $P > 0.05$, Table 2).

Populations of fish and invertebrates and their algal habitats

Algae: The percentage cover of kelp and other canopy-forming algae did not vary seasonally, but did vary from site to site (e.g. Hallett Cove locations v. Moana locations) (Table 3; Fig. 5a,b). Port Stanvac was not detected to be different from the reference sites in cover of kelp or total canopy. The percentage covers of turf-forming algae differed among sites (Table 3; Fig. 5c). Algal turfs, an ephemeral group of opportunistic algae, showed a significant 'site(location(use)) × season' interaction

($F_{25,60}$: all $P < 0.05$, Table 3) indicating that covers differ among seasons at some sites, as has previously been reported (Russell & Connell 2010, 2011). Again, Port Stanvac was not detected to be different from the reference sites. These analyses support previous research that has identified sparse canopies in the proximity of the Christies Creek Waste Water Treatment Plant outfall, particularly on rocky reef that support extensive covers of sediment (Cheshire et. al 1999); i.e. sediment-trapping turfs or rock that accumulates sediment through their simple topography and close proximity to sand. Variation in canopy cover and composition has large affects on the composition and cover of non-canopy algae (Irving et al. 2004) and invertebrates (Goodsell et al. 2004). The algae found among the sites are likely to vary as a consequence of physical differences among sites (e.g. topography and height of reef), composition of community dominants (e.g. canopy-forming algae) and alterations to water chemistry (e.g. nutrient and sediment input).

Invertebrates: Port-Stanvac did not differ from any reference locations for species richness of invertebrates (i.e. total numbers of species; Fig. 6a, Table 4a) or total abundance of invertebrates (Fig 6b, Table 4a). Species richness varied among the sites, but unlike previous report surveys (e.g. Russell & Connell 2011) did not interact with the season (i.e. site(location(use)) × season interaction). As a sum of all invertebrate populations quantified, their total abundance varied from site to site and season to season in an inconsistent manner (Table 4a); Port Stanvac did not show different trajectories through time or different abundances or variations from the reference locations (Fig. 6b).

The capacity to reliably detect environmental change centres on analyses of species that are both widely distributed in space, common and abundant. In this regard, the two most abundant categories of invertebrates were urchins and molluscs. Urchins as total abundance of four species (*Amblypneutes* sp., *Coniocidaris impressa*, *Centrostephanus tenuispinus, Heliocidaris erythrogramma*) and as the abundance of the most common species, *H. erythrogramma* (purple urchins), were temporally stable (Fig. 7a,b), but varied from site to site (i.e. site(location(use)); Table 4b). The total abundance of the species' of mollusc showed variation across seasons and locations (i.e. $P < 0.05$; Fig. 8a; Table 4c). Both of the common species *Turbo undulatus* and *Phasinella ventricosa* were detected to be variable across seasons and locations (Fig. 8b,c; Table 4c). Again, Port-Stanvac did not differ from any reference location for molluscs.

Fish: Analysis of the diversity and abundances of fish differed among sites and seasons and did not reveal Port Stanvac to be different from reference sites within any season (Fig. 9, Table 5). The numbers of species of fish varied strongly among sites and seasons (i.e. site(location(use)) × season: $P < 0.001$, Fig. 9a). The abundance of the species of fish that is both common and with strong associations with algal canopies (*Odax cyanomelas*) also varied seasonally by site (i.e. site(location(use)) × season: $P < 0.001$; Fig. 9b, Table 5b); though this variation seems to be driven by a relatively small increase in the number of individuals counted at the Noarlunga Outside site in the Autumn 2011 survey, numbers are still not substantially different from those recorded in Russell & Connell (2010) and are again lower in the summer 2012 survey (Fig. 9b). The abundance of the species of fish that is both common and associated with fishing (*Notolabrus tetricus*), noting that Port Stanvac is in close proximity to a zone closed to fishing, was not only counted in very low numbers but also varied by site and season (Fig 10a, Table 5b). The fish that is relatively easy to count with little observer bias and useful to community groups, *Parma victoriae*, differed among sites independent of season (Fig 10b, Table 5).

The issue of fixed versus independent sampling is a persistent issue. Resolution depends on the primary issues that motivate the study and costs involved. Independent sampling is often the least problematic method of implementation, analysis and interpretation when sampling is required across a wide range of taxa. In general, independently placed sampling units (e.g. transects) improves the reliability of statistical interpretations because it reduces Type I and Type II error rates; i.e. the statistical chance of increasing or decreasing the probability of incorrectly concluding an environmental impact. For sparse populations that are highly clumped, fixed sampling can be beneficial (e.g. some abalone sampling by government agencies), and this would seem to be appropriate for this species of fish that tends to be clumped and sedentary. The costs involved, however, in this additional type of sampling do not appear to improve the reliability of tests to reliability detect environmental change. This report recommends the continued use of independent sampling and analyses of common and abundant species. Care appears to be required with interpretations of abundances of sparse species (e.g. *Parma victoriae)* and those that tend to be clumped (e.g. abalone). Community groups could be well advised to use fixed transects when estimating change to the abundances of these types of species under particular circumstances.

Discussion

This study examined the spatial and temporal trends in faunal and floral assemblages over six seasons spanning 2+ years at Port Stanvac and across sites close to and far from this location, and when combined with previous surveys (Russell & Connell 2010, 2011) provides data spanning Autumn 2010 – January 2012. There was little indication that the subtidal fauna and flora at Port Stanvac showed different trajectories through time or different abundances or variations from the reference locations. Temporal patterns were noisy across all sites irrespective of proximity to Port Stanvac. Similarly, spatial patterns were inconsistent among the all five locations. Temporal patterns at Port Stanvac did not appear to behave in a manner that was consistently different to those at the references. Port Stanvac appeared to resemble most reference locations for most taxa or measures of abundance and composition analysed. Whilst this strong spatial and temporal variability indicates that no reference site is representative of the subtidal flora and fauna at Port Stanvac, these data provide a useful basis on which to assess future changes that may be associated with desalination activities. Spatial differences were also identified at the level of sites averaged over all times. These patterns varied among taxa and sites within Port Stanvac. No general trends in this small-scale spatial variability could be identified and there was no tendency for sites at Port Stanvac to be more or less variable than those at the reference locations.

Temporal patterns and considerations for future sampling

The most common and widespread habitats, canopy-forming algae, were stable through time as were key species of invertebrate (*Heliocidaris erythrogramma*) known to strongly rely on them for food and shelter. While the fish species (*Odax cyanomelas*) known to strongly rely on canopies did differ by season, this was only at one site (exposed side of Noarlunga Reef) and in very low numbers. Apart from these habitats (primary producers) and these species (consumers of these producers) most other taxa and measures of their diversity tended to vary among seasons. Most of this variation was unpredictable site specific variation. That is, each site varied through time in different ways. Given that many of species of fish, invertebrate and algae are strongly associated with the presence and composition of canopy-forming algae and their key consumers, the temporal stability identified here may reduce the complexity of identifying whether or not the desalination activities induce environmental change. While most taxa varied through time and space in an inconsistent manner, this variation does not preclude rigorous assessment if the design principles of this report are adopted for future sampling.

The issue of fixed versus independent sampling was raised in the Results section because of some uncertainty associated with the interpretation of temporal patterns of abundance of a species of fish. This report recommends the continued use of independent sampling. In general, independently placed sampling units (e.g. transects) improves the reliability of statistical interpretations because it reduces Type I and Type II error rates; i.e. the statistical chance of increasing or decreasing the probability of incorrectly concluding an environmental impact. For highly clumped species, fixed sampling can be beneficial (e.g. as used for abalone sampling by some government agencies), and this would seem to be appropriate for this species of fish that tends to be clumped and sedentary. The costs involved, however, in this additional type of sampling does not appear to improve the reliability of tests to reliability detect environmental change.

Recognising canopy algae as ecosystem dominants and susceptibility to change

These analyses support previous research that has identified sparse canopies in the proximity of the Christies Creek outfall, particularly on rocky reef that tends to associated with both the capacity to accumulated extensive covers of sediment (Cheshire et al. 1999; Connell et al. 2008). Sediment tends to accumulate on rock surfaces that support extensive covers of sediment-trapping turfs, as facilitated by nutrients, or surfaces that are low lying, simple in topography and in close proximity to sand. This variation in sediment accumulation, via turf-forming algae or rock topography, appears to drive variation in canopy cover that subsequently has large affects on the composition and cover of non-canopy algae (Irving et al. 2004) and invertebrates (Goodsell et al. 2004). The list of algae found among the sites (Appendix 1) are likely to vary as a consequence of physical differences among sites (e.g. topography and height of reef), composition of community dominants (e.g. canopy-forming algae) and alterations to water chemistry (e.g. nutrient and sediment input). Perhaps the greatest concern has been changes to composition and abundance of community dominants that can cascade through the entire ecosystem: i.e. through algae, invertebrates and fish (Connell 2007).

Recognising contemporary conditions as a function of 30 years of coastal use

Assessments of future change may benefit from recognising the contemporary spatial and temporal conditions of Port Stanvac and surrounding areas. The Port Stanvac location has been an area of heavy coastal use through the construction and use of infrastructure for shipping oil to the now disused Mobil Oil Refinery. This location is immediately adjacent to an area known for loss of kelp canopies (Horseshoe Reef and Noarlunga Reefs, Connell et al. 2008) as driven by coastal pollution through terrestrial discharge (Gorman et al. 2009). Major changes to the future water chemistry of this area, such as changes to stormwater and wastewater projects, may cause subtidal change (Gorman and Connell 2009), independently of the desalination plant operation.

Canopies of macroalgae, often called ‘kelp forests’, are key to the ecology of this subtidal ecosystem. These canopies form large undersea habitats, analogous to terrestrial rainforests, and act as ‘foundations’ to entire ecosystems that sustain some of the most diverse and productive ecosystems on the planet. Their loss, or major change to their composition, creates substantial change to the natural communities that rely on them. In many ways kelp forests have become sentential species because of their role in regulating regional patterns in diversity, productivity and food webs. Hence, assessments of species change of fish and invertebrates may be understood in terms of any direct affects of human activities, as well as their indirect effects that modify kelp forest presence and composition. In South Australia, the apparent loss of canopy-forming algae on the Adelaide metropolitan coast has been of public concern with continuous years of anecdotal evidence culminating in community groups dedicated to observing subtidal flora and fauna (Reef Watch), reports commissioned by local state agencies (Cheshire et al. 1999) and postgraduate theses that quantified recent loss and experimental attempted restoration (e.g. Turner 2004). Conclusive evidence of loss was published internationally in 2008 in the journal *Marine Ecology-Progress Series* (Connell et al. 2008) and is worth considering in relation to future subtidal changes on this coast.

Port Stanvac is centred within a catchment (Mt Lofty catchment) and a coast that has been associated with considerable change since the onset of major coastal urbanisation (Connell et al. 2008). Wilkinson et al. (2005) reviewed the history of coastal water pollution discharged from this catchment from 1945 to 2003. This report stated that a single largest source of land-based pollution is associated with a waste water treatment plant (~ 43 % of land-based discharge in 2003) that was commissioned in 1971, and then initially serviced 13,000 people in 1973, and ~ 150,000 people by 2003. This plant discharges through an outfall placed 300 m off-shore at 6 m depth and volumes of discharge have increased exponentially; from no discharge prior to 1973, then 20,452 million litres (ML) to 1980, then 63,485 ML to1990, and then another 103,891 ML to 2000. Land-based inflow to the coast includes groundwater from the urban catchment (Mt Lofty catchment) and creek (Christies Creek) from which a natural reed bed was cleared in the early 1970s and discharge of an estuary

(Onkaparinga River, 2-3 km south) on which sewage ponds are located and seepage into the ground water occurs. The population within the urban catchment saw two periods of growth and expansion of land use, 1971 to 1981 (33,804 to 67,365 people, respectively) and 1986 to 1991 (77,232 to 132,179 people, respectively) (Australian Bureau of Statistics Census Reports). Since 1991, the human population of this catchment has remained relatively stable (2006 population 149,736 people).

The recent cross-government consensus of nutrient driven habitat loss (i.e., Connell et al. 2008) motivated policy initiatives that aim to recycle nearly 45 % of Adelaide's wastewater and save supplies of drinking water. Coastal managers of Adelaide's connected land-to-sea landscapes, which are drying and drought prone coasts, have recently recognised that solutions for the sea (policy on reducing discharge) can act as solutions for the land (policy on establishing new sources of water that do not rely entirely on rainfall). Wastewater treatment plants will be upgraded to produce recycled water (for residential and industrial zones, recreational parks and wineries) so that most of the nutrient rich discharge (nearly three billion litres per annum) will be used more effectively to manage the land (reduce reliance on rainfall) and sea (reduce nutrient pollution), and their connection. There is the possibility that some ecological changes, such as a return of kelp forests, may occur across parts of the Metropolitan coast as a consequence of natural recovery or restoration attempts.

Conclusions and Recommendations

Neither multivariate nor univariate estimates of variance for a range of flora and fauna showed any general tendency for Port Stanvac to be more (or less) variable than the reference locations. The reference locations were as different from each other as they were from Port Stanvac, which was, therefore, within the range of spatial and temporal variability of that coast and time period. This report concludes that there was little to no indication that the subtidal fauna and flora at Port Stanvac have different trajectories through time or different abundances or variations from the reference locations. Spatial patterns were inconsistent among the 5 locations including Port Stanvac. Whilst this strong spatial and temporal variability indicates that no reference site is representative of the subtidal flora and fauna at Port Stanvac, these data provide a useful basis on which to assess future changes that may be associated with desalination activities. These spatial and temporal data provide the foundations needed for a 'Beyond-BACI' framework to reliably detect change.

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Table 1. GPS coordinates of the study sites.

Site name	GPS Coordinate
Hallett Cove North	35.0736° S 138.4943° E
Hallett Cove South	35.0525° S 138.5027° E
Port Stanvac North	35.0976° S 138.4775° E
Port Stanvac South	35.1034° S 138.4742° E
Horseshoe Reef Inside	35.1379° S 138.4629° E
Horseshoe Reef Outside	35.1394° S 138.4580° E
Noarlunga Reef Inside	35.1474° S 138.4630° E
Noarlunga Reef Outside	35.1474° S 138.4630° E
Moana Reef Inside	35.2065° S 138.4622° E
Moana Reef Outside	35.2091° S 138.4643° E

Table 2. Summary of multivariate analyses of the major community groups (PERMANOVA, Anderson et al. 2008). This table reports the significance of factors associated with reliable *F* tests of differences between Port Stanvac and reference sites (i.e. 'use' and 'use × season') and variation among sites (i.e. 'site(location(use)) and seasonal variation *per se* (i.e. 'season'), including seasonal variation among locations (i.e. location(use) × season) and sites (i.e. site(location(use) × season).

Factor	Fish	Invertebrates	Algae
use	ns	ns	ns
season	***	***	*
use ×season	ns	ns	ns
site(location(use))	***	***	***
location(use) ×season	ns	**	ns
site(location(use)) ×season	***	***	***

ns = not significant at 0.05, * $P < 0.05$, ** $P = 0.01$, ***$P < 0.001$

- A significant 'use' term is indicative of spatial differences between Port Stanvac and references sites.
- A significant 'use × season' term is indicative of Port-Stanvac having different trajectories through time relative to reference sites.

Table 3. Summary of univariate analyses of the primary habitat-types. See Table 2 for details of each Factor.

Factor	Kelp (*E. radiata*)	Other canopy	Turf-forming
use	ns	ns	ns
season	ns	ns	ns
use ×season	ns	ns	ns
site(location(use))	***	*	***
location(use) ×season	ns	ns	ns
site(location(use)) ×season	ns	ns^{+}	*

ns = not significant at 0.05, * $P < 0.05$, ** $P < 0.01$, ***$P < 0.001$*, ns^{+} $P = 0.054$

- A significant 'use' term is indicative of spatial differences between Port Stanvac and references sites.
- A significant 'use × season' term is indicative of Port-Stanvac having different trajectories through time relative to reference sites.

Table 4. Summary of univariate analyses of invertebrates. See Table 2 for details of each Factor.

(a) All invertebrates

Factor	Species richness	Total abundance
use	ns	ns
season	ns	ns
use ×season	ns	ns
site(location(use))	***	**
location(use) ×season	ns	ns
site(location(use)) ×season	ns	**

(b) Urchins

Factor	Total abundance	*Heliocidaris erythrogramma*
use	ns	ns
season	ns	ns
use ×season	ns	ns
site(location(use))	***	***
location(use) ×season	ns	ns
site(location(use)) ×season	ns	ns

(c) Molluscs

	Total abundance	*Turbo undulatus*	*Phasinella ventricosa*
use	ns	ns	ns
season	ns	ns	ns
use ×season	ns	ns	ns
site(location(use))	***	***	ns
location(use) ×season	*	**	*
site(location(use)) ×season	*	ns	ns

ns = not significant at 0.05, * $P < 0.05$, ** $P < 0.01$, **$P < 0.001$

- A significant 'use' term is indicative of spatial differences between Port Stanvac and references sites.
- A significant 'use × season' term is indicative of Port-Stanvac having different trajectories through time relative to reference sites.

Table 5. Summary of univariate analyses of fish. See Table 2 for details of each Factor.

(a) All fish

Factor	Species richness	Total abundance
use	ns	ns
season	**	ns
use ×season	ns	ns
site(location(use))	***	***
location(use) ×season	ns	ns
site(location(use)) ×season	**	***

(b) Abundance of individual species

Factor	*Odax cyanomelas*	*Notolabrus tetricus*	*Parma victoriae*
use	ns	ns	ns
season	ns	ns	ns
use ×season	ns	ns	ns
site(location(use))	***	ns	*
location(use) ×season	ns	ns	ns
site(location(use)) ×season	***	*	ns

ns = not significant at 0.05, * $P < 0.05$, ** $P < 0.01$, **$P < 0.001$

- A significant 'use' term is indicative of spatial differences between Port Stanvac and references sites.
- A significant 'use × season' term is indicative of Port-Stanvac having different trajectories through time relative to reference sites.

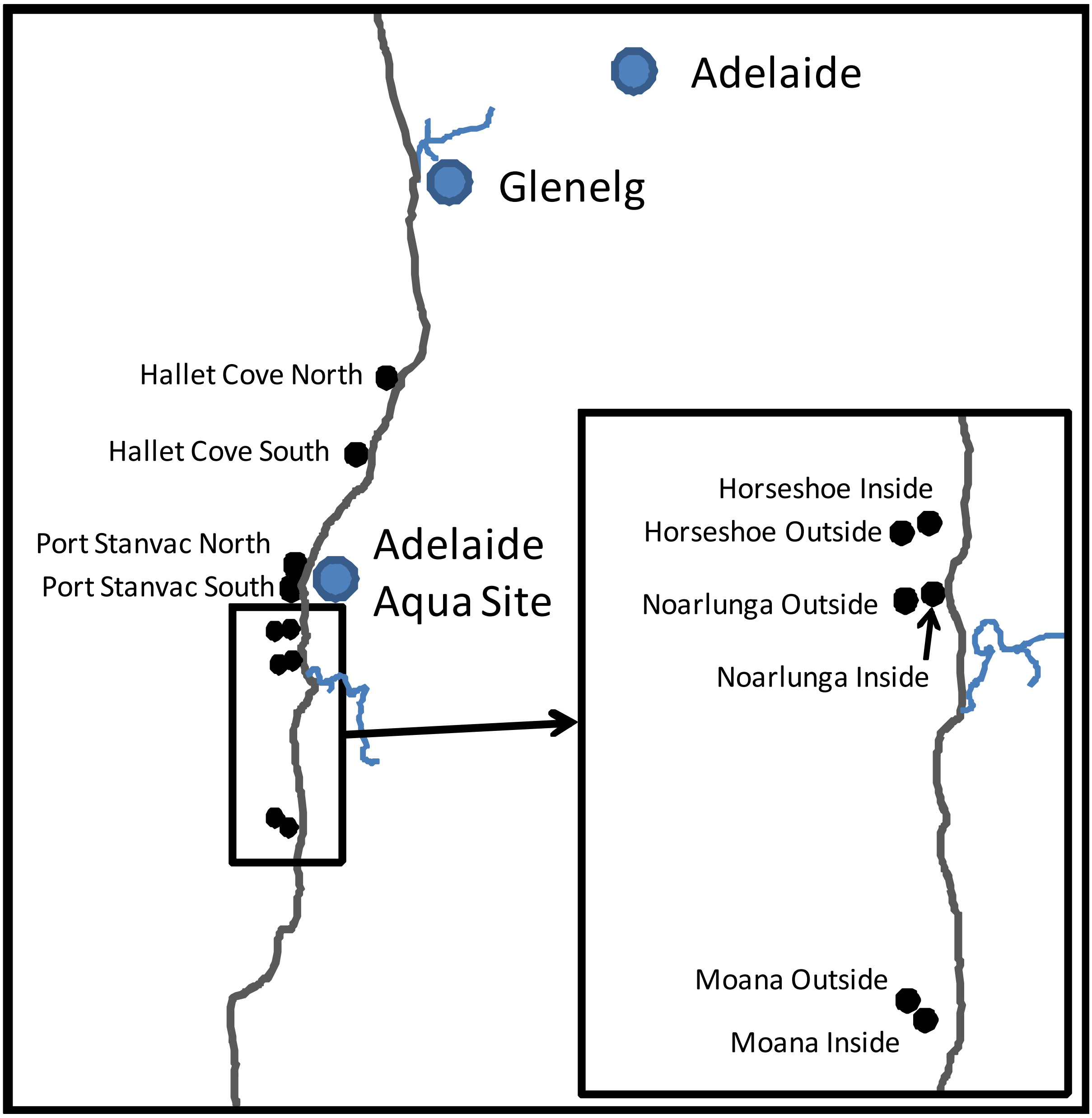


Figure 1. Map of the two Port Stanvac sites and eight reference sites.

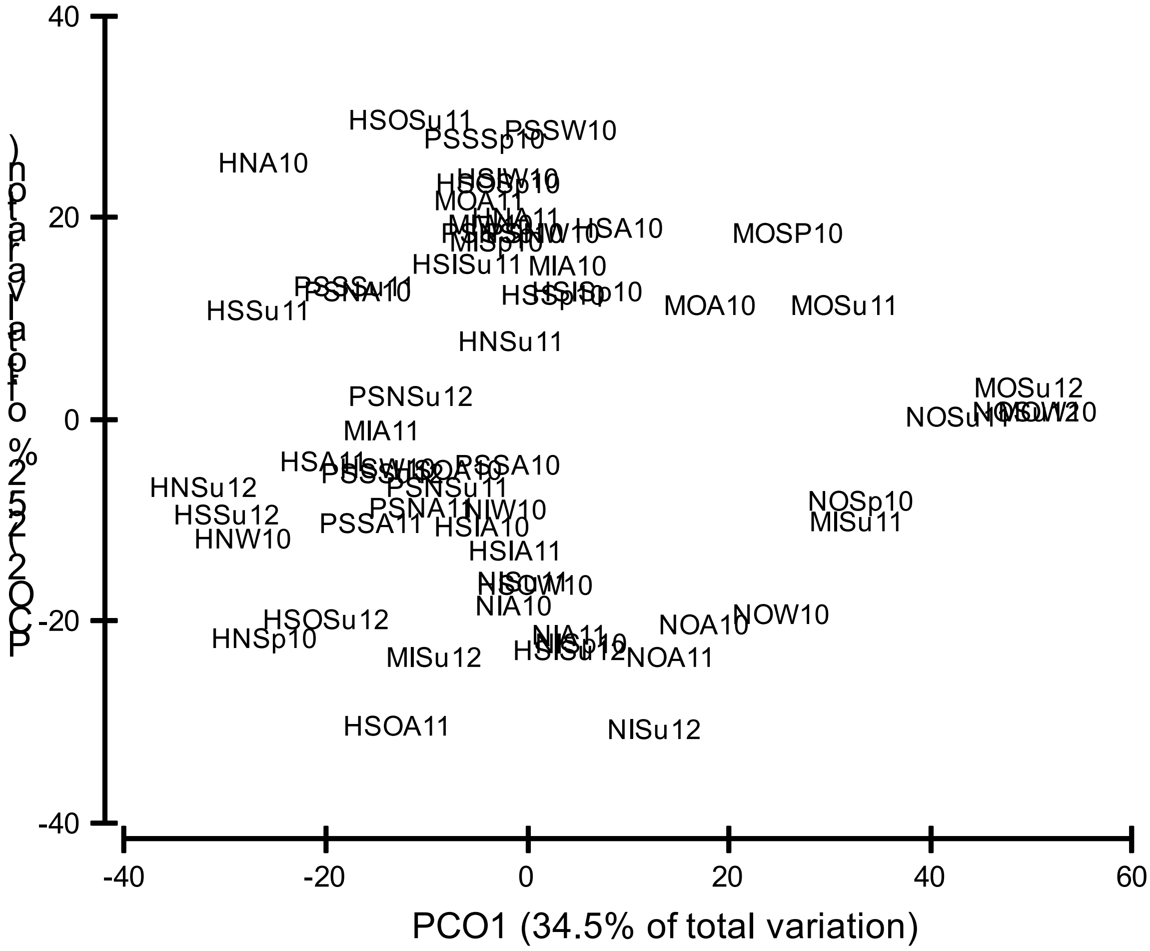


Figure 2. Principle coordinates ordination (PCO) plot of the benthic assemblages of algae (based on morphological groups) at the 10 study sites and 6 seasons. Abbreviations for Figures 2 – 4 are the same and designate both site and season. Sites: HN, Hallett Cove North; HS, Hallett Cove South; PSN, Port Stanvac North; PSS, Port Stanvac South; HSI, Horseshoe reef inside; HSO, Horseshoe reef outside; NI, Noarlunga reef inside; NO, Noarlunga reef outside; MI, Moana reef inside; MO, Moana reef outside. Seasons for each site are designated by adding a season abbreviation to the site: A10, Autumn 2010; W10, Winter 2010; Sp10, Spring 2010; Su11, Summer 2011; A11, Autumn 2011; Su12, Summer 2012.

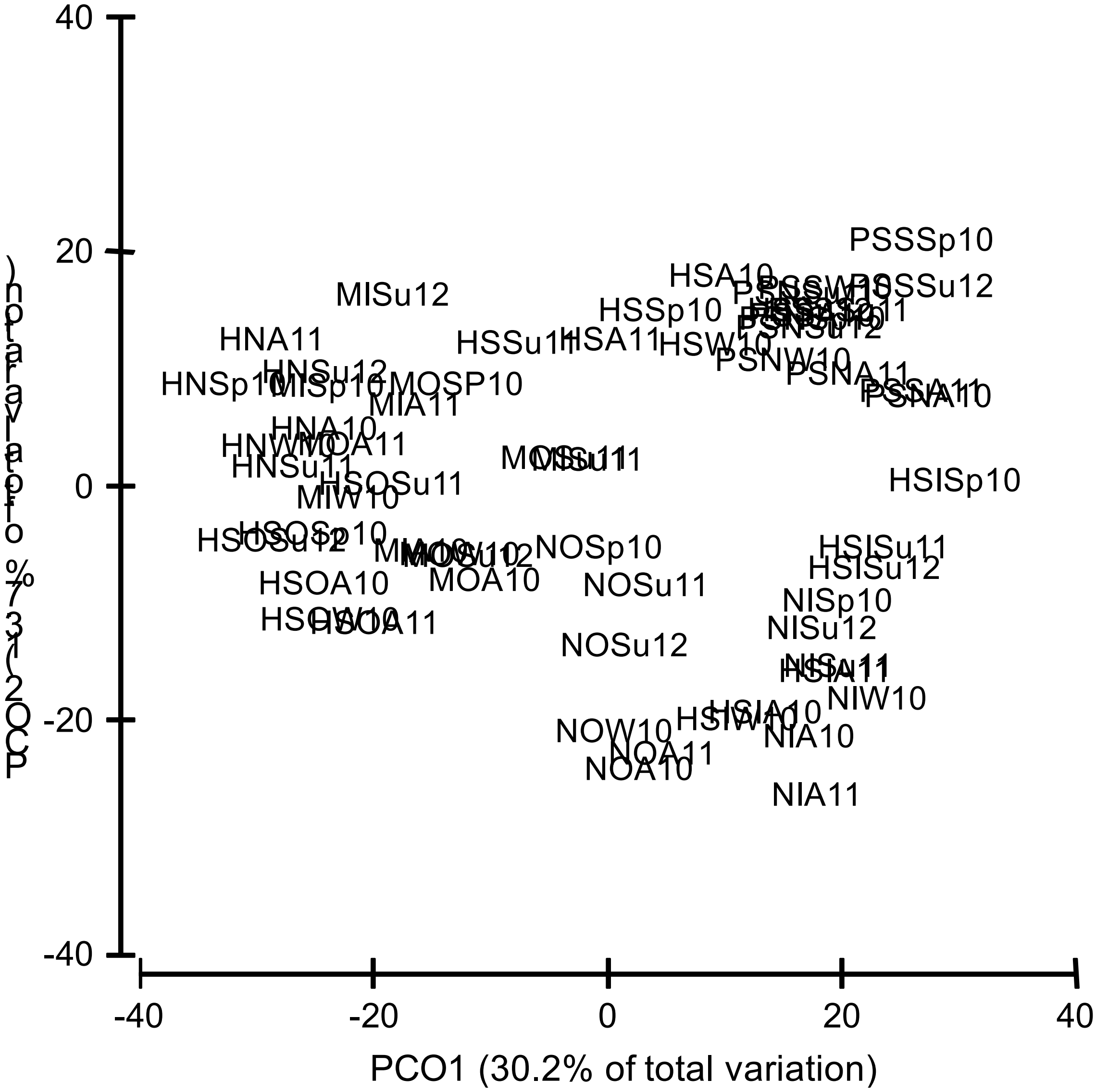


Figure 3. Principle coordinates ordination (PCO) plot of the benthic assemblages of invertebrates at the 10 study sites and 6 seasons. Site and season abbreviations as for Figure 2.

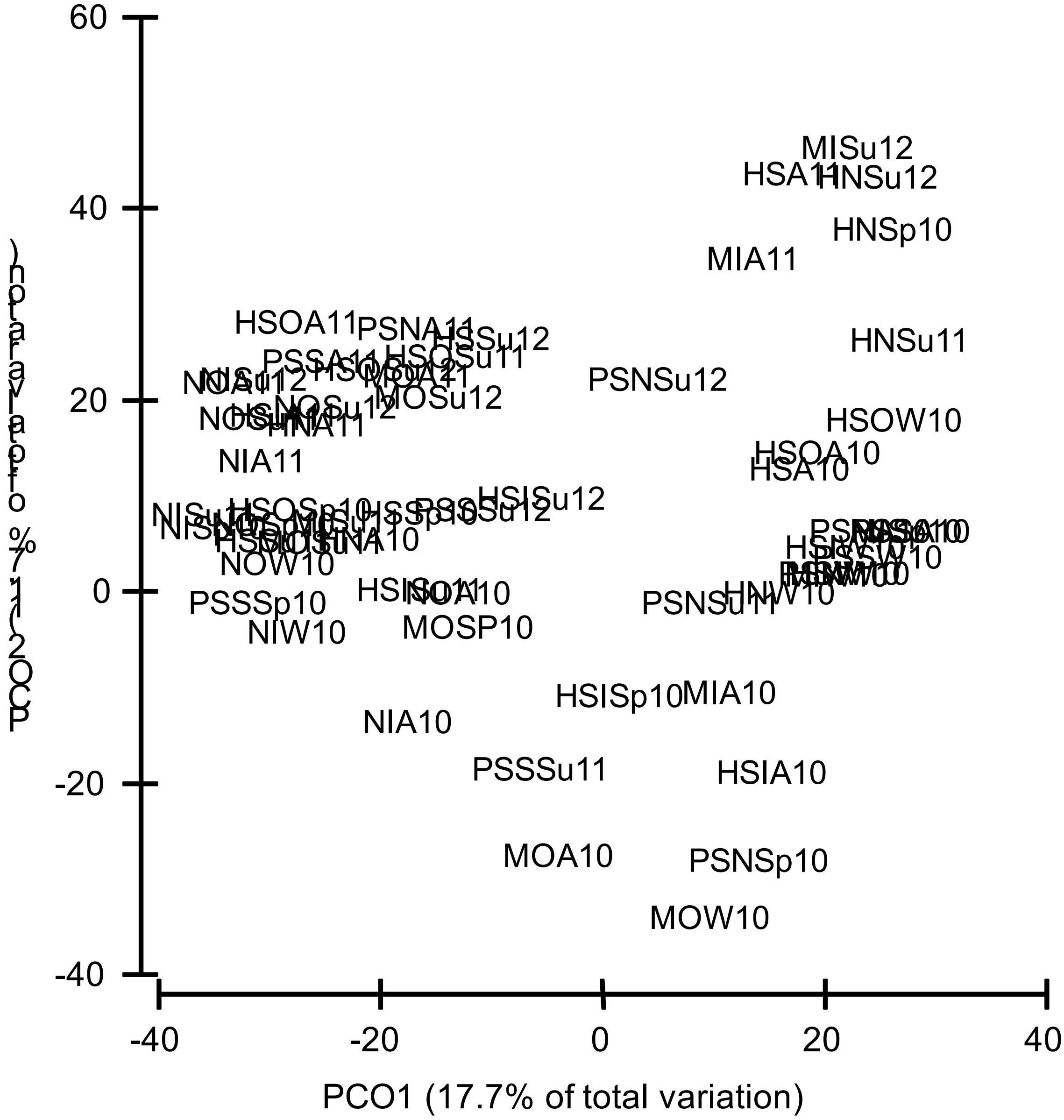
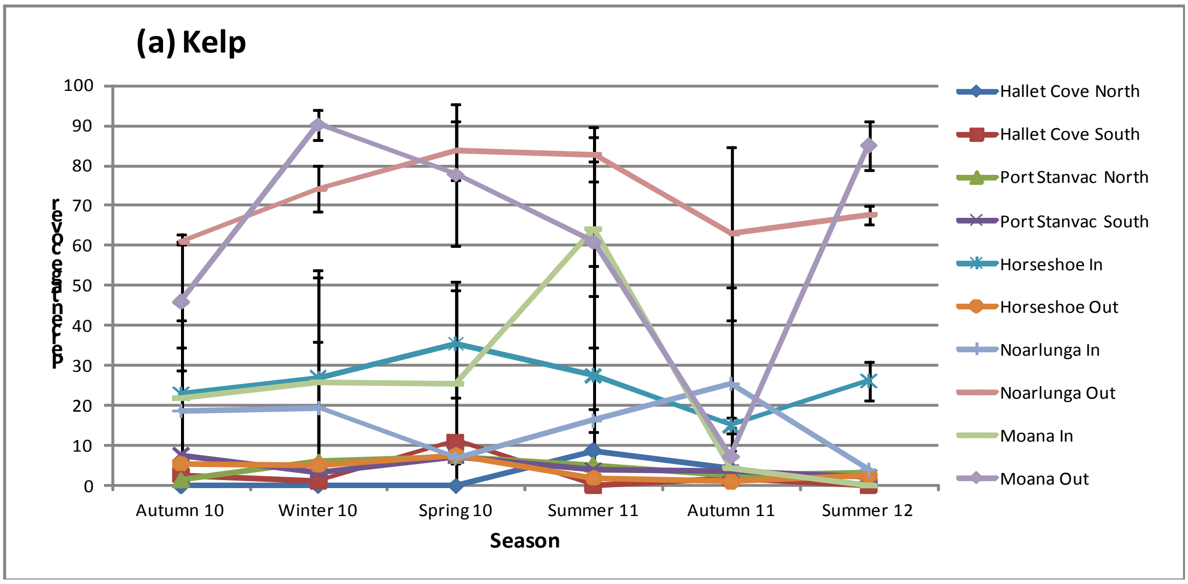
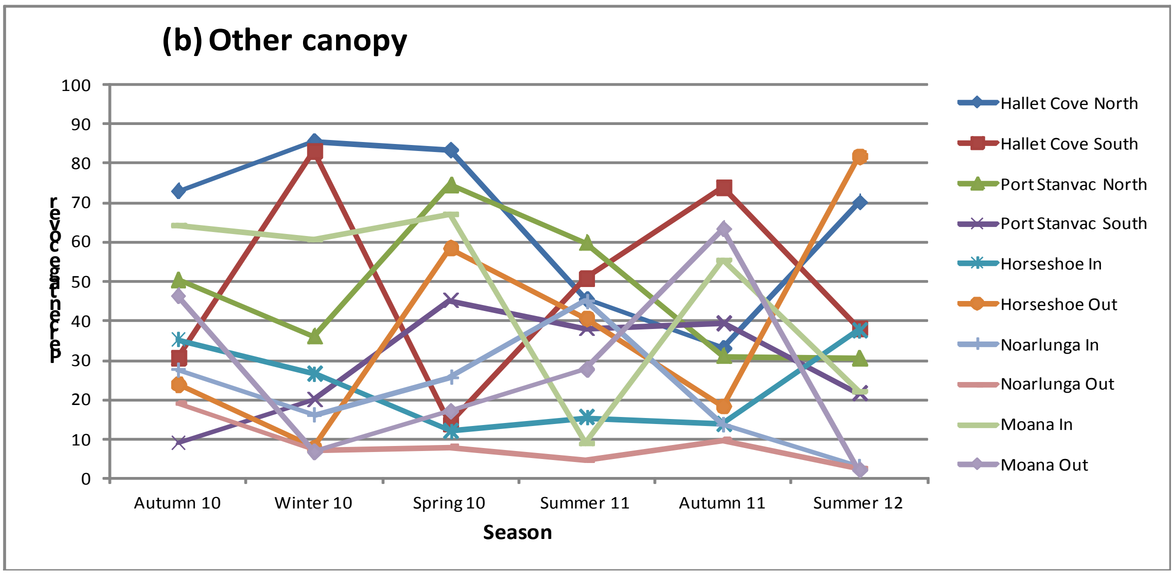


Figure 4. Principle coordinates ordination (PCO) plot of assemblages of fish at the 10 study sites and 6 seasons. Site and season abbreviations as for Figure 2.





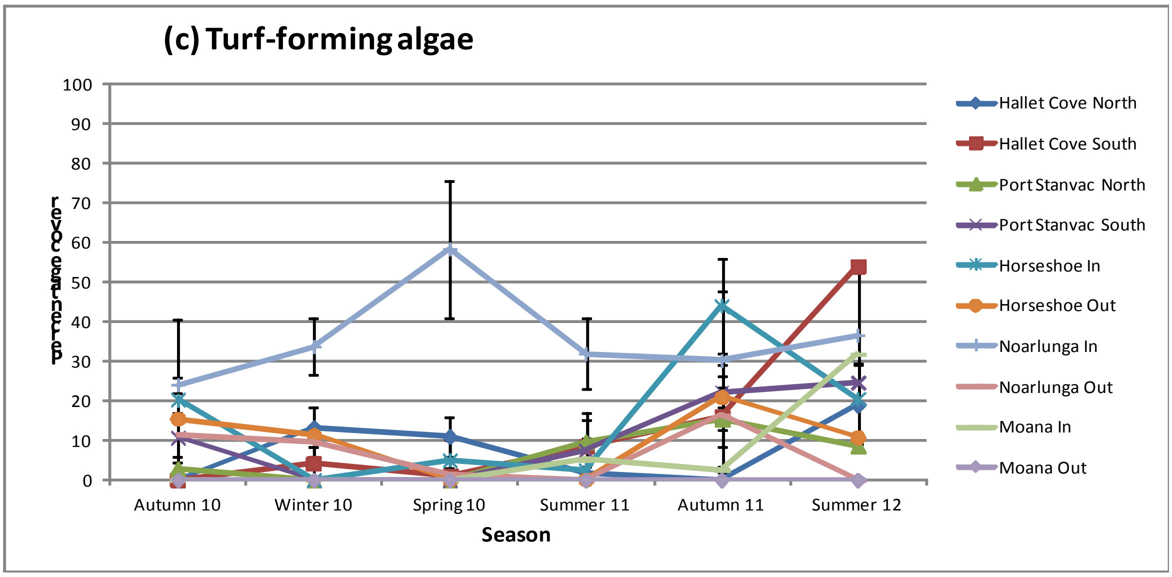


Figure 5. Plots of percentage cover of (a) kelp, (b) canopy-forming algae and (c) turf-forming algae across the 10 sites and 6 seasons. Note that standard error bars are not presented in (b) for clarity.

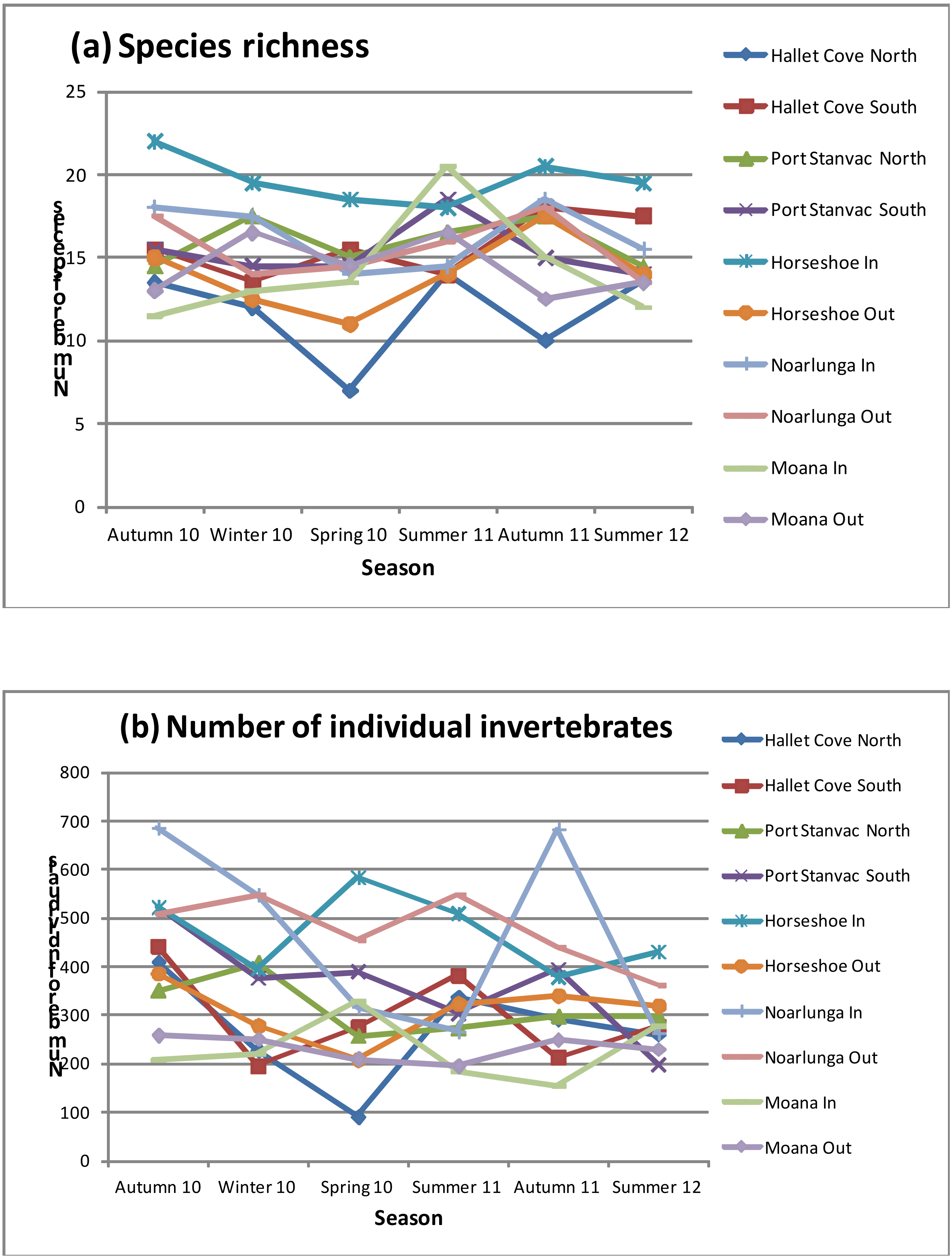
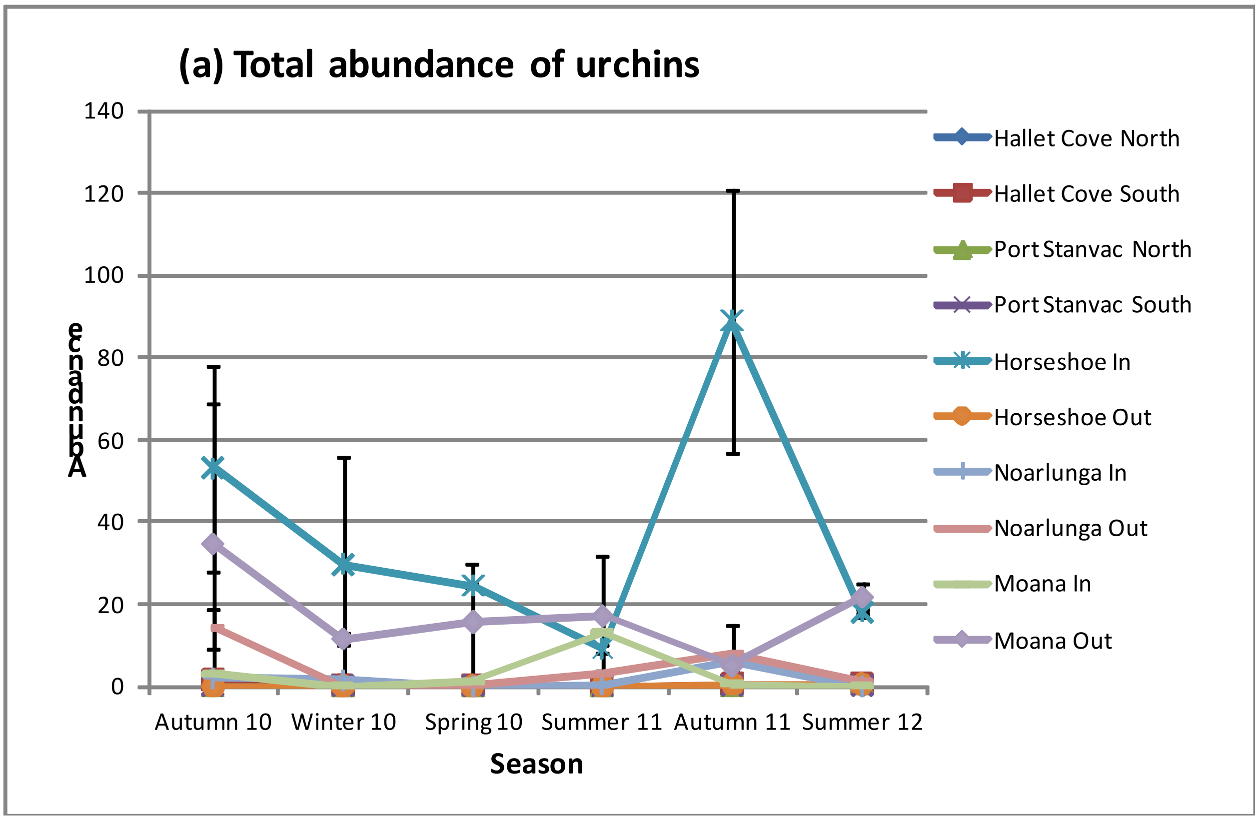


Figure 6. Plots of (a) species richness (total number of species) and (b) total number of all individuals of invertebrates across the 10 sites and 6 seasons. Note that standard error bars are not presented for clarity.



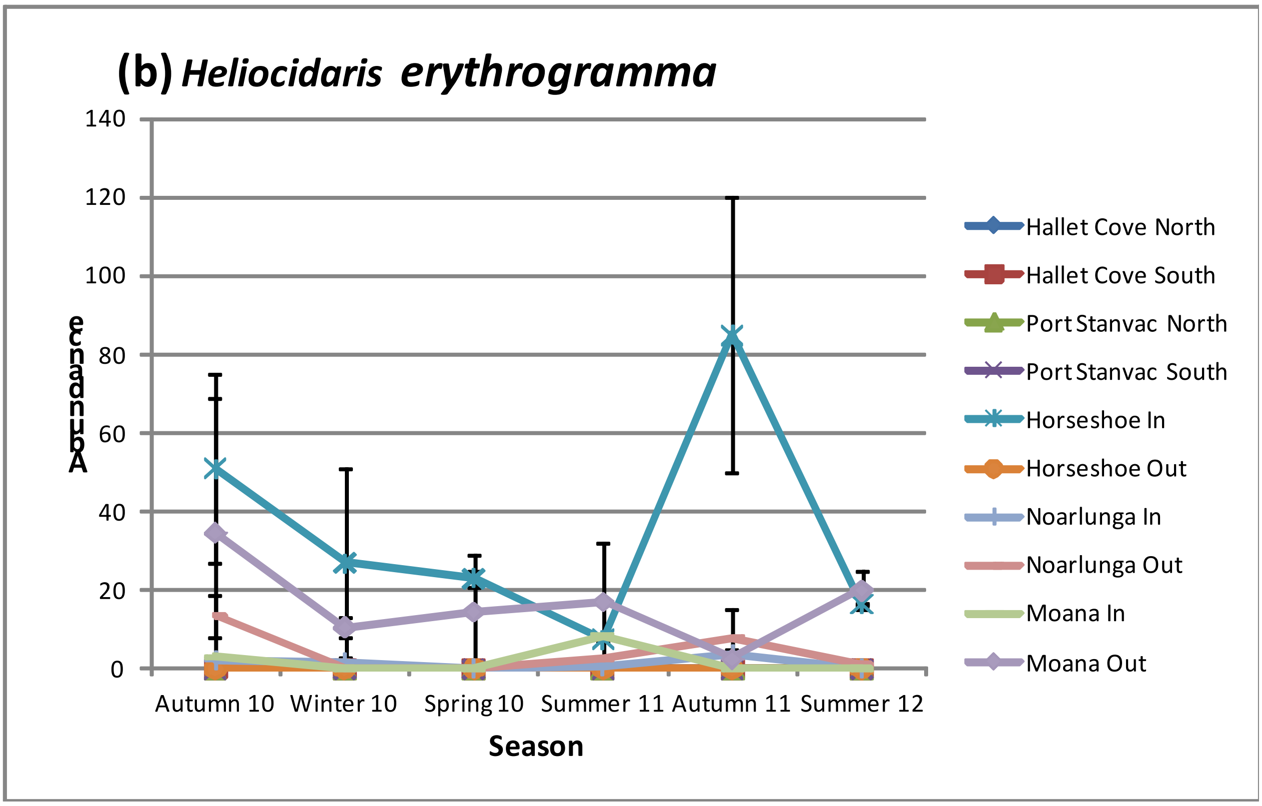


Figure 7. Plots of abundance (50 × 1 m transects) of urchins for (a) total number of all individuals and (b) *Heliocidaris erythrogramma* across the 10 sites and 6 seasons.

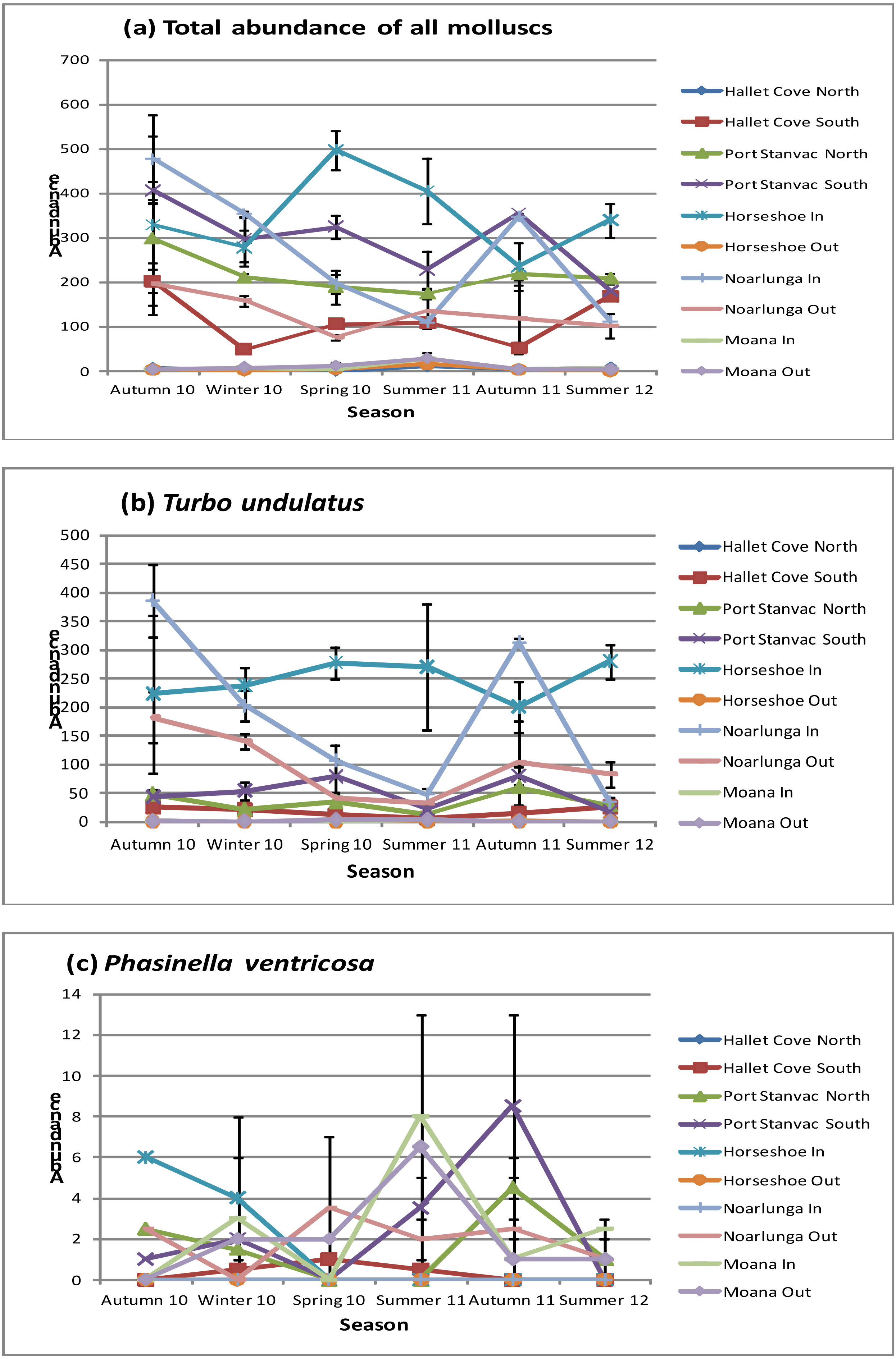
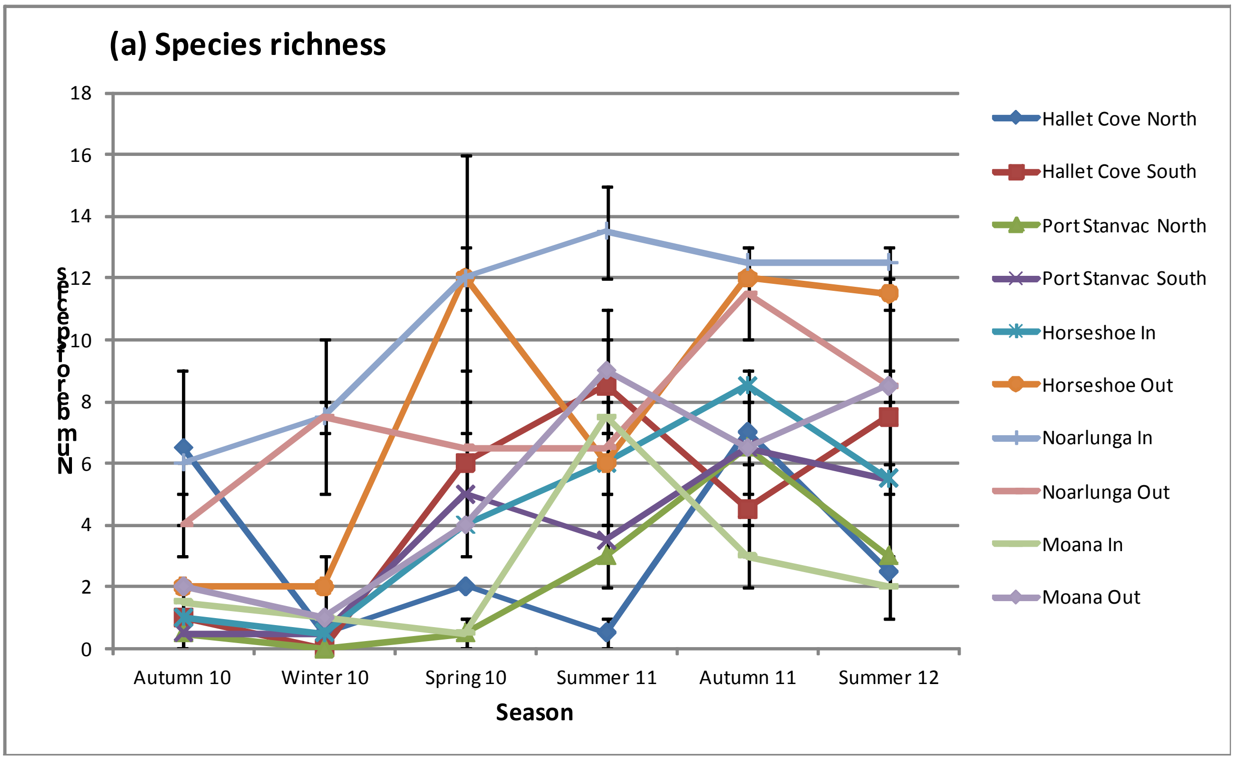


Figure 8. Plots of abundance (50 × 1 m transects) of molluscs for (a) total number of all individuals, (b) *Turbo undulatus* and (c) *Phasinella ventricosa* across the 10 sites and 6 seasons.



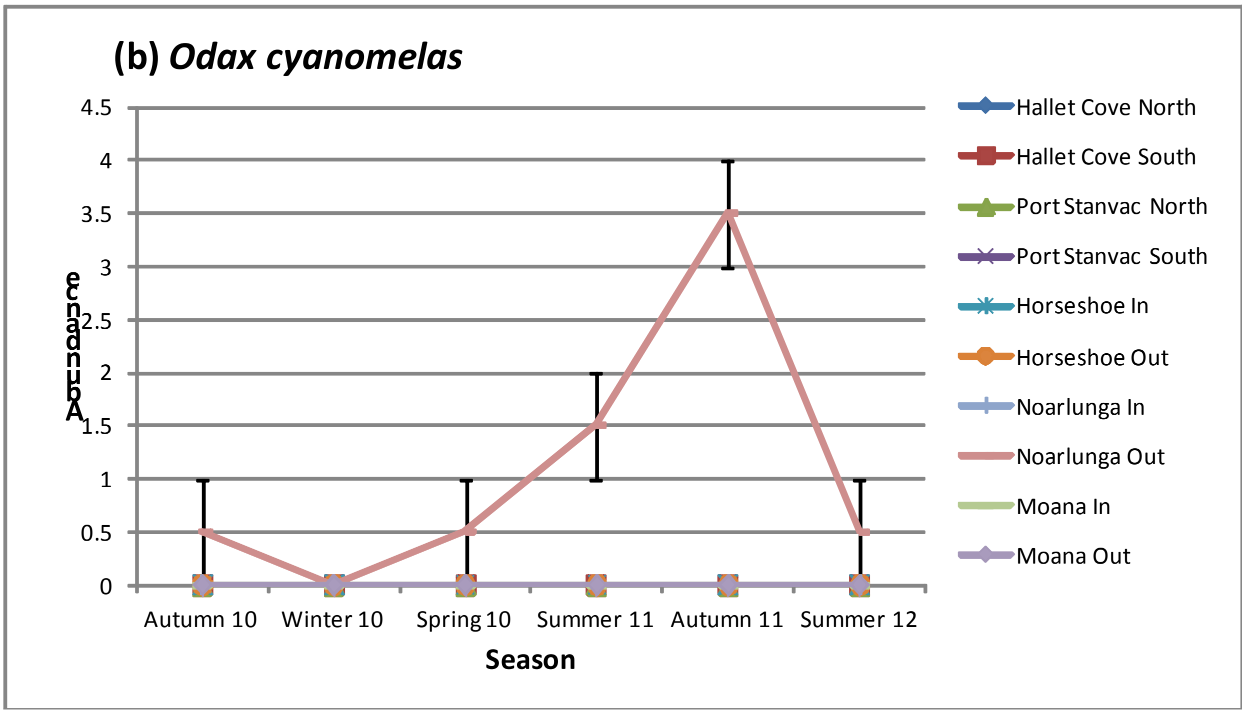
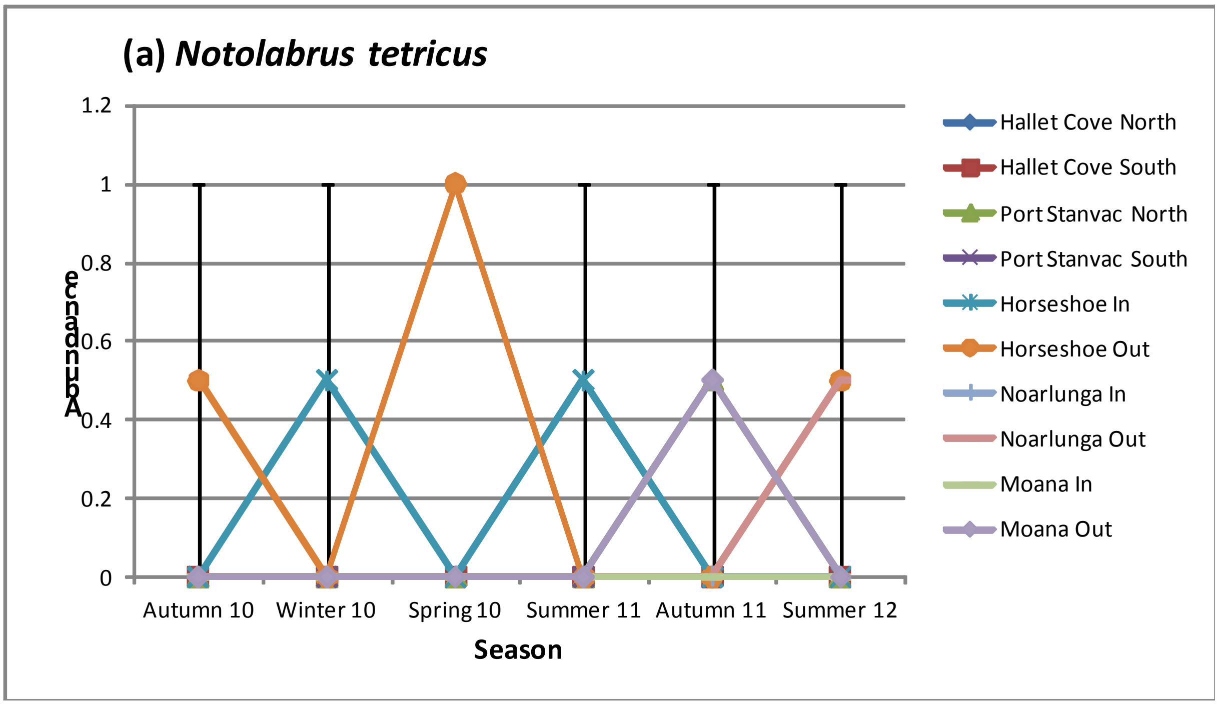


Figure 9. Plots of (a) fish species richness (total number of all species) and (b) abundance of *Odax cyanomelas,* across the 10 sites and 6 seasons.



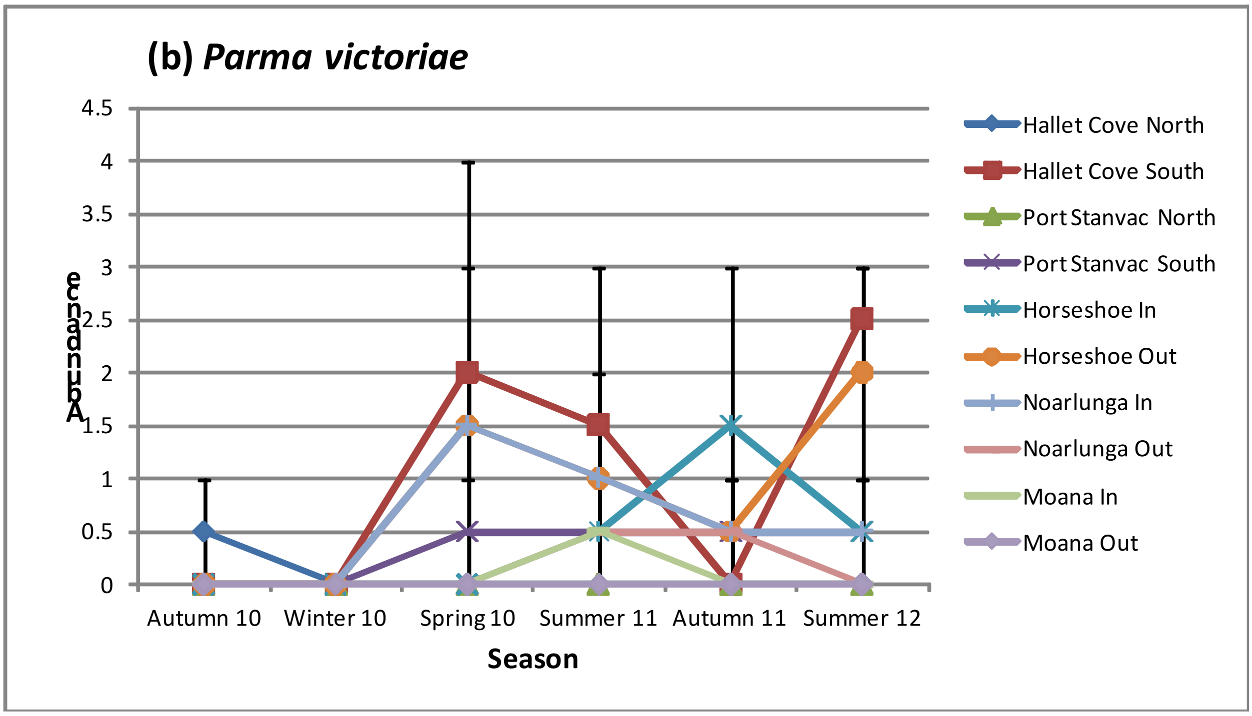


Figure 10. Plots of abundance of fish for (a) *Notolabrus tetricus* and (b) *Parma victoriae* across the 10 sites and 6 seasons.

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