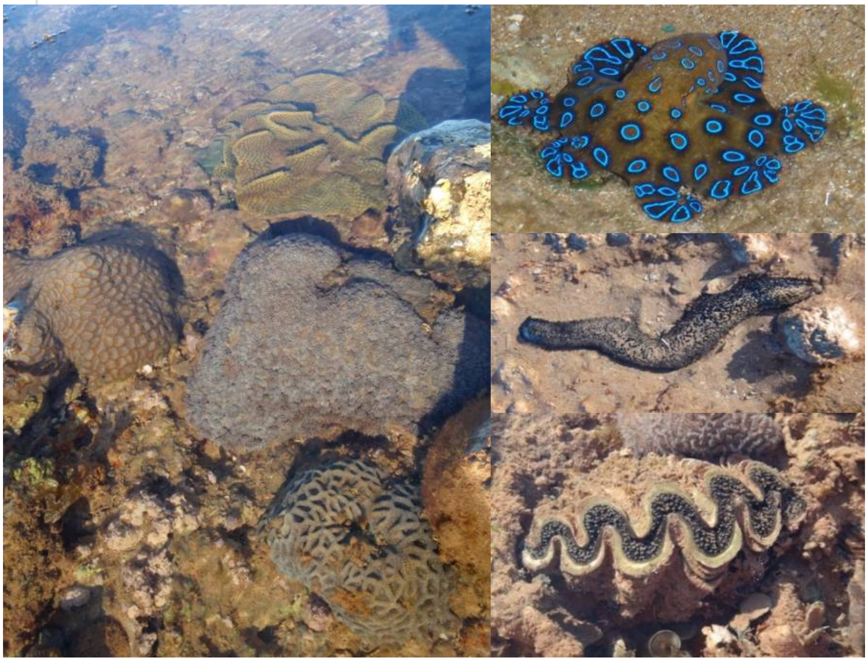
SINCLAIR KNIGHT MERZ

SKM

Rio Tinto

Cape Lambert Port B Development



BASELINE INTERTIDAL REPORT

Revision 2

20 August 2009

Cape Lambert Port B Development

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The sole purpose of this report and the associated services performed by SKM is to provide the findings from a baseline study undertaken in accordance with the scope of services set out in the contract between SKM and the Client (Rio Tinto). That scope of services, as described in this report, was developed with the Client.

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The baseline results are based on four separate surveys, one in each season over a 12 month period.

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Executive Summary

The baseline intertidal study was completed over a 12 month period to describe the temporal and spatial variability in benthic life form composition on intertidal reef platforms in the Cape Lambert region, with an aim to develop a monitoring method that could assist in detecting potential impacts from future dredging programs.

Results from the baseline monitoring program found that the reef pavements at Cape Lambert were temporally and spatially dynamic. The hard substrates were characterised by fine silt to coarse sand, turf algae, macroalgae, hard and soft corals, sponges and *Brachidontes* sp. The distribution and abundance of benthic taxa recorded at Samson Beach and West Reef were variable between seasons, among areas within sites and heights on the shore, predominantly due to differing periods of inundation and underlying heterogeneity of the reef.

There was a high degree of spatial and temporal variability in terms of benthic composition among sites, within sites and times. Benthic categories that displayed marked seasonality included macroalgae, in particular *Sargassum* sp. and *Cystoseira* sp. These genera dominated the reef flat at the southern end of Samson Beach and the northern end of West Reef during late summer to autumn. Seasonally shifting sand sheets associated with dominant areas of turf algae were responsible for temporal changes identified between spring and summer.

Results to date show significant differences between times and within sites sampled, demonstrating great variability in the intertidal communities growing on the reef pavements at Cape Lambert.

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1. Introduction

The proposed Cape Lambert Port B development will involve a significant dredging and spoil disposal program that requires the removal of up to 16 Mm^3 of benthic material. The dredging and spoil disposal program may potentially influence water quality and in turn benthic habitats in close proximity to the development, including intertidal habitats.

A baseline study was completed over a 12 month period to describe the temporal and spatial variability in benthic life form composition on intertidal reef platforms at Cape Lambert. Samson Beach and West Reef (**Figure 1**) were selected as case studies.

This intertidal study constitutes part of an overarching baseline monitoring program described in the Port B Dredging and Spoil Disposal Management Plan (DSDMP; SKM 2009a). The larger program includes a seasonal baseline subtidal study and a comprehensive water quality monitoring program. The following report summarises the findings from the four surveys undertaken seasonally, approximately every 3 months, over a 12 month period.

1.1. Background

Intertidal hard substrates can be ecologically diverse, providing habitat for benthic primary producers (BPP) and an abundance of sessile and mobile benthic organisms (Connell et al. 1997). The Environmental Protection Authority (EPA) classifies BPP as predominantly marine plants including seagrasses, mangroves, seaweeds and turf algae but in addition, includes scleractinian corals that have a symbiotic relationship with phytoplankton embedded in their tissue (EPA 2004). Based on the visual survey undertaken by SKM in March 2008 (SKM 2008), macroalgae and turf algae dominate large expanses of the intertidal platforms around Cape Lambert.

Cape Lambert is located in the north-west of Western Australia where the local oceanic conditions are strongly influenced by the macrotidal environment and prevailing regional winds, which promote shallow water mixing and the suspension of sediments. The local water quality is temporally and spatially variable, depending on the location’s bathymetry, exposure to prevailing winds and the proximity to shallow water environments and mangrove stands.

The tides in this region are semi-diurnal with a slight diurnal inequality and a defined spring neap cycle (Pearce et al. 2003). The tidal regime is likely to be the defining predictable factor that might influence the distribution of intertidal BPP and other benthic taxa in the Cape Lambert region. This is because the difference in tidal height between successive tides determines the periods of emersion and inundation and consequently the likelihood of desiccation. A study of the subtidal Benthic Primary Producer Habitat (BPPH) at a number of monitoring sites around Cape Lambert found that sedimentation, turbidity and temperature were driving factors of the benthic cover found (SKM 2009b). These environmental factors are influenced by the tides and weather experienced in the region.

1.2. Aims

The seasonal intertidal surveys were proposed as a means to collect baseline data on the current condition of the intertidal platforms, and in particular sensitive BPPH (EPA 2004) in the Cape Lambert region.

The aim of this study was to record a baseline data set that describes the condition and temporal and spatial variations in the benthic composition on the intertidal platforms in the Cape Lambert region using Samson Beach and West Reef as case studies. The program has been developed to assist in the detection and monitoring of natural and anthropogenic changes to benthic habitats. In order to achieve this, the following null hypotheses were tested:

- overall ecological interaction:
  - H_0: There is no change in the percent cover of benthic taxa between seasons, between sites, between areas within sites, and at different heights on the shore
- spatial variability:
  - $H_0 1$: There is no difference in community composition between sites, between areas within sites and height on the shore during any season
  - $H_0 2$: There is no clear sequence of community change between heights on shore during any season.
- temporal (seasonal) variability:
  - H_0: There is no difference in the percent cover of benthic taxa at Samson Beach or at West Reef between seasons.

Note that 'height on the shore' represents the distance (m) from the upper intertidal to the spring tide low water mark.

1.3. Report Structure

The report is structured as follows:

- **Section 1**: Provides the aims and objectives of the intertidal baseline report
- **Section 2**: Summarises the methods used to survey the intertidal reef platforms
- **Section 3**: Details the statistical analyses performed
- **Section 4**: Describes and presents the results from the seasonal surveys
- **Section 5**: Provides a discussion on the significance of the results recorded
- **Section 6**: Provides a conclusion on the findings of this report

2. Methods

This section provides details on the sites that were selected for the study:

- where, when and how the seasonal surveys were undertaken;
- how the methods were modified over the course of the four surveys; and
- how the survey data were quantified using digital imagery and statistical software.

2.1. Site Selection

The intertidal region at Cape Lambert is characterised by rocky platforms, mud flats and mangrove communities. Two large rocky intertidal platforms exist at Samson Beach and West Reef, these were selected as the most appropriate for monitoring due to the large expanses of hard substrate, their distance from existing infrastructure and accessibility (**Figure 1**).

The Samson Beach survey area (~1 km in length) is located approximately 2.5 km (direct line) south east to the beginning of the existing jetty (base), adjacent to the Point Samson township. There is a large amount of community interest to ensure the aesthetic value of the beaches and recreational areas around Point Samson are retained. The monitoring of the intertidal platform in combination with the water quality monitoring (SKM 2009c) directly offshore ensures any changes over time are documented.

The West Reef survey area (~400 m in length) is located approximately 4.5 km (direct line) south west of the existing tug pen, south of the Port Walcott Yacht Club on Boat Beach and north of Mangrove Point (a nominated water quality monitoring location).

Figure 2 illustrates the characteristics of each of the intertidal platforms and defines the zones of interest.

2.2. Timing

The baseline data set was obtained from four surveys undertaken over a period 12 months:

- Survey 1 - July 2008 (winter) – initial set up survey
- Survey 2 - September 2008 (spring)
- Survey 3 - February 2009 (summer)
- Survey 4 - April 2009 (autumn).

Surveys were timed to coincide with spring low tides on the following dates (**Table 1**).

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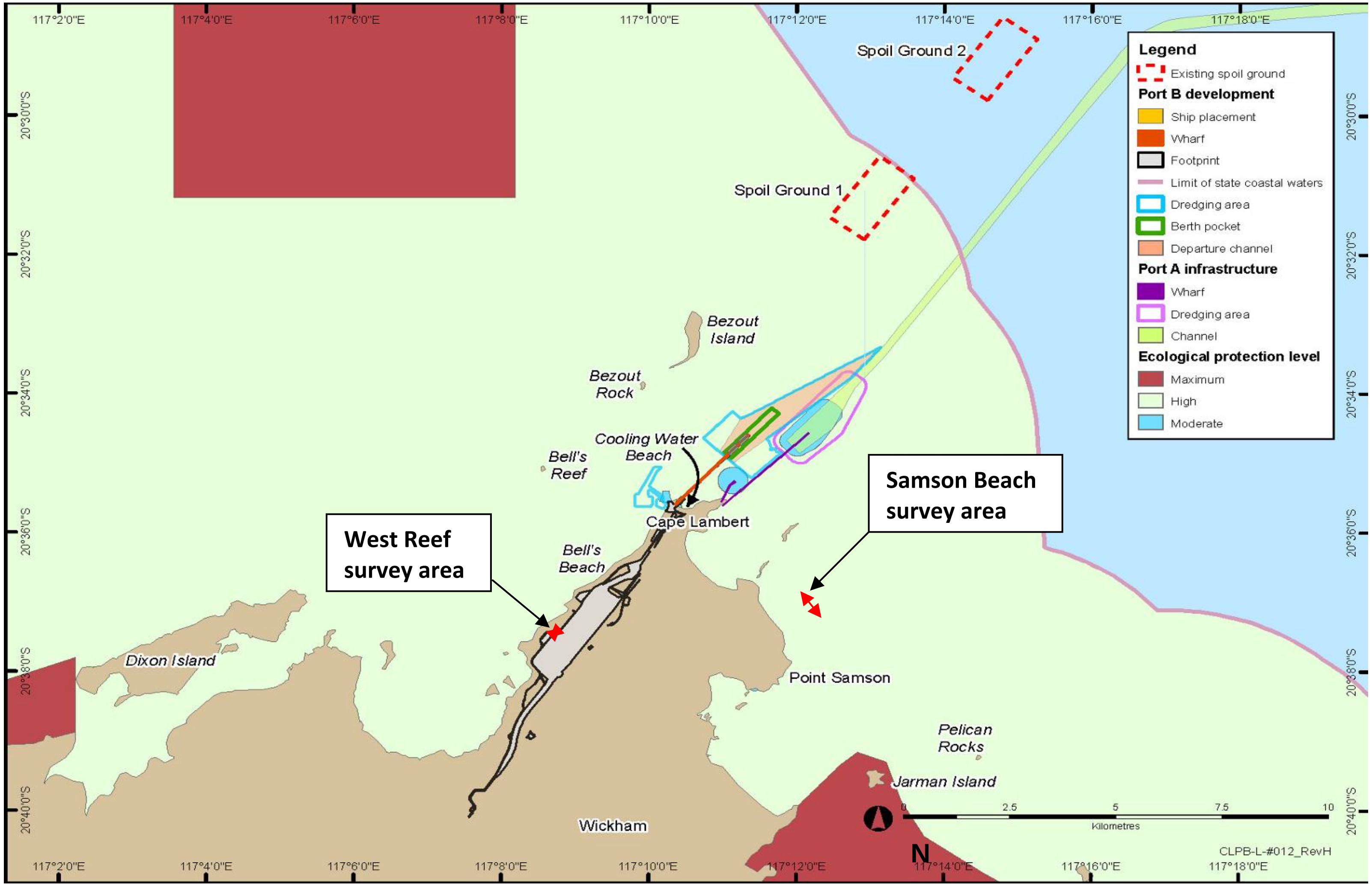
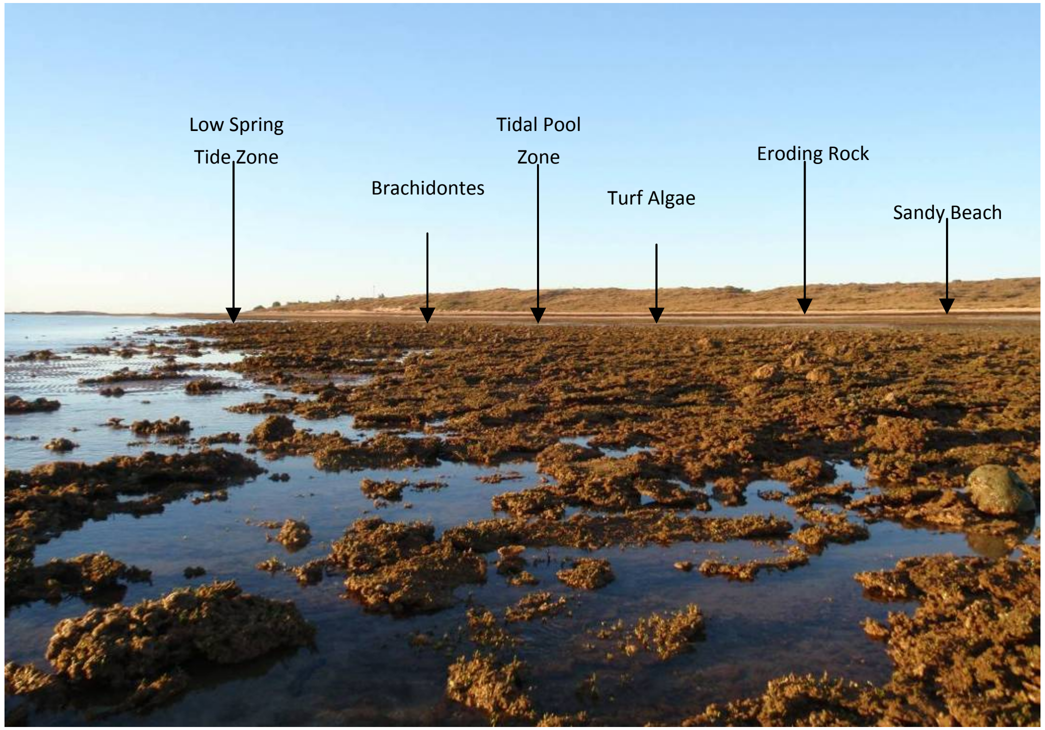
- **Table 1 Predicted tidal height at time of sampling for each survey**

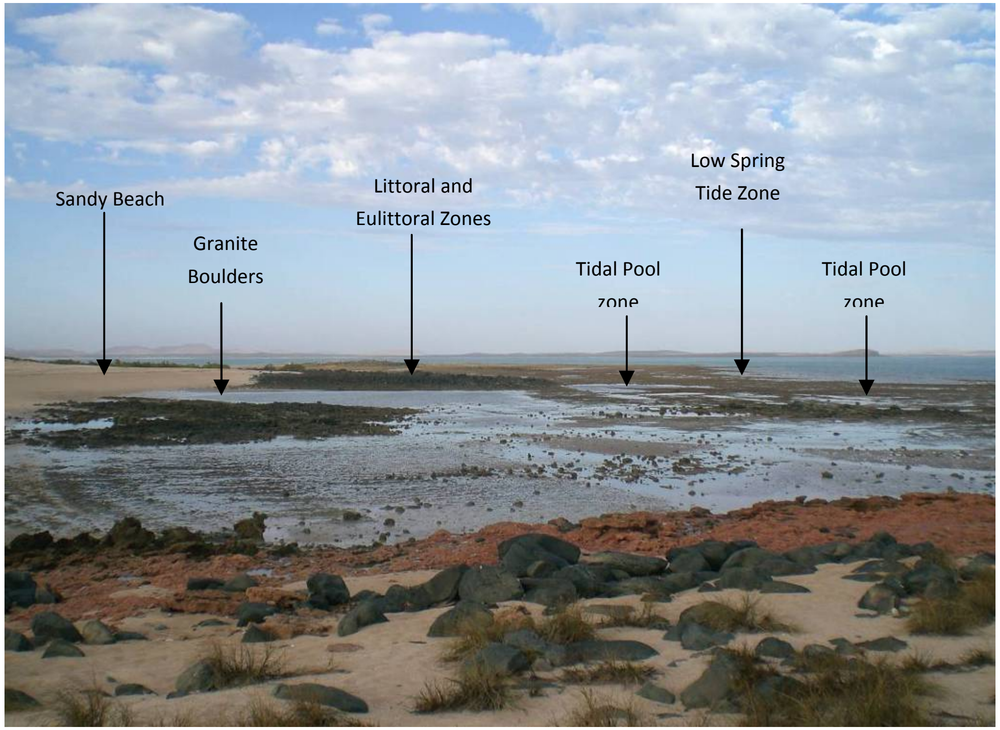
	Survey 1 (Winter)			Survey 2 (Spring)		
Area Surveyed	**Date**	**Time**	**Predicted Tide Height (m)**	**Date**	**Time**	**Predicted Tide Height (m)**
Samson Beach T1	21-07-08	19:08	0.8	18-09-08	06:35	0.3
Samson Beach T2	22-07-08	07:17 / 19:37	1.3 / 0.9	18-09-08	18:45	0.7
Samson Beach T3	23-07-08	07:49	1.3	19-09-08	07:06	0.3
West Reef T1	23-07-08	20:05	1.0	17-09-08	06:05	0.5
West Reef T2	24-07-08	08:23	1.3	17-09-08	18:16	0.6
	Survey 3 (Summer)			**Survey 4 (Autumn)**		
Area Surveyed	**Date**	**Time**	**Predicted Tide Height (m)**	**Date**	**Time**	**Predicted Tide Height (m)**
Samson Beach T1	10-02-09	17:53	1.2	26-04-09	17:57	0.6
Samson Beach T2	11-02-09	06:15	0.5	25-04-09	17:24	0.8
Samson Beach T3	11-02-09	18:30	0.9	25-04-09	17:24	0.8
West Reef T1	12-02-09	06:49	0.4	27-04-09	06:01	1.3
West Reef T2	12-02-09	06:49	0.4	24-04-09	16:51	1.2

Source (Seafarer, 2009)



- **Figure 1 Cape Lambert intertidal survey areas**





- **Figure 2 Intertidal reef platform at Samson Beach (A) and West Reef (B)**

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2.3. Permanent Transects

Permanent transects were established on the intertidal hard substrate at Samson Beach and West Reef to the south-east and south-west of the existing Cape Lambert jetty, respectively. Three transects were fixed at Samson Beach and two at West Reef. The length of each transect varied on each survey as it was dependant on the gradient of the reef pavement, and extended from the upper shore to the lowest point exposed by the spring low tide (i.e. perpendicular to the shore). Permanent pegs were hammered into the reef pavement at designated distances along the transect seaward. A measuring tape was attached to each of the permanent pegs to provide a reference along the transect.

Photographs of the permanent quadrats (50 cm x 50 cm) were taken at designated distances along the transects, usually 10 m apart (depending on the presence of a tidal pool). Quadrats are square sampling devices that are placed on the platform and digitally photographed to record a representative sample of the benthos, without having to harvest the area (see **Figure 3** as example).

- **Figure 3 Example of quadrats (50 cm x 50 cm)**

A series of ten quadrats (each 50 cm x 50 cm) were randomly placed and photographed within an area defined by each 20 m length of the tape (i.e. 0–20 m, 20–40 m, and so on). Five quadrats were randomly placed either side of the transect tape within a 10 m wide strip on either side of the tape. For example, for the section of the tape between 20 m and 40 m, five quadrats were randomly deployed each side of the tape, but always within 10 m of the tape. Thus the area surveyed for each section of the tape was always 20 m long x 20 m wide and so each set of ten quadrats were deployed randomly within an area of 400 m^2.

Note permanent quadrats were not analysed and included in this report as randomly placed quadrats ensure better characterisation of the larger reef community. In addition, analyses involving random quadrats are more powerful (replicate quadrats) and will essentially describe the same trends with more confidence.

2.4. Modification of Methods

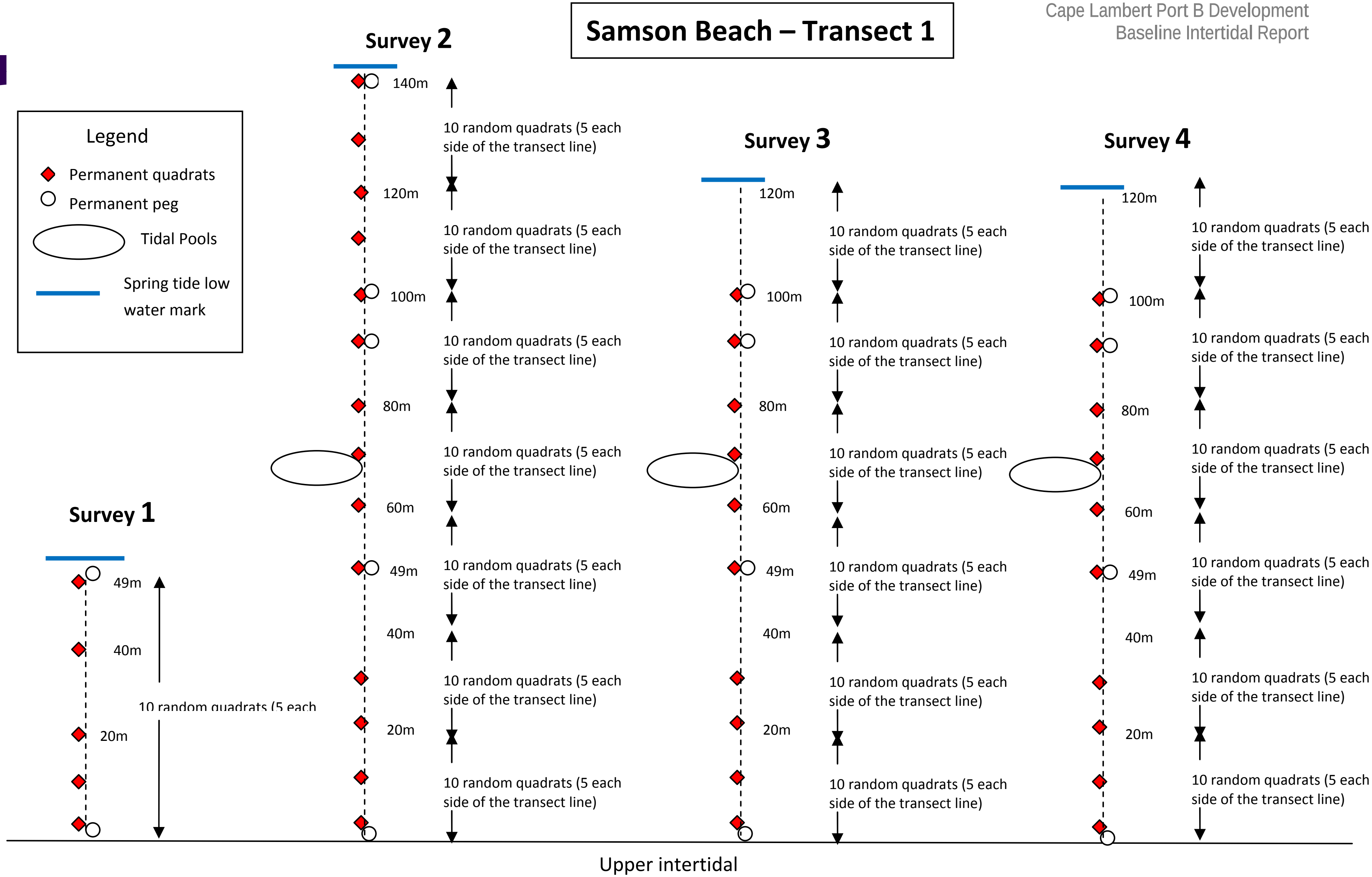
A critical part of this study was the development of a monitoring technique that could assist in detecting change through time. This meant that the techniques may require modification during the process to determine the most appropriate method.

Initially during Survey 1, Transect 1 and Transect 2 were established at Samson Beach. The original method assumed that the intertidal platform was divided into distinct zones dominated by a particular benthic category. As such, random quadrats were deployed in a given zone not determined by distance. For example, the assumed Brachidontes zone at Samson Beach was expected to exist between 40 m and 80 m seaward, and within this zone ten random quadrats were photographed. However, while surveying Transect 3 at Samson Beach, it was observed by the survey team that mixed zones existed and as such the methods were adapted in the field.

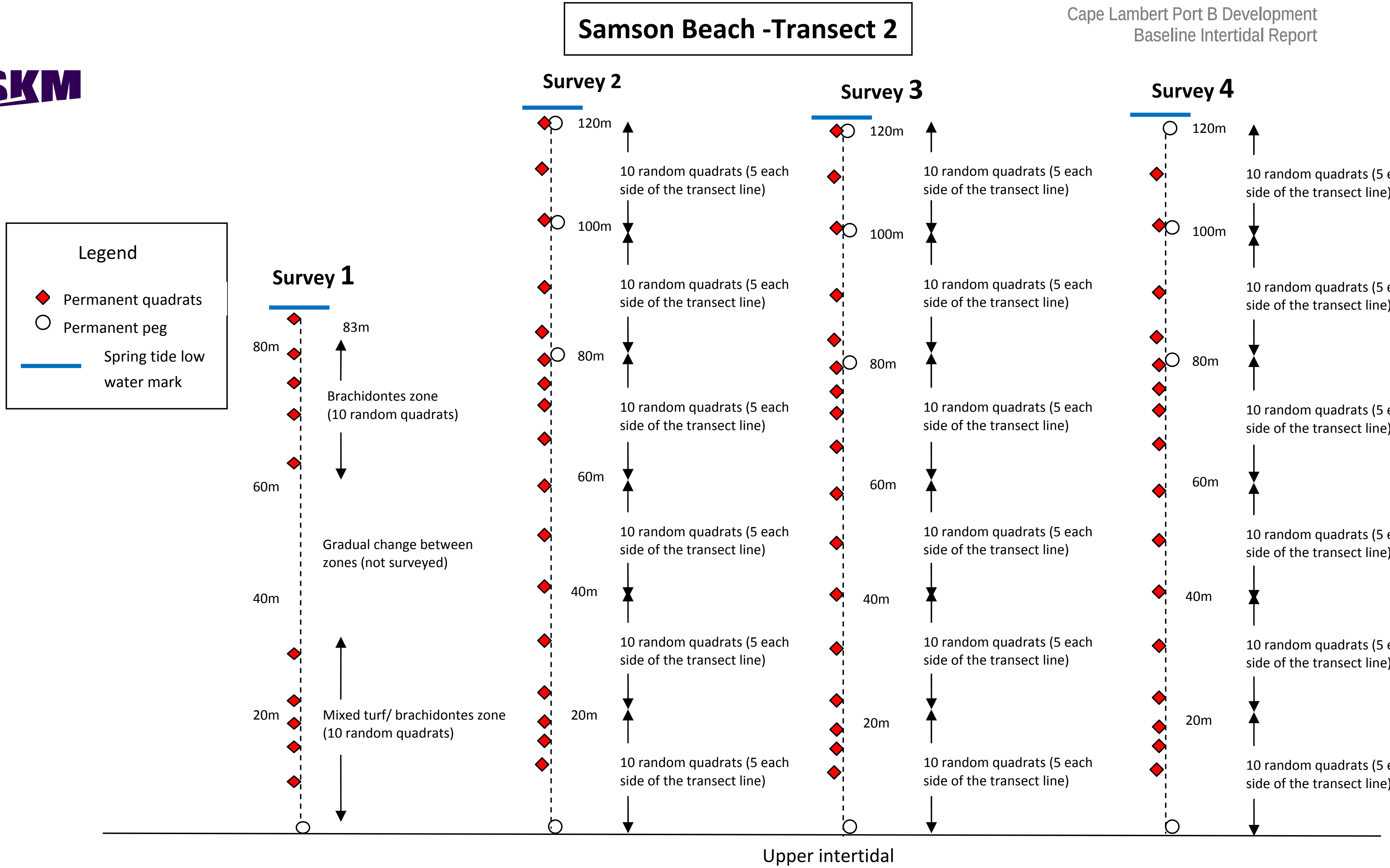
It was found that random quadrats deployed at regular intervals (0–20 m) were a better way to capture variation along transects, instead of trying to define definitive zones by an in situ visual assessment. This is because these zones or lack thereof were identified through statistical analyses. This also meant that the final design was balanced between transects, which made each transect statistically comparable (refer to **Section 3.5**).

Given the methods employed during Survey 1 were changed during the Survey, the winter data was removed from all multivariate statistical analyses. This is because these analyses require all transects to be surveyed using the same method so data is comparable. However, Survey 1 (winter) data were still analysed using univariate techniques to illustrate how benthic categories changed over space and time.

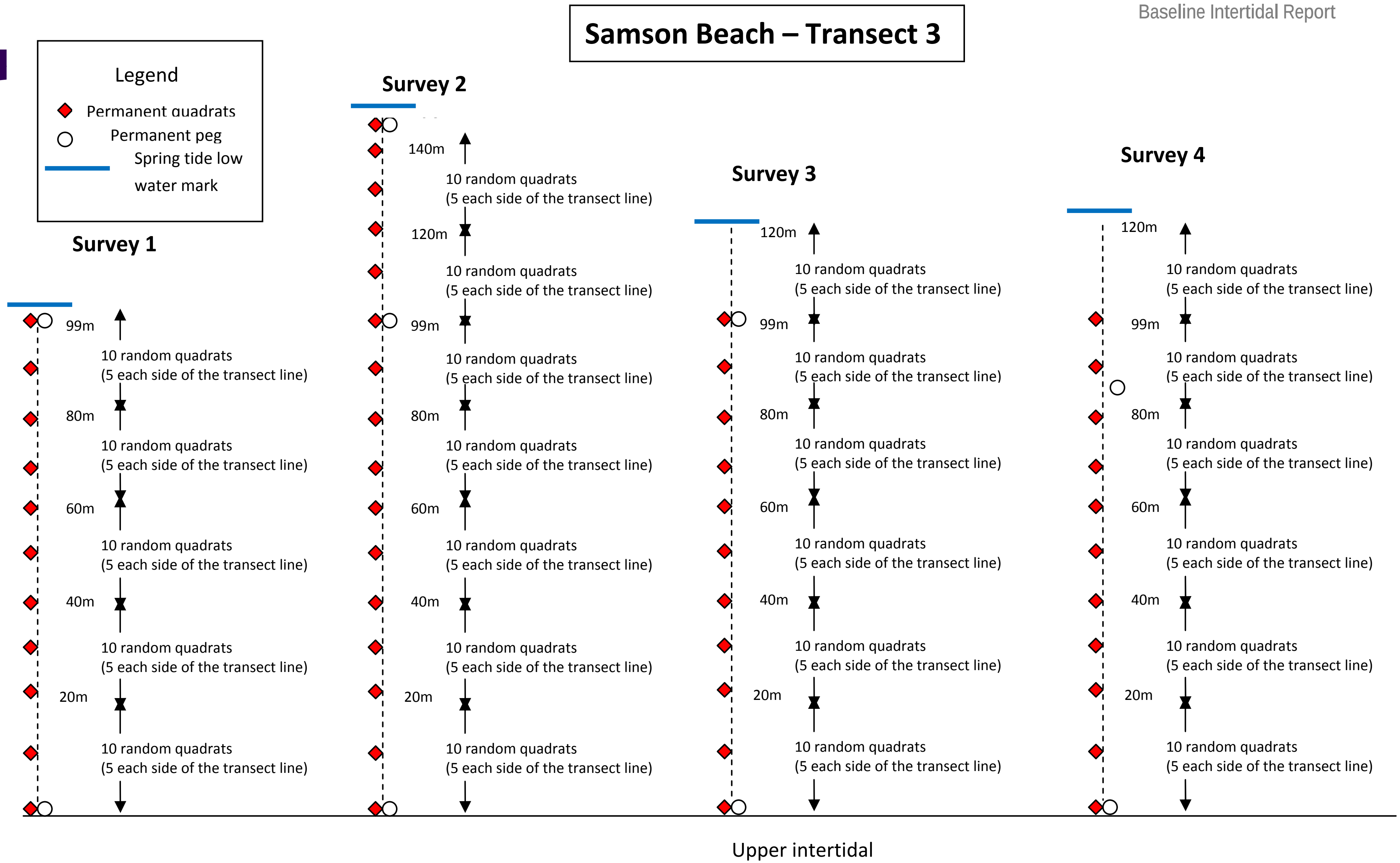
For a more detailed explanation see **Figure 4** through to **Figure 8**, which illustrate differences between the four surveys at each transect location. Note that survey methods did not change between Survey 2 and Survey 4, with the exception of the additional area surveyed due to the difference in the height of the spring low tides.



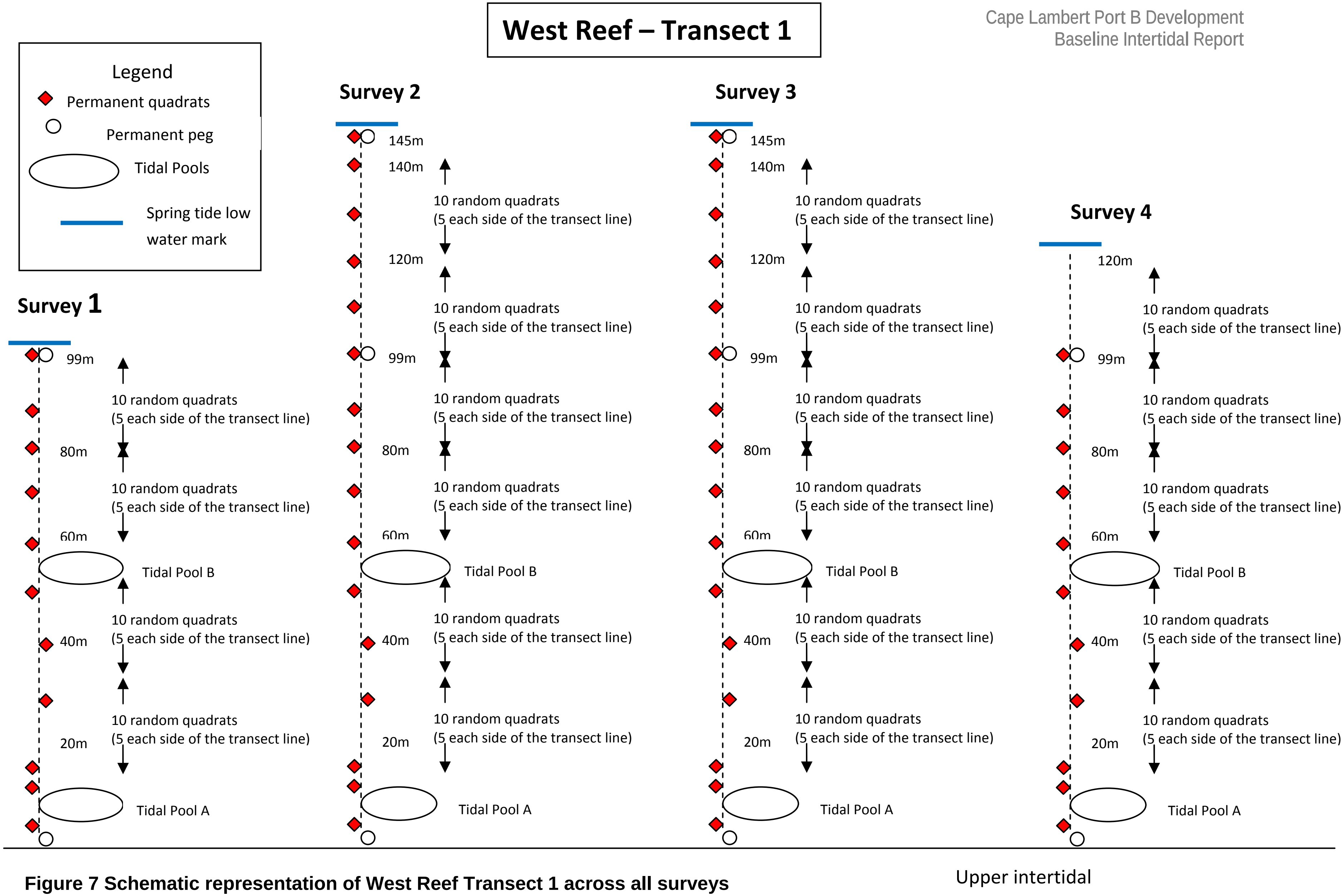
- **Figure 4 Schematic representation of Samson Beach Transect 1 across all surveys**



▪ **Figure 5 Schematic representation of Samson Beach Transect 2 across all surveys**

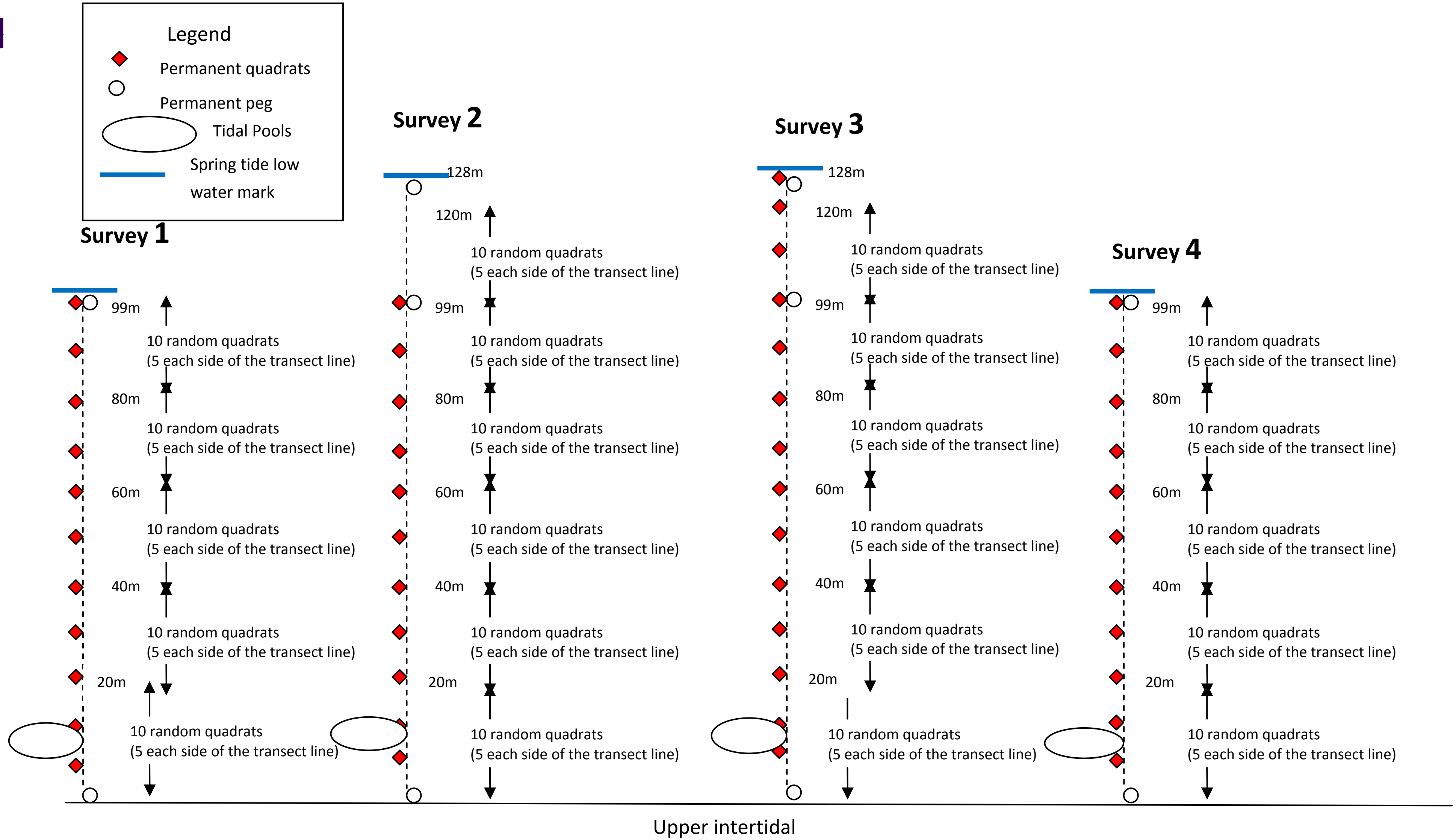


- **Figure 6 Schematic representation of Samson Beach Transect 3 across all surveys**



- **Figure 7 Schematic representation of West Reef Transect 1 across all surveys**

West Reef – Transect 2



- **Figure 8 Schematic representation of West Reef Transect 2 across all surveys**

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2.5. Digital Imagery Analysis

The digital images of individual quadrats from all transects at both sites were analysed using Coral Point Count (CPCe) Software using random point generation. A precision test was performed to determine the number of random points needed to precisely characterise the benthos. From this, 20 points were deemed sufficient and overlayed onto each image of the quadrat. Each point was then assigned to a category of biota or substrate type. These categories are listed in **Table 2**. Once all points on each quadrat were assigned, the percent cover of the different benthic categories was calculated. The results presented are based on the percent cover of the various benthic categories along each transect at both sites.

- **Table 2 Categories used in image analysis of permanent and random quadrats**

Categories	**Description**
Ascidian	Ascidians
Bare rock	Rock or bare substrate with no algae or coral
Brachidontes	Small mussels
Dead coral with algae	Dead coral with algae
Gorgonian	Sea whip / Sea fan
Hard Coral	Hard coral
Holothoridae	Sea cucumbers
Macroalgae	Large algae generally greater 5 mm in height
Rubble	Rubble–broken fragments of dead coral
Sand	Ranging from silt to coarse sand
Seagrass	Seagrass
Shadow	Shadow or bright spot
Shell	Shells
Soft coral	Soft coral
Sponge	Sponges
Tape	Quadrat frame
Tridacna	Clams
Turf Algae	Fine algae, generally filamentous smaller than 5 mm
Turf Sand	A mixture of turf algae and sand
Unknowns	Unknown, could not be identified

3. Statistical Analysis and Data Presentation

This chapter describes the statistical approaches used to summarise and test the data; the assumptions of these approaches; and guidelines to assist the reader to interpret the results presented in the next section.

3.1. Background

The overall aim of this baseline study was to assess how the intertidal composition changed seasonally (temporal variation) as well as among different sites, areas within sites and at varying heights on the shore (spatial variation). Temporal and spatial processes can have interacting effects on intertidal communities, and a primary objective was to assess the importance of such interactions in influencing community structure at the study locations. Achieving this required the use of statistical approaches to describe complex but ecologically important interactions.

An interaction occurs when the effects of one factor on the response variables are not the same across levels of another factor. However, interpreting higher order interactions involving many sources of variation (terms in the model) is not straightforward. Therefore, to aid interpretation, temporal and spatial sources of variation were examined separately. This chapter has been divided into three main sections: assessing ecological interactions; assessing spatial variation; and assessing temporal variation.

3.2. Assessing Ecological Interactions

This section provides the null hypothesis to be tested, the statistical approach used to test ecological interactions, a summary of the statistical test assumptions and the guidelines for interpretation.

3.2.1. Null Hypothesis

There is no change in the percent cover of benthic taxa between seasons, between sites, between areas within sites, and at different heights on the shore.

3.2.2. Statistical Approach and Assumptions

Permutational ANOVA (PERMANOVA) was used to assess complex ecological interactions in the data. PERMANOVA is a computer program for testing the simultaneous response of one or more variables to one or more factors in an ANOVA experimental design on the basis of any distance measure, using permutation methods. A full treatment of how it partitions the multivariate variation (defined by the distance measure used) according to individual factors is given in Anderson (2005). With traditional one-way ANOVA, the assumptions are that the errors are independent, that they are normally distributed with a mean of zero and a common variance, and that the treatment effects are additive. In the case of PERMANOVA test using permutations, the only assumption is that the observation units are exchangeable under a true null hypothesis. That is it assumes that the observation units are independent of one another both spatially and temporally (Anderson 2005). There are no explicit assumptions regarding the distributions of the original variables. Thus data

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are not assumed to be normally distributed. Although there is also no explicit assumption regarding the homogeneity of spread within each group, PERMANOVA will be sensitive to differences in spread (variability) among groups. Thus statistical difference might be due to differences in measure of central tendency and or due to dispersion of sampling units. PERMANOVA is considered an approved approach in the scientific literature as a tool to undertake multivariate statistics (Lear et al 2008).

3.2.3. Interpretation

The traditional way to report the results of a hypothesis test is to state that the null hypothesis was or was not rejected at a specified level of significance. For the purpose of this test, the significance of an interaction was based on the conventional 5% significance level (i.e. 0.05). This means that a p-value that is less than 0.05 is significant and therefore the null hypothesis would be rejected. More specifically, the weight of evidence against the null hypothesis is increased as the p-value approaches zero. The PERMANOVA output provides a P (perm) value for a given source. For example, if the benthic composition is significantly different between seasons, then this P (perm) value will be less than 0.05. It should be noted that convention holds that lower order effects should not be interpreted even if statistically significant. An interaction occurs when the effects of one factor, say site, on the response variables (different benthic species) are not the same across levels of another factor (e.g. season). **Table 3** provides a description of the sources of variation described by each term in the model.

Another approach to interpret the findings of this statistical model is to determine the relative contribution each term in the model makes in explaining the variation observed in this study. This approach is referred to as Components of Variation. Typically, terms that explain large amounts of variation will also be those terms that are statistically significant.

- **Table 3 Definition of sources of variation and interpretation table**

Source	Interpretation
Se	Seasonal variation
si	Site variation
di	Distance from shore variation
Tr(si)	Area variation within sites
Sexsi	Season by site interaction e.g. communities at both West Reef and Samson Beach change seasonally but in opposite trajectories
Sexdi	Season by distance interaction e.g. communities at different distances from shore change seasonally but in opposite trajectories
sixdi	Site by distance interaction
Sextr(si)	Season by site interaction but change is not consistent among replicate transects
tr(si)xdi	Distance by site by site interaction but change is not consistent among replicate transects
Sexsixdi	Season by site by distance interaction
Sextr(si)xdi	As above, but change is not consistent among areas in the same site

Source	Interpretation
Res	Variation among quadrats

3.3. Assessing Spatial Variation

This section provides the null hypothesis to be tested, the statistical approach used to test spatial variation, a summary of the statistical test assumptions and the guidelines for interpretation.

3.3.1. Null Hypotheses

Two null hypotheses relating to spatial variation in the data set were investigated:

- $H_0$1: There is no difference in community composition between sites, areas within sites and height on the shore during any season
- $H_0$2: There is no clear sequence of community change between heights on the shore during any season

3.3.2. Statistical Approach and Assumptions

To assess the first hypothesis, an ordination approach called non-metric multidimensional scaling (nMDS) and analysis of similarity (ANOSIM) was used. nMDS and ANOSIM are non-parametric multivariate techniques (Clarke and Gorley, 2006). Sample similarities were calculated with the Bray-Curtis coefficient, after square-root data transformation. This was done to reduce the influence of benthic life forms characterised by relatively large abundances. nMDS was used to produce two-dimensional ordination plots. One-way ANOSIM (Clarke and Gorley, 2006) was used to provide formal tests of the null hypotheses relating to spatial variation.

To assess the second hypothesis, an index of multivariate seriation in PRIMER 6 was used. Seriation is a term used to define the serial change in benthic assemblages on intertidal platforms as a result of natural processes where mixed zones exist. This term has been used in place of zonation which implies clear cut patterns and discontinuous bands of different benthic assemblages (Clarke and Warwick 2001).

3.3.3. Interpretation

The primary goal of ordination methods is to reduce the dimensionality of a large data set with many response variables in order to allow the most obvious patterns and structures to emerge. With nMDS, the samples are mapped (usually in two dimensions) in such a way that the rank distances between sample pairs reflect the relative dissimilarity of benthic composition. Thus, sites that are close together on the nMDS plot share similar benthic communities and those far apart share different benthic communities.

To compress the ordinations to two dimensions for reporting results in a loss of the clarity of data (i.e. sites may appear close to each other in two dimensional space but were not close in the original ordination). The stress value on each of the MDS ordinations in this report is a measure of how well the two dimensional ordination truly represents the multi dimensional ordination. Stress values greater than 0.25 indicate that the ordination does not provide a true representation of the replicates and should be treated with caution.

ANOSIM tests produce a statistic (R-statistic) that lies in the range (-1 to 1). R is a very useful statistic for interpretation because it is not unduly influenced by sample size. R = 1 only if all replicates within sites are more similar to each other than any replicates from different sites. R is approximately zero if the null hypothesis is true, so that similarities between and within sites will be the same on average (Clarke and Gorley, 2006).

An R value close to zero (i.e. a weak trend) may be statistically significant because it is consistent but not of great value in interpreting data (Clarke and Warwick 2001). Consequently, SKM chose *a priori* to interpret significant trends (i.e. significance < 5%) as: weak (R value of 0 to 0.3); moderate (R value of 0.3 to 0.6); and strong (R value of 0.6 to 1.0).

The index of seriation provides a p-value, with significance based on the conventional 5% significance level. The seriation index assesses the extent to which samples follow a simple trend, with adjacent samples being the closest in benthic composition, samples two distances apart the next closest and so on, with benthic assemblages from the first and last distance differing the most.

Seriation was also visually assessed using univariate figures created in Excel. These figures are provided as a visual aid to assess how different benthic organisms change at heights on the shore over time.

3.4. Assessing Temporal Variation

This section provides the null hypothesis to be tested, the statistical approach used to test the temporal variation, a summary of the statistical test assumptions and the guidelines for interpretation.

3.4.1. Null Hypothesis

The following null hypothesis relating to temporal variation in the data set was investigated:

- $H_0$1: There is no difference in the percent cover of benthic taxa at Samson Beach or at West Reef between seasons.

3.4.2. Statistical Approach and Assumptions

To assess the degree of temporal variability ANOSIM in PRIMER 6 was used. ANOSIM is an analysis of similarity and in this case pair wise comparisons between seasons. Sample similarities were calculated with the Bray-Curtis coefficient, after square-root data transformation. This was done to reduce the influence of benthic life forms characterised by relatively large abundances. One-way ANOSIM (Clarke and Gorley, 2006) was used to provide formal tests of the null hypotheses relating to spatial variation.

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3.4.3. Interpretation

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Where results were identified as significantly different, with a mid range R statistic, nMDS plots were visually examined. Evidence of seasonal change was based on the clustering or dispersion of replicate quadrats from the same season.

3.5. Data Pre-Treatment and Manipulation

For the purpose of analysis replication, the following notes on data manipulation are provided:

- winter (Survey 1) was removed from all multivariate statistical analyses because all transects were not surveyed using the same method (as outlined in **Section 2.4**) and therefore the data was not comparable between sites and seasons. However, this did not exclude winter data from being analysed by univariate methods as illustrated in **Appendix B**
- all data that were collected in the 0-20 and >100 distance categories were removed, as again, it was not always comparable across all areas within sites surveyed
- data retained as replicate quadrats for residual term – lowest level of replication
- square root transformation applied to reduce the influence of comparatively ‘over’ dominant benthic types
- Bray Curtis resemblance applied
- four factor model used:
  - season (3 levels – spring, summer, autumn) fixed variable depending on the time of year
  - site (2 levels – Samson Beach, West Reef) treated as a random factor because the aim is to make generalities to other intertidal areas at Cape Lambert beyond the two study sites
  - transects (5 levels – Samson Beach T1, T2, T3, West Reef T1, T2) random factors nested in sites
  - distance (4 levels – 20-40 m, 40-60 m, 60-80 m, 80-100 m) fixed.
- season crossed with transects nested within site and crossed with distance = Season x Transects (site) x Distance
- all default PERMANOVA settings used i.e. reduced model, type 3 sums of squares.

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4. Results

This section provides a summary of the dominant taxa identified on the intertidal reef platforms and the results from the hypotheses tests described in **Section 3**.

4.1. Taxa Present

The flora and fauna recorded on the reef pavement at Samson Beach and West Reef were comprised of macroalgae, turf algae, seagrass, *Brachidontes* sp., corals, sponges, *Tridacna* sp. and Holothurians. Within these categories, certain taxa were dominant and these have been provided in **Table 4** and illustrated in **Appendix A**.

- **Table 4 Benthic categories and associated dominant taxa present**

Category	Dominant taxa
Macroalgae	*Padina gymnospora* *Caulerpa racemosa* *Halimeda lamouroux* *Hydroclathrus clathratus* *Sargassum* sp. *Cystoseira* sp.
Turf algae	Species unknown (Chlorophyta and Phaeophyta)
Seagrass	*Thalassia hemprichii*
Brachidontes sp.	*Brachidontes ustulate*
Corals	*Acropora* sp. (hard) *Turbinaria* sp.(hard) *Mussidae* (hard) *Faviidae* (hard) *Porites* sp. (hard) *Lobophytum* sp. (soft)
Sponges	*Cinachyra* sp.
Tridacna sp.	*Tridacna maxima*
Holothurians	*Holothuria leucospilota* *Holothuria atra*

4.2. Ecological Interactions

A primary aim was to assess the importance of how temporal and spatial sources of variation interacted together to influence change in intertidal communities at the study locations. Simply put, does the time of year and area on the reef flat affect which benthic organisms dominate?

The test results show that the Se x tr(si) x di interaction is statistically significant at the 5% significance level with a P(perm) value of 0.001 (**Table 5**). A significant result provides evidence that the composition of the benthic communities are changing differently among seasons (Se) and among replicate transects (tr) in the same site (si), and that the differences are not consistent among heights on the shore. In summary the results show that the intertidal platforms are a dynamic environment.

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- **Table 5 PERMANOVA table of results**

Source	df	SS	MS	Pseudo-F	P(perm)*	Perms**
Se	2	51419	25709	14.539	0.068	180
si	1	97727	97727	2.3794	0.21	30
di	3	48238	16079	1.1082	0.504	850
tr(si)	3	1.24E+05	41220	41.609	**0.001**	998
Sexsi	2	3536.6	1768.3	0.22493	0.944	999
Sexdi	6	16851	2808.5	0.8851	0.601	999
sixdi	3	43528	14509	1.4783	0.173	997
Sextr(si)	6	47330	7888.4	7.9629	**0.001**	999
Tr(si)xdi	9	88665	9851.7	9.9446	**0.001**	997
Sexsixdi	6	19038	3173.1	1.5471	0.101	997
Sextr(si)xdi	18	37013	2056.3	2.0757	**0.001**	999
Res	549	5.44E+05	990.65			
Total	**608**	**1.12E+06**				

** Statistically significant at the 0.05 level is shown in bold.*

*** Means number of permutations*

When completing statistical analyses of this type, it is important to assess the contribution of each interaction to the level of variability observed. On its own, the season, height on shore interaction (Se x tr(si) x dis) explained 4.52% of the variation (**Table 6**). However, variation among replicate quadrats (the residual term) contributed the greatest amount of variation. For example, ten random (replicate) quadrats in the 0 – 20 m area could all be very different in regard to the percent cover of each benthic category (turf algae could vary between 0 – 100% cover).

- **Table 6 Estimates of components of variation**

Source	Estimate*	% contribution to total
S(Se)	124.03	5.31
V(si)	195.68	8.38
S(di)	10.845	0.46
V(tr(si))	332.25	14.24
V(Sexsi)	0	0.00
S(Sexdi)	0	0.00
V(sixdi)	64.851	2.78
V(Sextr(si))	170.86	7.32
V(tr(si)xdi)	292.58	12.54
V(Sexsixdi)	46.499	1.99
V(Sextr(si)xdi)	105.47	4.52
V(Res)	990.65	42.45
Total	**2333.715**	**100**

**Note that negative values were replaced by zeros*

4.3. Spatial Variation

This section details how benthic taxa changed over the reef platforms in Cape Lambert. Overall spatial variability was tested to assist in identifying the differences between sites and areas within a site. Seriation was tested, to identify if benthic taxa (i.e. turf algae, macroalgae etc) changed in dominance seaward down the platform.

4.3.1. Overall Spatial Variation

Results from **Table 5** show that West Reef does not differ from Samson Beach in terms of benthic cover in any season (Si; P (perm) = 0.21). However, within each site, the benthic composition differs significantly (Tr(Si); P (perm) = 0.001) illustrating that intertidal platforms in the Cape Lambert region are heterogeneous, with benthic assemblages varying over small spatial scales (<100 m).

An ANOSIM test was performed to assist in identifying the driving factors behind this result (**Table 7**). For example, at Samson Beach, Transects 1 and 3 were significantly different during the autumn survey (R Stat 0.704; p-value 0.001) as can be seen in **Figure 9**, which shows a marked separation of the green and blue symbols. This result has been attributed to the abundance of macroalgae (*Sargassum* sp. and *Cystoseira* sp.) that dominated the upper intertidal at only the southern end of Samson Beach and the northern end of West Reef during autumn.

- **Table 7 ANOSIM Pair wise tests between areas within each season**

Season*	Spring		Summer		Autumn	
Groups	**R Stat**	**P-value**	**R Stat**	**P-value**	**R Stat**	**P-value**
Areas Surveyed	0.26	0.001	0.224	0.001	0.321	0.001
SB T1 and T2	0.088	0.001	0.059	0.009	0.274	0.001
SB T1 and T3	0.182	0.001	0.355	0.001	**0.704**	**0.001**
SB T1 and WR T1	0.41	0.001	0.208	0.001	0.237	0.001
SB T1 and WR T2	0.347	0.001	0.351	0.001	0.504	0.001
SB T2 and T3	0.087	0.001	0.136	0.001	0.159	0.001
SB T2 and WR T1	0.468	0.001	0.26	0.001	0.279	0.001
SB T2 and WR T2	0.185	0.001	0.23	0.001	0.152	0.002
SB T3 and WR T1	0.371	0.001	0.315	0.001	0.505	0.001
SB T3 and WR T2	0.1	0.001	0.213	0.001	0.247	0.001
WR T1 and T2	0.393	0.001	0.133	0.001	0.207	0.001

**Note the test was undertaken for each season to remove any compounding effects from seasonality*

*** Bold values represent a strong trend*

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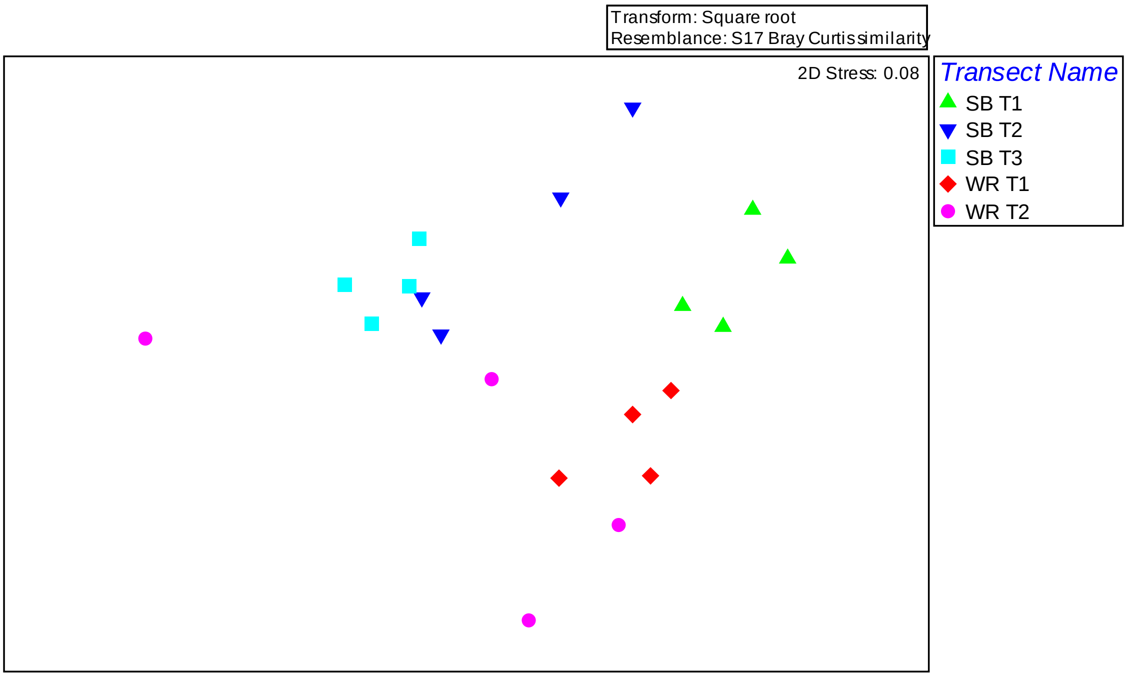

- **Figure 9 nMDS ordination between transects during Autumn (using averaged data) (SB = Samson Beach; WR = West Reef)**

4.3.2. Seriation Patterns

The intertidal zone at both Samson Beach and West Reef exhibited marked changes in benthic composition with height on the shore. There appeared to be no distinct zones; however, a gradient in benthic composition seaward was evident. The gradual serial change in benthic assemblages on intertidal platforms as a result of natural processes is known as seriation.

A test known as the index of seriation was completed to assess the significance of the seaward change (**Table 8**). It was found that during each season at Samson Beach Transect 1 and 2 and West Reef Transect 2, there was a significant (P-value <0.05) serial change in benthic taxa seaward as illustrated in **Figure 10** to **Figure 12**. For example, at Samson Beach, turf algae dominated the upper intertidal and decreased in percent cover moving seaward.

The driving factors behind the significant result for Samson Beach Transect 1 were the categories Brachidontes, turf sand, turf algae and sand (**Appendix B**). For Samson Beach Transect 2, the categories Brachidontes, macroalgae and turf sand were the most important discriminating categories. At West Reef Transect 2, the categories sponge, macroalgae, turf sand and turf algae were the most important discriminating categories (**Appendix B**).

West Reef Transect 2 was an outlier, as serial change in benthic assemblages was only significant during summer (**Table 8**). This is reinforced by the nMDS plot that illustrates no distinct pattern (**Figure 13**). The similarities between distant categories (i.e. 20 – 40 m and 80 – 100 m) have been attributed to the dominance of sponge, turf sand and turf algae that are reasonably consistent, in terms of benthic cover, at varying heights on the shore (**Appendix B**).

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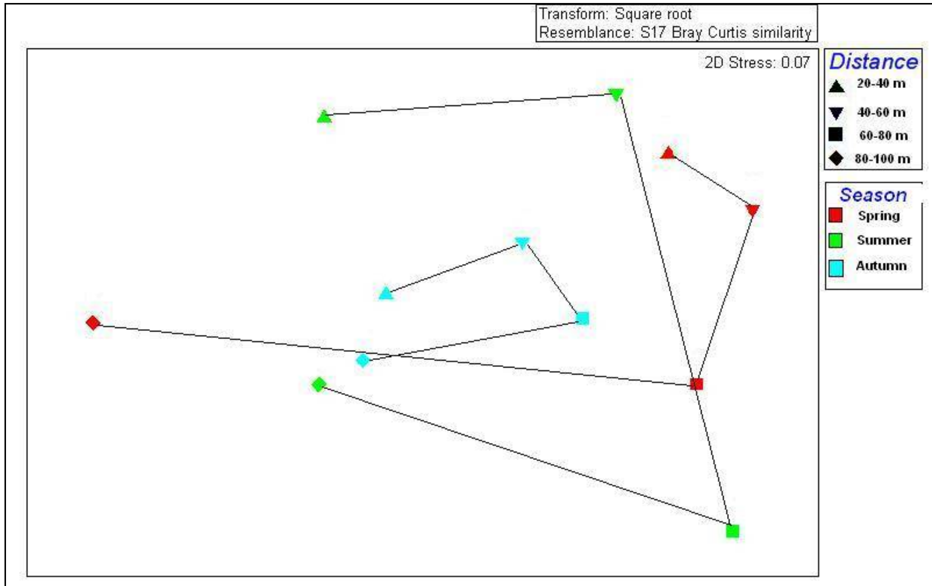
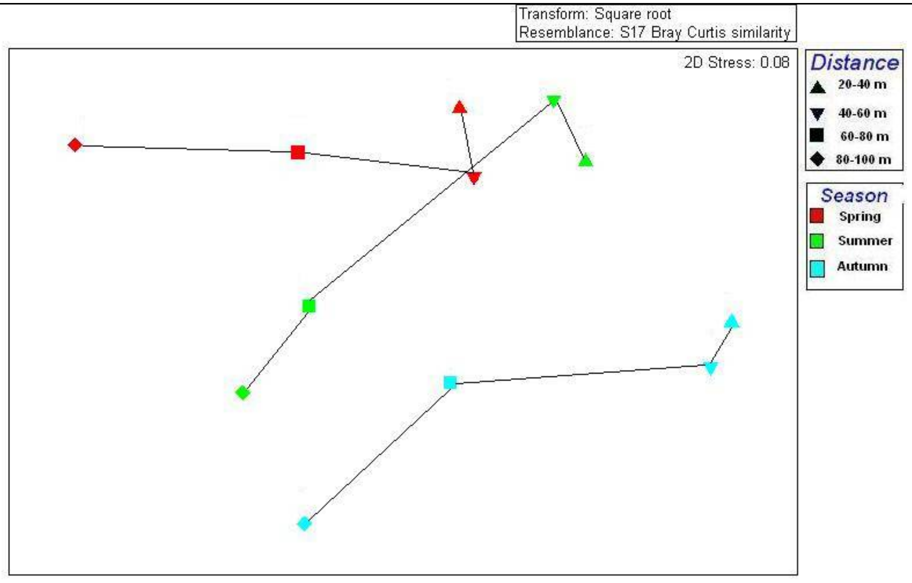
- **Table 8 Index of seriation**

	Samson Beach			West Reef	
Transect	**1**	**2**	**3**	**1**	**2**
Spring	**0.001**	**0.001**	**0.001**	0.026	**0.001**
Summer	**0.002**	**0.001**	**0.005**	**0.003**	**0.001**
Autumn	**0.001**	**0.001**	0.599	0.235	**0.001**

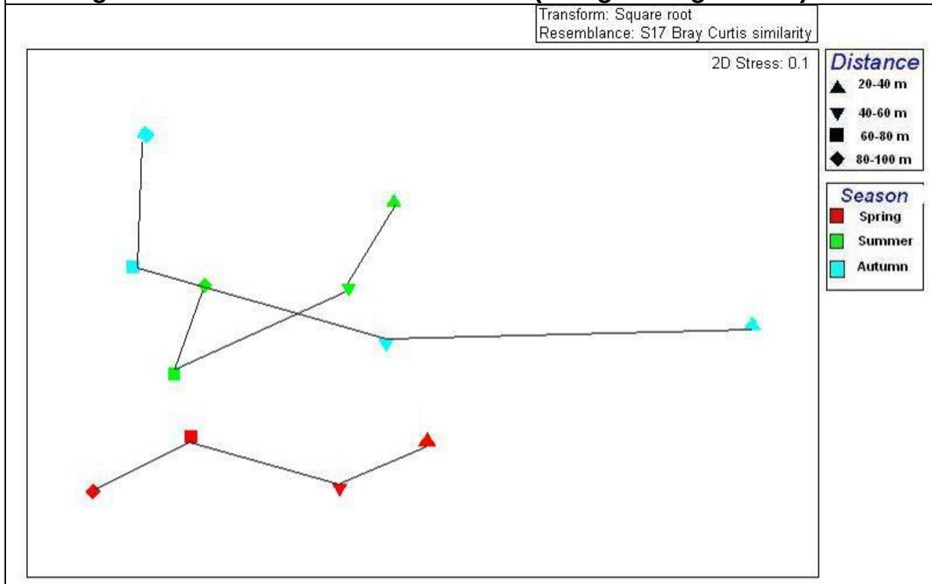
**significant values shown in bold*



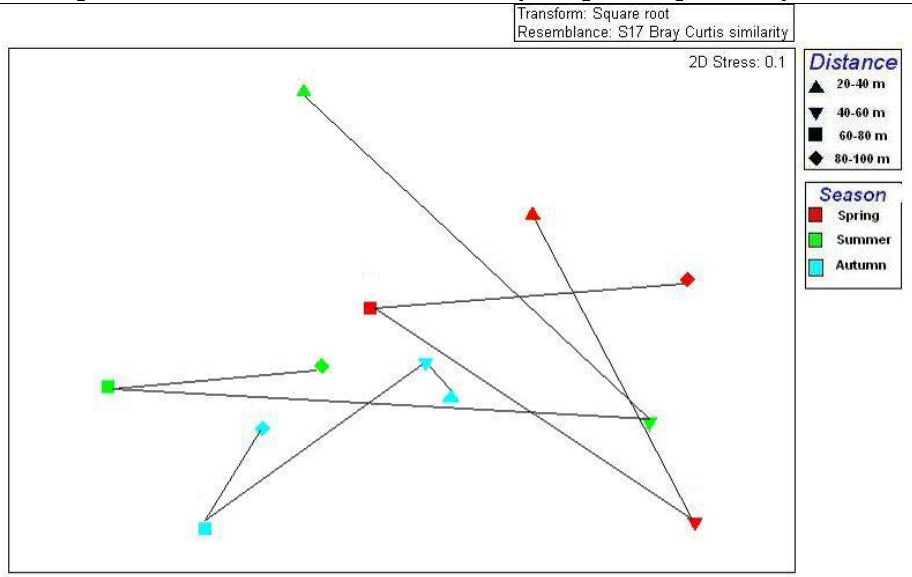
- **Figure 10 Samson Beach Transect 1 (using averaged data)**



- **Figure 11 Samson Beach Transect 2 (using averaged data)**



- **Figure 12 West Reef Transect 2 (using averaged data)**



- **Figure 13 West Reef Transect 1 (using averaged data)**

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4.3.3. Temporal Variation

Results from **Table 5** show that as a whole, benthic assemblages on reef pavements in the Cape Lambert region do not significantly change between seasons (Se: P (perm) = 0.068). However, results detail that there were significant seasonal differences in percent cover of benthic taxa at an transect level at differing heights (Se x Tr(si) x Di) P (Perm) = 0.001). Simply put, when assessing temporal change regionally, the confounding spatial effects (i.e. difference between areas within sites) are considerable and mask larger seasonal changes and therefore need to be assessed at a smaller spatial scale.

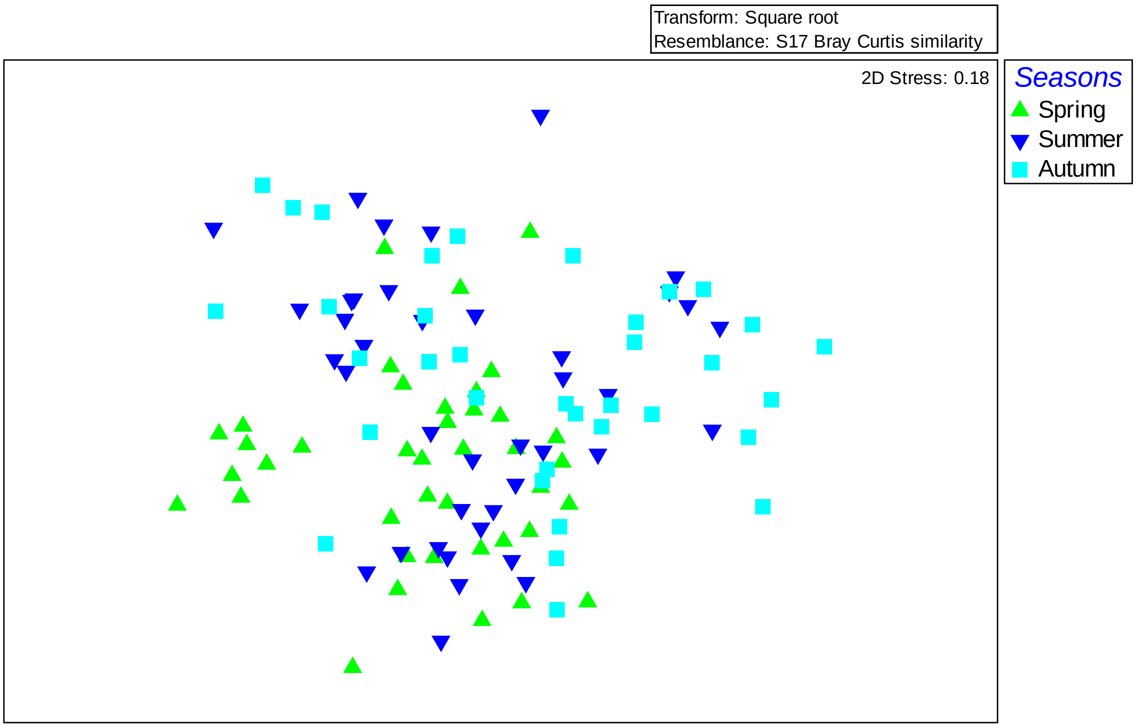
To examine this further an ANOSIM pair wise test was undertaken between each of the seasons for each individual transect as illustrated in **Table 9**. To assist in determining whether the percent cover of benthic taxa significantly changes between seasons nMDS plots were also examined (**Figure 14** to **Figure 16**).

From the analyses, it can be seen that Samson Beach T2, Samson Beach T3 and West Reef T2 all showed marked changes in the benthic composition between seasons. Each of the nMDS plots for these sites show that spring (2) and autumn (4) have contrasting benthic compositions as shown by the separation of these seasons in **Figure 14** to **Figure 16**. This separation is supported in **Table 4**, which shows R statistics > 0.35. One of the main discriminating factors is the rapid colonisation of macroalgae in late summer, which dominated the upper intertidal region during the autumn survey.

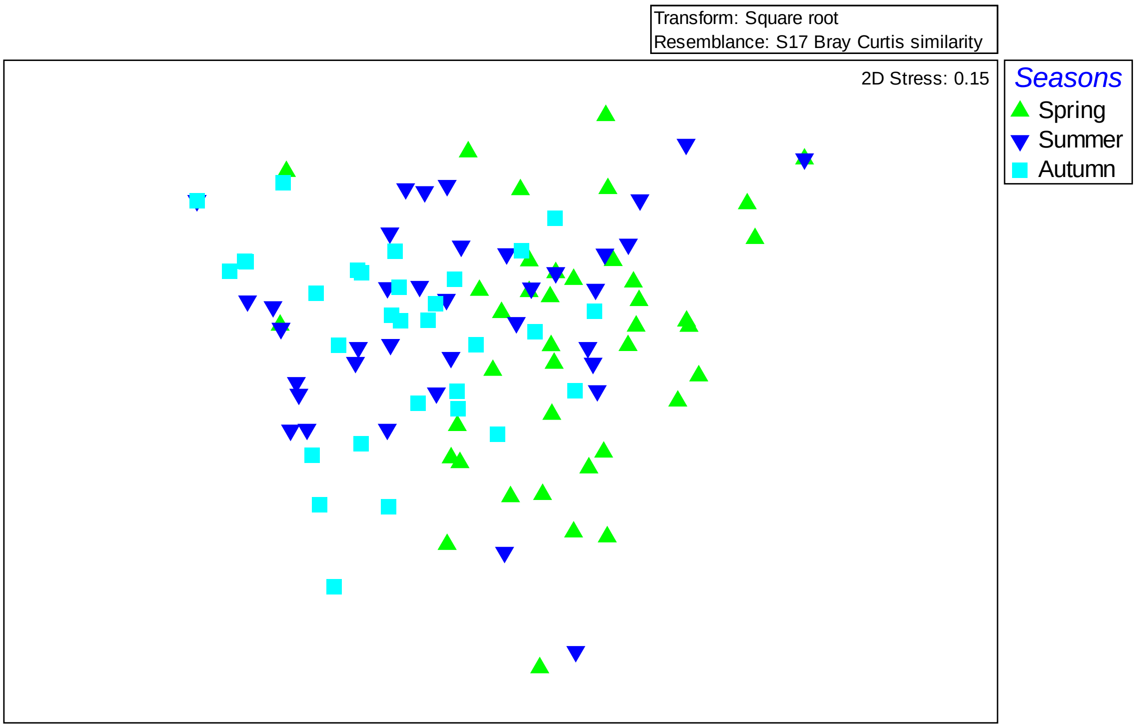
Note that the p-value was less than the 5% significance level at all of the survey areas, between at least one season groupings. However, most had a very low R statistic indicating the result maybe false, as both groups had a large number of replicates, resulting in a large number of possible permutations.

- **Table 9 Differences in benthic cover at each transect between seasons**

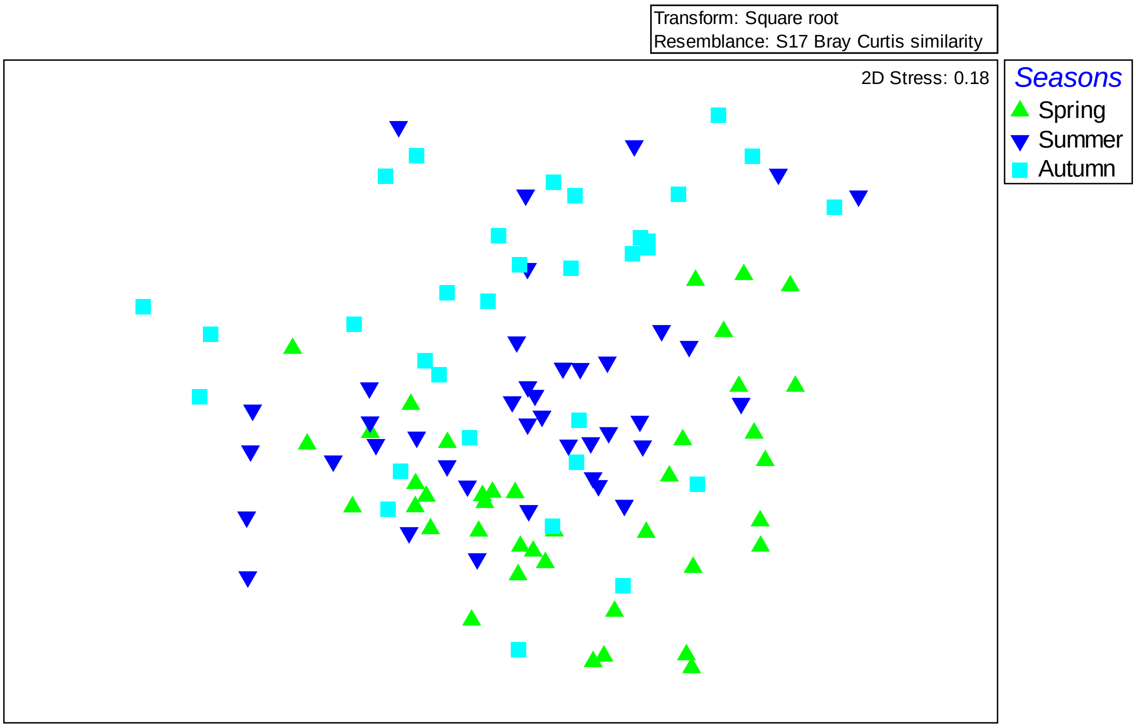
Site	Samson Beach						West Reef			
Transect	1		2		3		1		2	
Between Seasons	R Stat	P-value	R Stat	P-value	R Stat	P-value	R Stat	P-value	R Stat	P-value
Spring (2), Summer (3)	0.11	0.01	0.24	0.00	0.13	0.00	0.22	0.00	0.30	0.00
Spring (2), Autumn (4)	0.14	0.00	0.39	0.00	0.36	0.00	0.20	0.00	0.47	0.00
Summer (3), Autumn(4)	0.14	0.00	0.13	0.00	0.04	0.21	0.10	0.01	0.39	0.00



- **Figure 14 Samson Beach Transect 2 - differences between seasons**



- **Figure 15 Samson Beach Transect 3 – differences between seasons**



- **Figure 16 West Reef Transect 2 – differences between seasons**

5. Discussion

The primary aim of this study was to record a baseline data set that describes the temporal and spatial variability in benthic life form composition on intertidal reef platforms in the Cape Lambert region. The program was developed with the aim of assisting in the detection and monitoring of natural and anthropogenic changes to benthic habitats in the Cape Lambert region.

It was found that Cape Lambert intertidal platforms are dynamic. The platforms are heterogeneous, with benthic assemblages varying temporally over small spatial scales (< 100 m). The distribution and abundance of benthic taxa recorded at Samson Beach and West Reef were variable between seasons, among areas within sites and at varying heights on the shore, predominantly due to differing periods of inundation.

5.1. Ecological Interactions

A primary component of the baseline intertidal study was to assess the importance of how temporal and spatial sources of variation interact together to influence change in intertidal communities at the study locations. It was found that the composition of the benthic communities are changing differently among seasons and among replicate transects in the same site, and that the differences are not consistent among varying heights on the shore.

This interaction reinforces the notion that the intertidal platforms are a dynamic environment, whereby the distribution and abundance of BPP and other benthic taxa can vary greatly as a result of physical processes (such as temperature and tidal fluctuations, wave energy, periodic cyclones), biological processes (such as competition, predation) and chemical processes (such as salinity, nutrients) acting over varying spatial and temporal scales (Underwood and Chapman, 1996).

The ever-changing nature of this type of environment makes it very difficult to predict and attribute change. The ability to detect and attribute change within a certain habitat is based on being able to identify, explain and ultimately predict direct and indirect interactions among species (Underwood 1999). This includes the processes affecting distributions, abundance and dynamics of species in assemblages. “Indirect interactions are those where distribution, abundance, growth, reproduction, behaviour and recruitment of one species are modified by a second species, but the rate, scale or magnitude of the direct interaction is modified (indirectly) by a third species” (Underwood 1999).

The physical conditions experienced by intertidal environments play a vital role in the species composition and assemblages observed. In a parallel Port B BPPH Subtidal study (SKM 2009b) strong correlations between the benthic cover and environmental variables (water temperature, sedimentation and turbidity) were found. The influence of environmental variables, such as high ambient temperatures and periodic cyclones were examined prior to each survey and during the analysis.

The baseline intertidal monitoring program has provided the necessary information to assist in recording large scale changes to the intertidal reef platforms. That is, significant changes in the percent cover of dominant benthic taxa between season, sites, areas within sites and heights on the shore. For example, from the data collected it would be expected that macroalgae, in particular *Sargassum* sp., will increase cover during summer and autumn. However, given the coarse resolution of the data (i.e. for the benthic categories; turf algae) it is unlikely that species specific or small scale changes will be detected.

The 12 month baseline data set from four surveys (one in each season) provides a snap shot of what may be happening during that time of year. These platforms are shown to change over small temporal (weather event) and spatial scales (<100 m) so it is likely they are constantly changing and adapting in response to natural disturbances and processes. When detecting and attributing anthropogenic change, it must be considered in the context of natural variation so that the ecological significance can be assessed.

5.2. Spatial and Temporal Variability

There is a need to understand natural variability in the distribution of benthic taxa through time and over varying spatial scales to assist in the detection of any impacts that may be a result of natural processes or dredging activities. In particular, this involves monitoring the changes to the distribution and abundance of macroalgae, turf algae, seagrass and corals that are specifically listed in the EPA Guidance Statement on BPPH Protection (EPA 2004).

Between Survey 1 (winter) and 2 (spring), temporal and spatial changes in benthic cover between surveys were mainly attributed to the turf algae and turf sand benthic categories. This is likely to be due to the fast growing and resilient nature of algal turfs. Marked changes in the distribution of algal turfs may identify areas of disturbance. In inshore subtidal areas of the Great Barrier Reef, benthic algae, predominantly algal turfs, comprised up to 90% of benthic cover after disturbances such as mass-bleaching events (Sweatman et al. 2001) as turf algae can rapidly colonise the surface of dead corals.

Turf sand was one of the benthic categories that contributed the most to the observed differences. Algal assemblages reduce the flow of water in the boundary layer, enhancing sediment deposition and reducing resuspension (Eckman et al. 1989; Carpenter and Williams 1993). Algal turfs physically trap sediment, restricting resuspension (Purcell 2000). The increased sediment deposits reduce the potential for coral settlement (Birrell et al. 2005).

Temporal changes in benthic cover between Surveys 2 (spring) and 4 (autumn) have been attributed to the rapid growth of the brown macroalgae, *Sargassum* sp. in the tidal pools, eroded channels and crevices, while *Cystoseira* sp. dominated the reef flat, at the southern end of Samson Beach and the northern end of West Reef. *Cystoseira* sp. is commonly found on intertidal platforms in the Pilbara region (Dr John Huisman, Murdoch University, per comm.) and this survey is the first known record of its occurrence in the Cape Lambert region. Since both of these genera have been recorded in the Dampier Archipelago (Huisman and Borowitzka 2003), which shares the same underlying geomorphology and climate, their dominance at Cape Lambert was not unexpected.

The pronounced growth of macroalgae during late summer and autumn may be due to light availability and prevailing weather conditions. The constant inundation by seawater would supply plenty of dissolved nutrients for growth (Dayton 1975). The reduced light available during the winter months as a result of the shorter days compared to the summer months may contribute to the higher percentage of macro and turf algae recorded in the summer and autumn surveys.

Spatially, topographical heterogeneity may be a major factor regulating species distribution and abundance within a community (Bourget et al. 1994). The microhabitat types differentially affect settlement, abundance and post settlement mortality as well as the distribution of recruits within algae mosaics (Benedetti-Cecchi and Cinelli 1992).

5.3. Seriation Patterns

The benthic composition at both Samson Beach and West Reef significantly changed with height on the shore. This was expected given that there are a number of environmental gradients relating to exposure to air and waves, and substratum composition that can have a profound influence on the distribution of benthic taxa in intertidal environments (Underwood and Chapman 1996).

The period of emersion is one of the main determining factors leading to the seriation of intertidal hard substrates. The high and low tide marks represent distinct physical barriers that restrict species to certain areas. The lower eulittoral zone is characterised by a high diversity of species that have adaptations associated with aquatic living as they are rarely emersed (McMahon 2003). At both Samson Beach and West Reef this zone was characterised by hard corals, soft corals, macroalgae, turf algae, *Tridacna* sp. and holothurians.

The eulittoral, mid shore zone lies between the low and high tide mark. Species inhabitating this area are exposed to predictable, attenuated periods of emersion between successive tides (McMahon 2003). At West Reef, the eulittoral zone was a mixed zone characterised by a combination of macroalgae, turf algae, bare rock, silt to fine sand and some juvenile corals as well as a series of tidal pools running parallel to the shore. Similarly, the eulittoral zone at Samson Beach was a mixed zone characterised by a combination of macroalgae, turf algae, bare rock, coarse sand and a series of tidal pools but also a distinct area dominated by the mussel, *Brachidontes* sp. A sub-study of the tidal pools at Samson Beach and West Reef was undertaken and is provided in **Appendix C**.

The upper eulittoral fringe near the high tide mark is characterised by unpredictable long periods of emersion. As a consequence, this zone is occupied by species with specific adaptations to limit desiccation and prolong survival (McMahon 2003). At Samson Beach, this area was dominated by turf algae, with a large percentage covered by a thin veneer of sand (turf sand category). During autumn at the southern end of Samson Beach and the northern border of West Reef, this zone was characterised by an abundance of macroalgae, particularly *Sargassum* sp. and *Cystoseira* sp. At West Reef, there is also an upper series of tidal pools but beyond this, there were distinct outcrops of igneous rocks. These outcrops were typically eroded fissures that provided habitats for only hardiest of species, such as the oyster *Saccostrea cucullata*, because of their ability to cope with desiccation.

Results from this study are consistent with studies from other tropical regions, where the abundance and distribution of benthic taxa is primarily determined by the period of tidal related inundation (Connell et al. 1997; McMahon 2003).

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6. Conclusions

The intertidal reef platforms in the Cape Lambert region were temporally and spatially dynamic. The hard substrates were dominated by fine silt to coarse sand, turf algae, macroalgae, hard and soft corals, sponges and *Brachidontes* sp. The distribution and abundance of benthic taxa recorded at Samson Beach and West Reef were variable between seasons, among areas within sites and heights on the shore, predominantly due to differing periods of inundation.

It was originally thought that West Reef could be used as a reference site to Samson Beach in the event that any impacts from dredging activities may occur. However statistical analysis between the two sites suggested that the benthic composition at each monitoring location was considerably different and therefore West Reef would not be appropriate as a reference. Similar to the Water Quality Monitoring Program, the baseline data collected from this study could be used as a measure to assist in determining dredging related change.

Given the variability evident in the intertidal communities growing on the reef pavements at Cape Lambert, caution should be undertaken if the intertidal area is to be monitored for impacts. Without an adequate baseline data set, an impact could be attributed to future dredging when no impact in fact existed (i.e. natural variability was the cause of any change in intertidal communities). Similarly no impact could be detected when in fact there was an impact.

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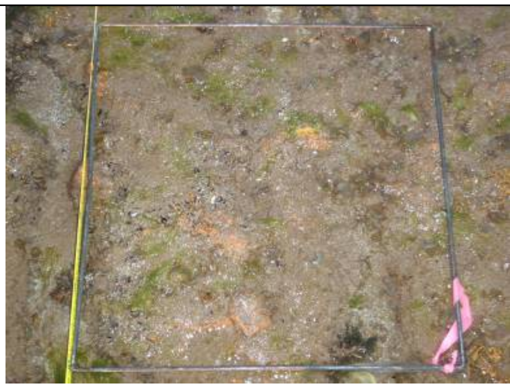
Appendix A Dominant Benthic Taxa

Dominant benthic taxa at West Reef and Samson Beach

Turf Algae (Chlorophyta and Phaeophyta)



Macroalgae

Padina gymnospora

Caulerpa racemosa

Halimeda lamouroux

Hydroclathrus clathratus

Sargassum sp.	*Cystoseira* sp.
	

Seagrass

Found only in the upper intertidal pool of West Reef T1.

Thalassia hemprichii


***Brachidontes* sp.**

Found at Samson Beach only.

Brachidontes ustulate	*Brachidontes usulate* (up close)
	

Corals

Acropora sp. 	*Turbinaria* sp. 
Mussidae 	Faviidae 
Porites sp. 	*Lobophytum* sp. 

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Sponges

Cinachyra sp.	Unknown sponge sp.
	

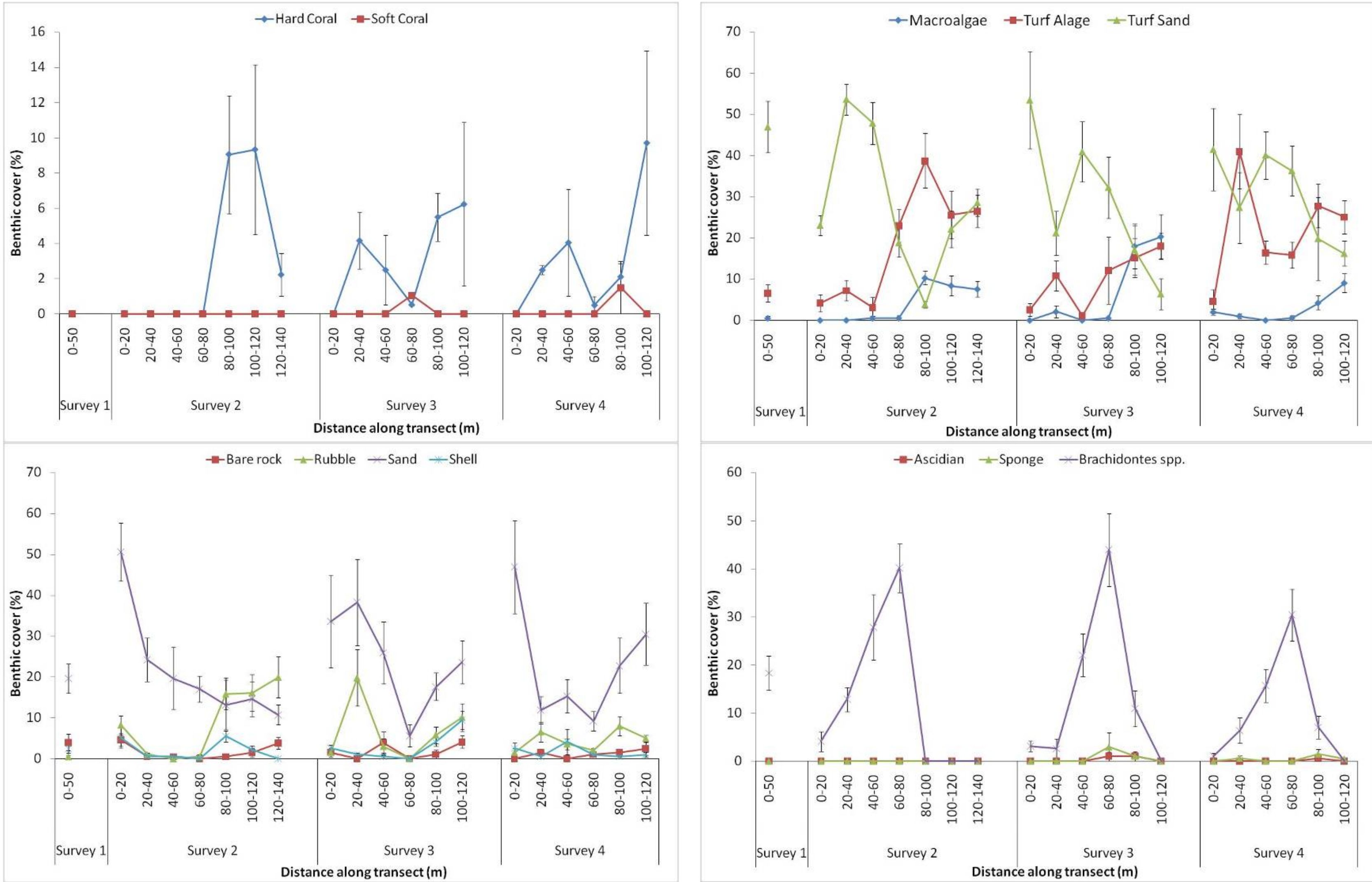
Holothoridae

Holothuria leucospilota	*Holothuria atra*
	

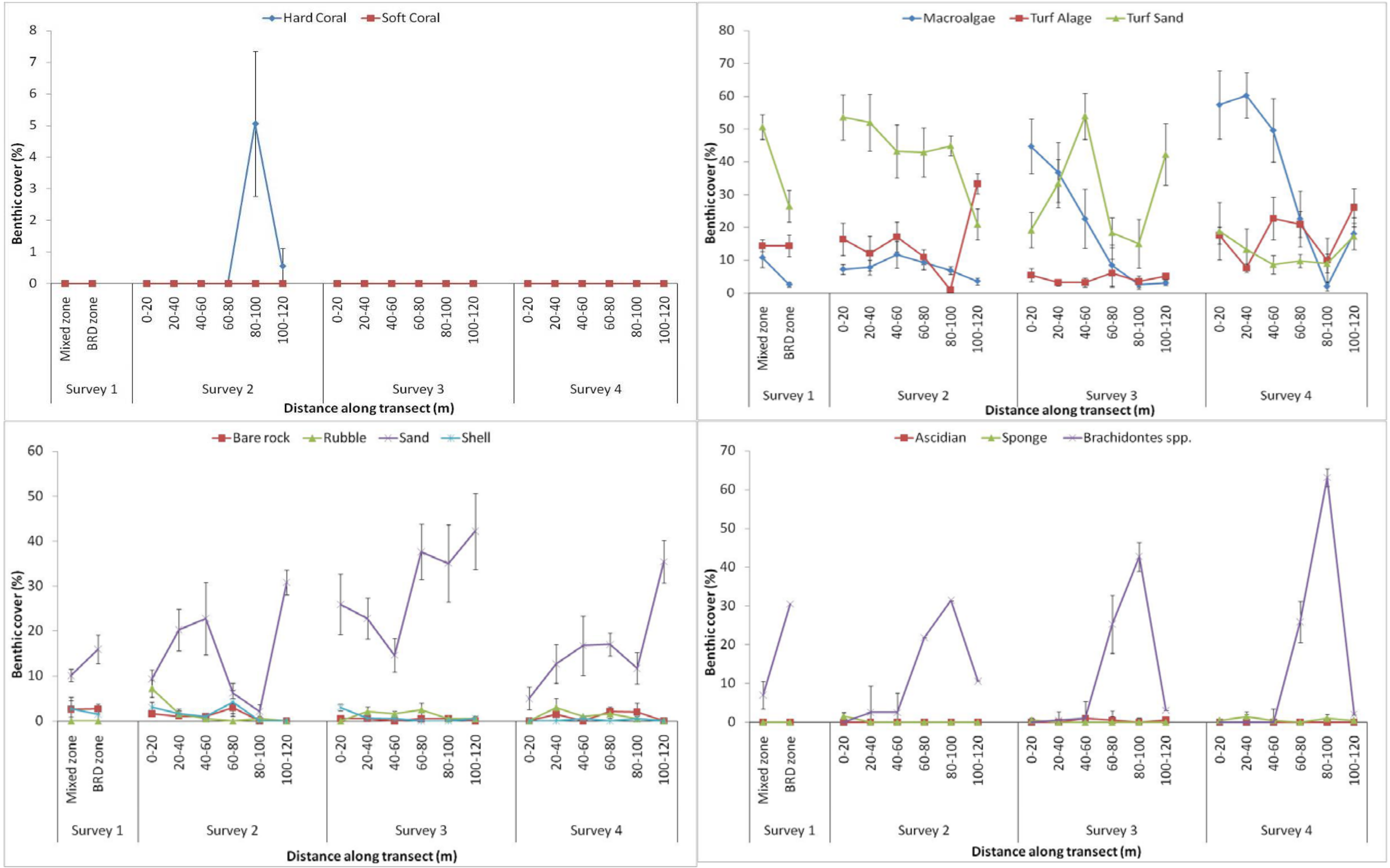
***Tridacna* spp.**

Tridacna maxima	?
	

Appendix B Figures of Individual Benthic Categories over Time and Space



- **Figure B 1 Percent cover of benthic categories along Transect 1 at Samson Beach**



- **Figure B 2 Percent cover of benthic categories along Transect 2 at Samson Beach**

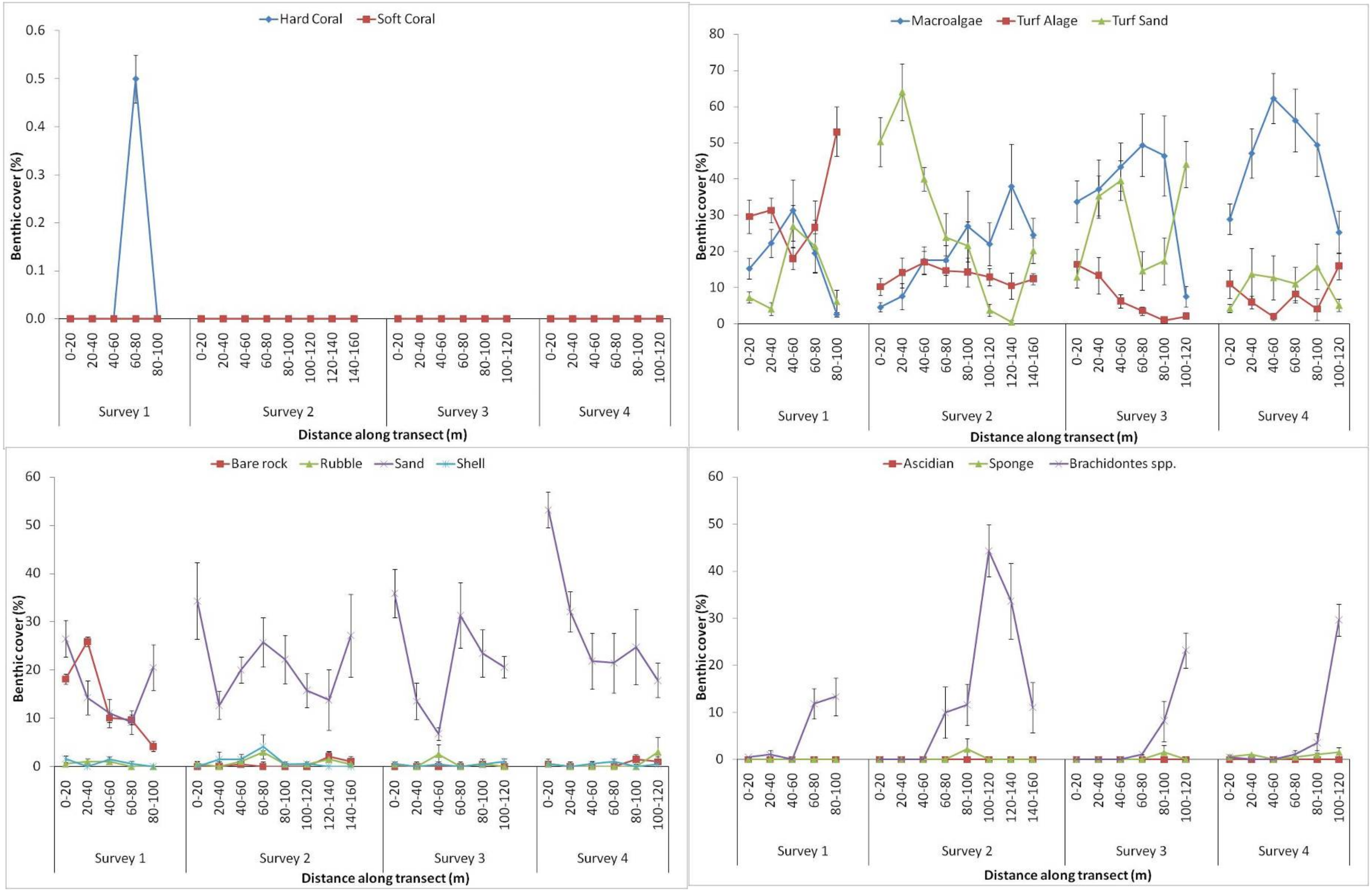


Figure B 3 Percent cover of benthic categories along Transect 3 at Samson Beach

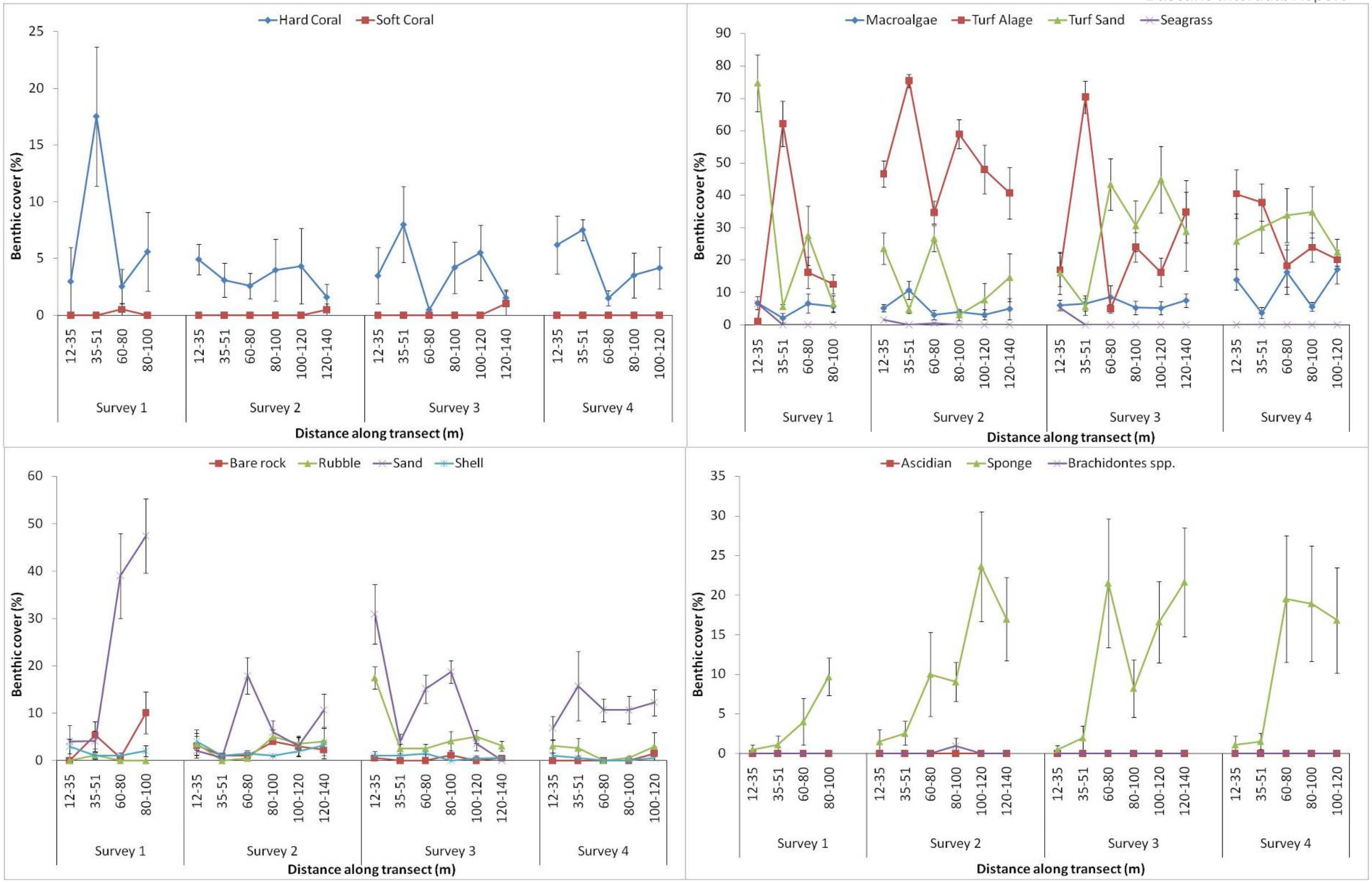
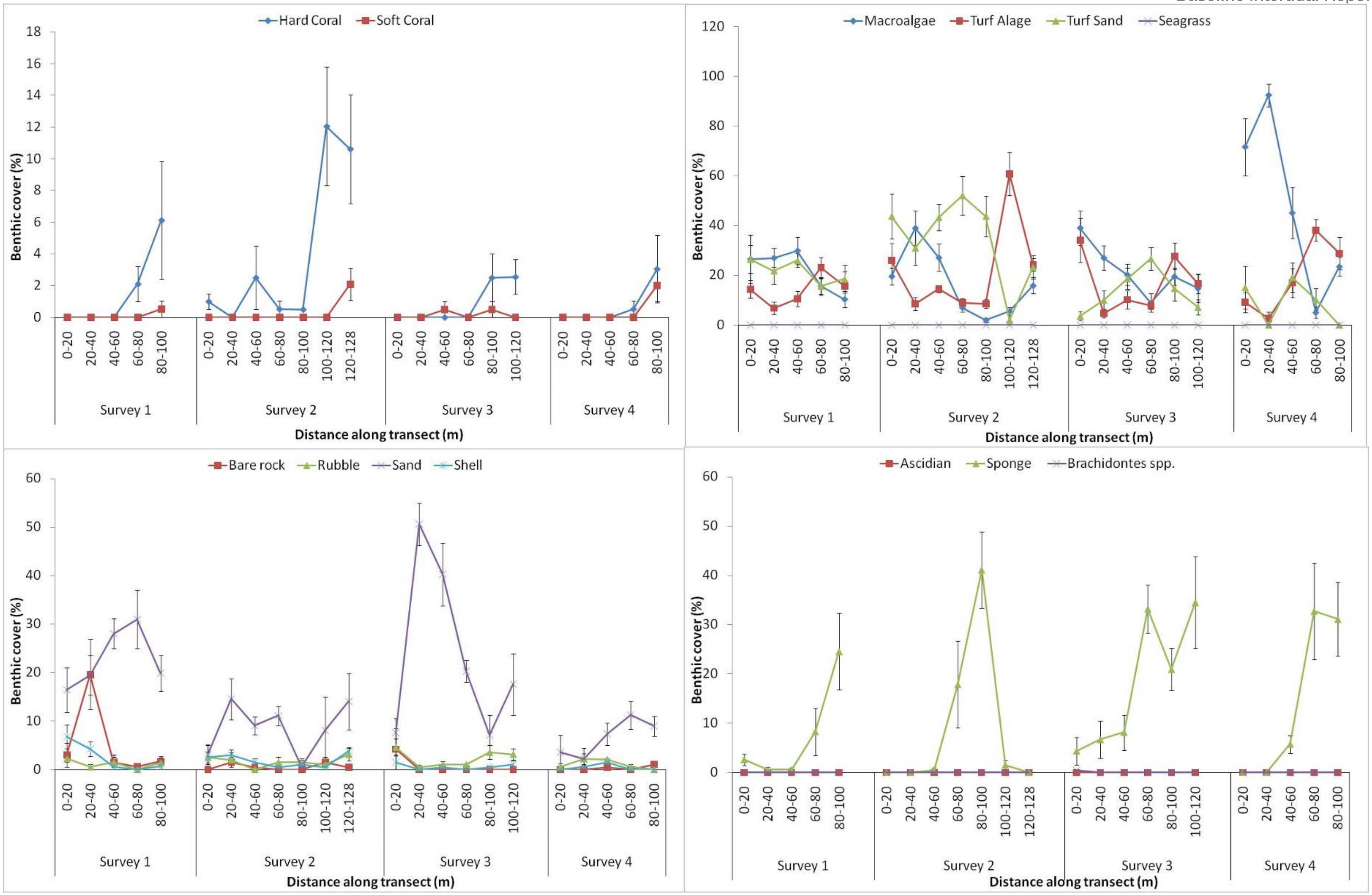


Figure B 4 Percent cover of benthic categories along Transect 1 at West Reef



■ **Figure B 5 Percent cover of benthic categories along Transect 2 at West Reef**

Appendix C Tidal Pool Study

Introduction

The tidal pool zone at Samson Beach lies below the upper turf algae zone and comprises a series of tidal pools that stretch along the entire length of the reef. At West Reef the tidal pool zones lies below the granite outcrops and again around 30m further down the platform. The tidal pools that exist display considerable variability in terms of what the pools look like and the corals that inhabit them.

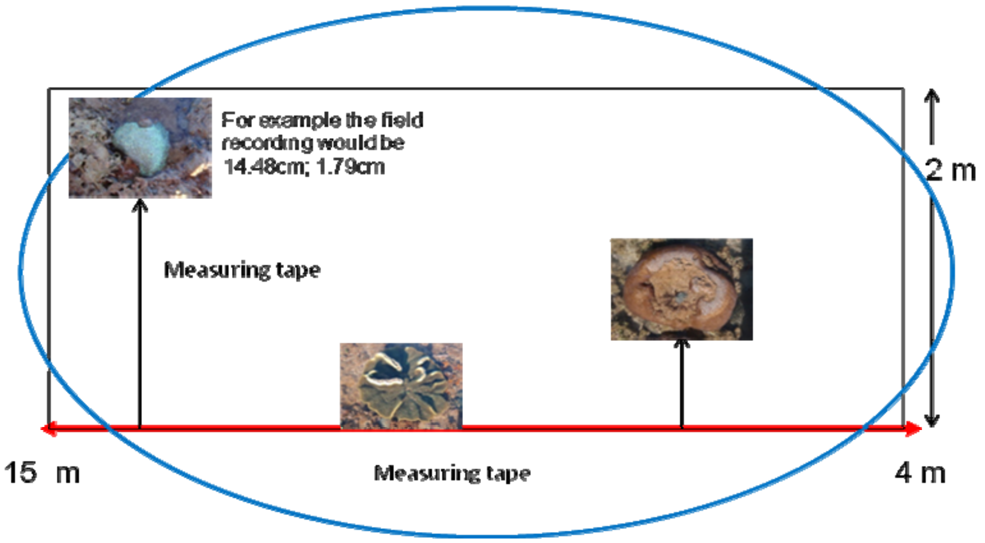
Aims

The aim was to record temporal and spatial changes in the existing corals and to identify new juvenile corals.

Methods

Tidal pools at Samson Beach T1, West Reef T2 and West Reef T3 were selected to survey for the study. Initially, the tidal pool corals were studied solely on a presence / absence basis. The transect was laid out as described in **Section 2.3**. A measuring tape was attached between two permanent pegs. From this measuring tape, another tape was laid out perpendicular to a maximum length of 2 m. Once a coral was identified, it was photographed and its position measured (e.g. transect distance 14.48 m; 1.79 m out) (see **Figure C 1** below). The method was adapted between Survey 2 and Survey 3 due to the following disadvantages:

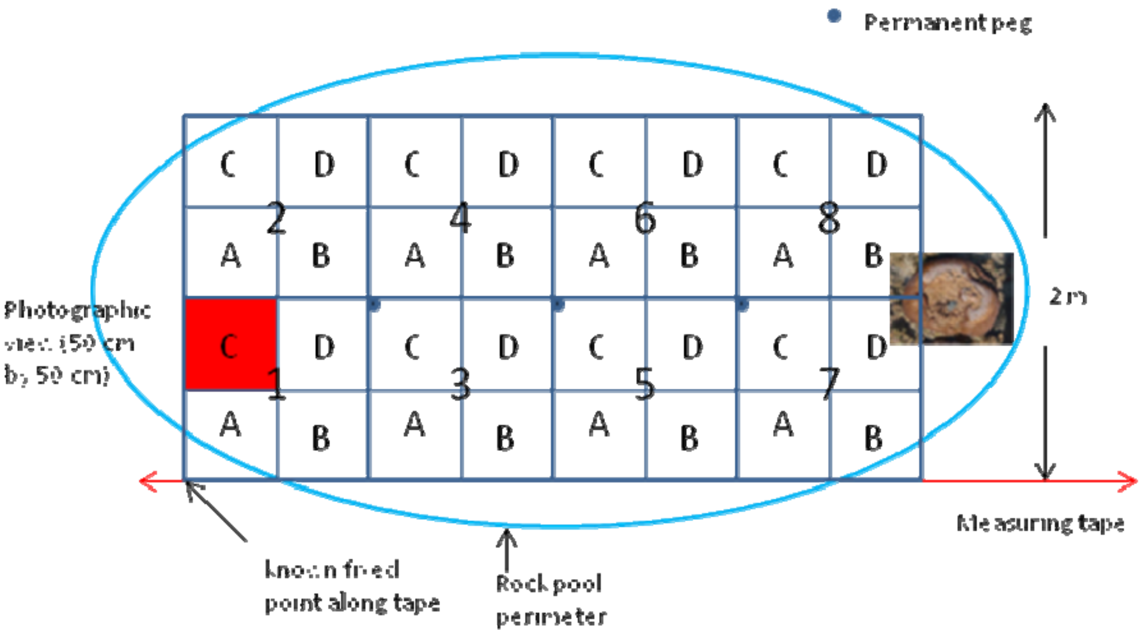
- time consuming
- tape may fluctuate due to wind
- only presence / absence analysis.



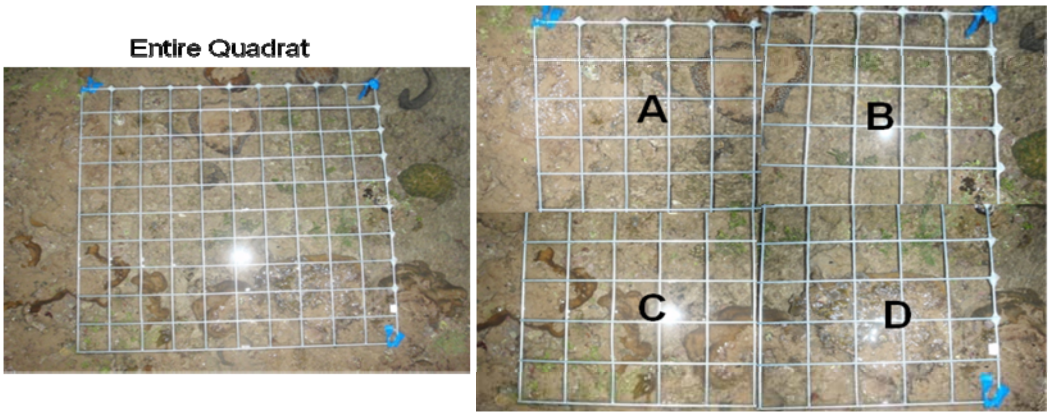
- **Figure C 1 Schematic representation of the initial tidal pool survey method**

Results from the interim report (Survey 1 and 2 (SKM 2009)) found that the initial method did not allow a measure of the coral size, nor did it illustrate a complete representation of the tidal pool and how other significant benthic categories change over time. Consequently, the methods were adapted to employ the use of a 1 m by 1 m quadrat with 10 cm by 10 cm squares, as shown below in Figure C 2 and Figure C 3. The quadrat was positioned against the transect measuring tape and a permanent peg and was then photographed. The advantages of this method are:

- relatively quick
- permanent pegs for consistency
- digital images allows for post analysis and determination of coral species
- allows for analysis of growth changes (not completed for this report based on only two surveys having been completed using this method).



- **Figure C 2 Schematic representation of the adapted tidal pool survey method**



- **Figure C 3 Example photographs**

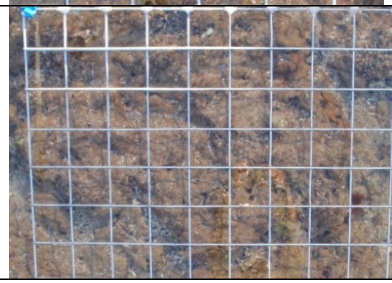
Results

Surveys of the three individual tidal pools indicated that there was a slight shift in benthic composition towards turf and macroalgae during the summer-autumn period within both tidal pools (Samson Beach T1 and West Reef T1). West Reef T2 experienced rapid seasonal growth of macroalgae during summer and autumn, essentially covering the corals that were observed during the initial survey in winter. Consequently, the monitoring could not be continued within this tidal pool.

The coral communities in both tidal pools were dominated by corals from the family Faviidae with corals from families Mussidae, Poritidae and Acroporidae also present (**Table C 1** and **Table C 2**). Although West Reef T1 tidal pool has a larger number and diversity of corals than Samson Beach tidal pool T1, neither pool showed detectable changes in the number or diversity of corals. Coral health remained largely unchanged in both tidal pools from winter to autumn (**Appendix B**) and there were no observed coral mortalities during any of the surveys. Only one coral (*Goniopora* sp.) showed signs of bleaching during summer in Samson Beach tidal pool (water temperature reached approximately 33 degrees Celsius) and then appeared to recover during autumn.

Note in **Table C 1** and **Table C 2**, ‘no image’ was recorded for a number of photos. This was either due to unusable photographs as a result of high winds that caused the surface of the tidal pool to become rippled or due insufficient time available (incoming tide and/or nightfall) to capture all coral photographs.

- **Table C 1 Temporal and spatial changes in the Samson Beach tidal pool**

Samson Beach T1	**Survey 1 - Winter**	**Survey 2 - Spring**	**Survey 3 - Summer**	**Survey 4 - Autumn**
Diversity of coral taxa	Faviidae, Poritidae	Faviidae, Poritidae	Faviidae, Poritidae	Faviidae, Poritidae
Observed changes in benthic cover	N/A	No change in benthic cover	No change in benthic cover	Cover of turfing algae has increased
General comments	Most corals submerged	Most corals exposed	Most corals exposed. 1 *Goniopora* sp. bleached.	Most corals submerged. *Goniopora* that was bleached during summer has recovered
Subsample of corals to determine health cross all surveys				
Faviidae				
Poritidae				

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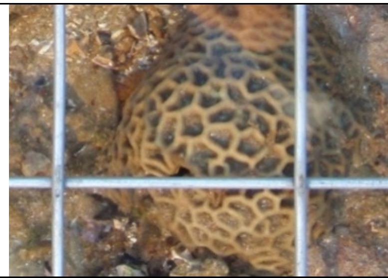
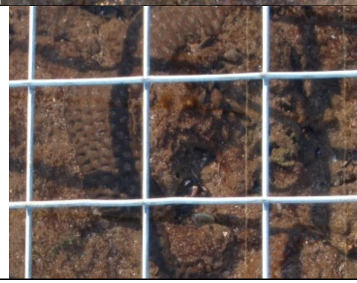
Samson Beach T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Goniopora sp.				
Goniopora sp.			No Image	
Tridacna sp.				

Samson Beach T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Goniastrea sp.				
Goniopora sp.				
Goniopora sp.				

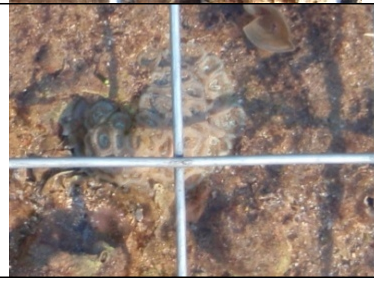
Samson Beach T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Faviidae				
Goniopora sp.		No image		

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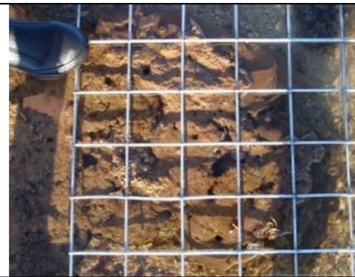
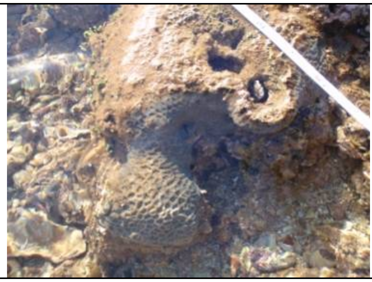
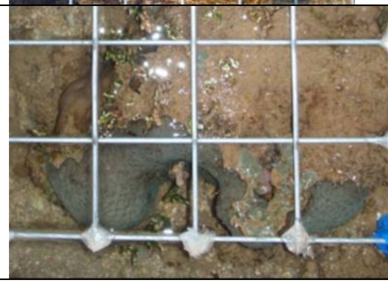
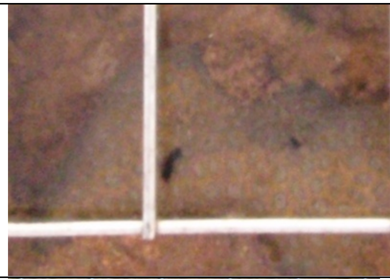
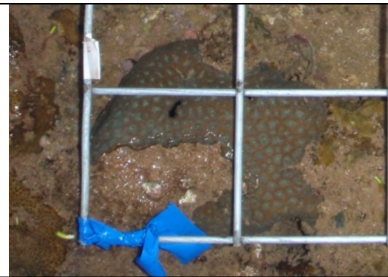
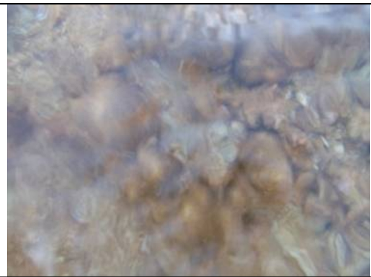
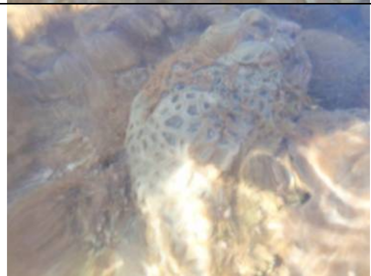
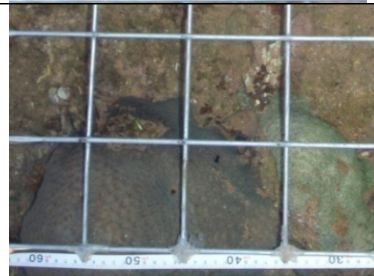
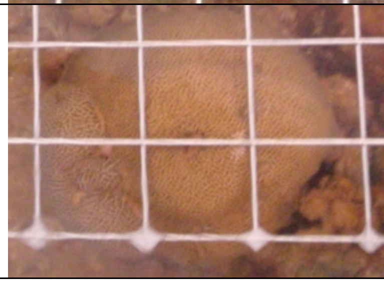
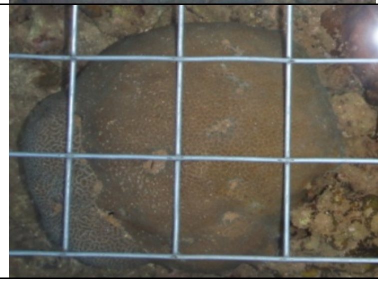
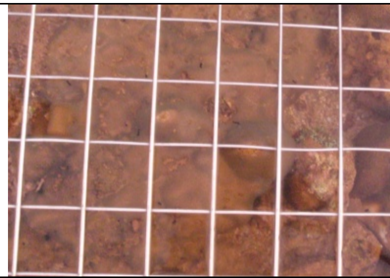
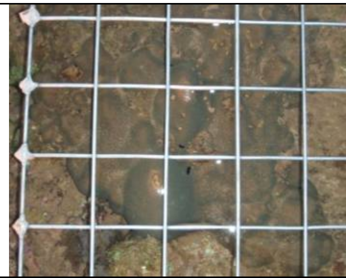
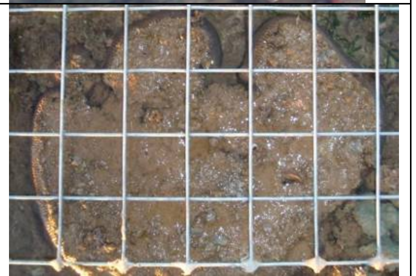
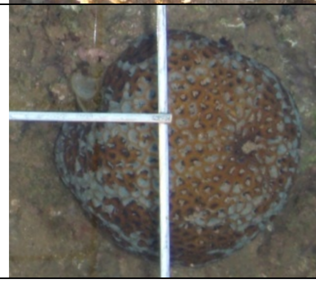
Table C 2 Temporal and spatial changes in the West Reef T1 tidal pool

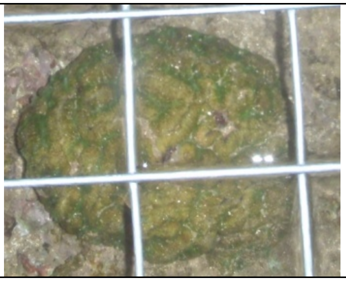
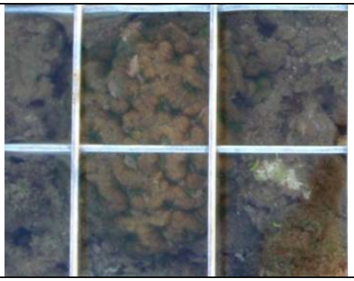
West Reef T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Diversity of coral taxa	Acroporidae, Faviidae, Poritidae, Mussidae	Acroporidae, Faviidae, Poritidae, Mussidae	Acroporidae, Faviidae, Poritidae, Mussidae	Acroporidae, Faviidae, Poritidae, Mussidae
Observed changes in benthic cover	N/A	No change in benthic cover	Increase in turf and Macroalgae	Macroalgae coverage similar to Summer
General comments		No change in coral health	No change in coral health	No change in coral health
Subsample of corals to determine health cross all surveys				
Favites sp.		No Image		
Favites sp.				

West Reef T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Faviidae				
Goniopora sp.				
Goniastrea sp.				

West Reef T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Poritidae				
Goniastrea sp.				
Goniopora sp.				

West Reef T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Favites sp.				
Goniastrea sp.		No Image		
Goniastrea sp.			No Image	

West Reef T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Favites sp.			No Image	
Goniastrea sp.		No Image		
Goniastrea sp.		No Image		

West Reef T1	Survey 1 - Winter	Survey 2 - Spring	Survey 3 - Summer	Survey 4 - Autumn
Mussidae		No Image		

Discussion

The composition of the tidal pools at Samson Beach and West Reef varied greatly compared to the surrounding intertidal environments. The tidal pools represent patches or ‘islands’ of habitat different from the surrounding shore, with the organisms within not exposed to such harsh conditions during low tide as are the flora and fauna living on the surrounding rock surfaces (Underwood and Skilleter 1996). This was observed at the Samson Beach and West Reef survey locations with the tidal pools surrounded by mainly turf algae and sand.

The abundance of macroalgae providing benthic cover within the tidal pools increased during the summer and autumn surveys at the majority of the areas surveyed. This was most evident at West Reef T2 tidal pool where the macroalgae increased during this period to a point where monitoring of corals could not be undertaken. These results are consistent with previous studies identifying that the species composition will be dependent on the time of year when an intertidal pool is sampled, where many pools (especially high ones) look markedly different in mid-summer than in mid-winter (Dethier 1982; Dethier 1984).

Sargassum sp. was the dominant species in the West Reef T2 tidal pool. Once established, a dominant species can spread rapidly throughout the pool either through vegetative growth or enhanced recruitment (Dethier 1984), as was observed during summer and autumn. When abundant, most dominants appear to prevent potential competitors from settling and surviving by monopolization of resources, abrasion of substratum, and/or collection of sediment (Dethier 1984). At wave-beaten sites unstable sediments are usually transient (Dethier 1984), this may result in sediment scour preventing the settlement of macroalgae. This would contribute as to why macroalgae had greater abundance in the higher intertidal pools. Advantages to macroalgae growing in tidal pools include reduced desiccation and greater exposure to essential nutrients.

The assemblages and composition of the tidal pools varied from site to site, between areas within sites and height on the intertidal platform. Sampling in natural rock pools has shown that assemblages in pools are variable within and between different exposures and heights on the shore (Underwood and Skilleter 1996). There are a number of factors that influence the composition and diversity within and between tidal pools including the size and shape of the pool, the height along the intertidal platform, the history and extent of disturbance, predation, competition and the amount of wave energy experienced. For a number of different reasons, the number of species generally increases with the size of a patch, with the diameter and the depth of the pool comprising the size of the patch (Underwood and Skilleter 1996). The effects of depth of a tidal pool have been shown to be the primary source of variability in the structure of these habitats (Underwood and Skilleter 1996).

An individual coral in the Samson Beach tidal pool was observed to show signs of bleaching during the summer sampling period, but had recovered from the bleaching by the autumn survey. Water temperature of around 33°C was recorded off Samson Beach with temperatures in the tidal pools likely to be higher at times. Coral bleaching is a stress response culminating in the loss of symbiotic dinoflagellate algae, zooxanthellae, from coral tissues (Maynard et al. 2009). Although there are differences in response among coral species and populations, most corals are likely to bleach but survive and recover if temperature anomalies persist for less than a month (Reaser et al. 2000). The temperature tolerance of the corals around Cape Lambert is undetermined and therefore the length of time coral species could withstand certain temperatures is not known.

Conclusion

Tidal pools in the Cape Lambert region vary considerably in terms of what inhabits them, depth and size. Results from the surveys of the three individual tidal pools indicated that there was a slight shift in benthic composition towards turf and macroalgae during the summer-autumn period, which was attributed to the rapid growth of S*argassum* sp.. Scleractinian corals that inhabit these tidal pools are robust, experiencing a range of water temperatures, sometimes in excess of 33°C.

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