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NOVA SOUTHEASTERN UNIVERSITY OCEANOGRAPHIC CENTER

Changes in a Tropical Seagrass Environment After Installation of Small Artificial Reefs

By
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I. Abstract

The 3-dimensional structural complexity of coral reef environments is positively correlated with measurements of biodiversity and biomass. EcoReefs are a type of artificial reef that resemble branching corals, such as *Acropora cervicornis*, which provide an environment of high structural diversity, and that are effective at recruiting and sustaining fish populations. Little is known, however, about the effects of EcoReefs on the surrounding environments in which they are deployed, so this study examined the results after installing Ecoreef modules in a seagrass environment. The installation occurred in March 2009 at Coco Cay in the Berry Island chain in the Bahamas and data was taken over the next two years to compare changes on Ecoreef deployment sites (experimental sites) to sites with no EcoReefs (control sites) and also an older and larger installation with both EcoReefs and Reefballs (Old Reef) that dates back to 2004. Two main categories of information were collected: at the same time (a) the changes in growth of two types of seagrass, *Thalassia testudinum* and *Syringodium filiforme*, and (b) the changes in fish populations in and around the EcoReef installations. Experimental sites consisted of 3 groups, 30-35 metres apart, each of 12 EcoReef modules in seagrass beds off the east side of the island. Both seagrass and fish data were collected within the module groups and also for the area 1 metre around the installation to see if there were any “halo” effects, i.e. where seagrass around a reef is cleared by resident fish populations. Seagrass measurements including direct measurements of blade length, width, percentage of epiphytic fauna, and the percentage of dead tissue on each blade were collected. Seagrass coverage was also estimated using a photographic technique. Fish counts were performed using a modified Bohnsack-Bannerot visual survey method, and augmented with transect counts. The results for seagrass indicated that there were some seasonal changes in growth and coverage. Fish populations accumulated rapidly on the Ecoreef modules: at the first-post installation collection data period 4 month later the experimental site fish populations were between 30 and 153 individuals, and remained at this level throughout the study, with a mean population per site of 84.4 individuals over the length of the study. Over the study period it was found that the majority of the fish (67**%**) on the experimental sites were haemulid, and scarid juveniles of less than 5 cm in length, in contrast to the older and larger mixed reef that had 73% above 5cm, including a stable population of 184 (+/- 24.5) grunts. The older site also had a distinct halo zone of cleared and cropped seagrass, whereas no halo zone was visible at the experimental or control sites, suggesting that the abundance and size of the fish establish and maintain this zone. The results from this study suggest that EcoReefs modules foster fish populations and cause changes in seagrass length, but do not result in the formation of a halo zone directly; the formation of this zone, where present, is likely the result of the fish species that settle on these structures.

Keywords: EcoReefs, Coco Caye, seagrass, fish, halo, Bohnsack-Bonnerot

II. Acknowledgements

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1.0 Introduction

1.1 Artificial Reef Background

Coral reefs are one of the most diverse biological ecosystems in the world and contain approximately 25% of all marine species (Mulhall, 2007). They are both biologically important, providing homes, grazing areas, breeding grounds, and cleaning stations for many diverse populations (Sutton, 1985), and economically important. Coral reefs attract tourists that dive and snorkel and utilize the reefs and beaches that are produced and protected by coral reef organisms and their associated structure (Wilkenson, 1998). Despite their importance, coral reefs are under constant threat.

These threats can take many forms. Common problems include: physical storm damage (Woodley et al., 1981), chemical contamination by pollutants (Dubinsky and Stambler, 2006), and human activities that directly impact the reefs, like destructive fishing practices (see Jackson et al., 2001). All of these practices can result in the complete or partial destruction of individual reefs. In an effort to combat this damage, artificial reefs have been suggested as a tool to combat reef degradation by providing additional habitat, (Rilov and Benayahu, 2000; Einbinder, et al., 2006) and are being constructed around the world.

Jensen (1997, p 449) defined an artificial reef as “a submerged structure placed on the seabed deliberately, to mimic some characteristics of natural reefs”. As coral reefs continue to degrade (Birkeland, 2004) artificial reefs have been examined as a prospective way to restore these ecosystems.(Bohnsack and Sutherland, 1985; Pratt, 1994; Carr and Hixon, 1997; Seaman and Jensen, 2000).

The increasing frequency of worldwide use of artificial structures in efforts to increase fish abundance and diversity, improve catch rates of targeted species, manipulate habitats, and restore damaged coral reefs (Bohnsack and Sutherland, 1985; Bohnsack, 1990; Seaman, 2000; Spieler et al., 2001, Døving, 2006) has led to many types of structures being used: concrete blocks, polyvinyl chloride (PVC) pipe, fish aggregating devices (FADS), tires, oil drums, sunken ships, and formed concrete hemispherical structures called Reef Balls, have all been used in the past (Sherman, Gilliam, and Spieler, 2002). Reef Balls have become a very popular tool for constructing artificial reefs. They have a large void space in the middle that was originally thought to attract fish. However, studies have shown that structure with less void space and increasing complexity had a more positive effect on fish rehabilitation (Sherman, Gilliam and Spieler, 2002; Charbonnel, et al., 2002). Although some types of artificial reef produce more biomass per unit area, scientists continue to attempt to develop artificial reefs that are not only functional in recruiting fish populations but also negative effects on the biota of the surrounding environment.

Although artificial reefs can be used as a tool for restoring damaged habitat, these potential negative effects on the surrounding environmental biota have rarely been examined (Bohnsack, Ecklund, and Szmant, 1997). This study sets out to examine such effects by looking at how artificial reef structures called Ecoreefs, , and the fish that settle on them, can affect the surrounding seagrass (*Thalassia testudinum* and *Syringodium filiforme*) where they are installed.

Other means of reef building materials, such as tires, are known to introduce toxic chemicals into the environment, and cement structures can contain alkaline additives which also leach into the environment (Aleksandrov *et al*., 2002). The EcoReefs modules used in this study, however, are constructed of a ceramic material (consisting primarily of the kaolinate compound $Al_2Si_2O_5(OH)_4$), which is non-toxic and pH neutral, and which previous observation indicate will initiate growth where other materials would hinder it Livingston, 1994).

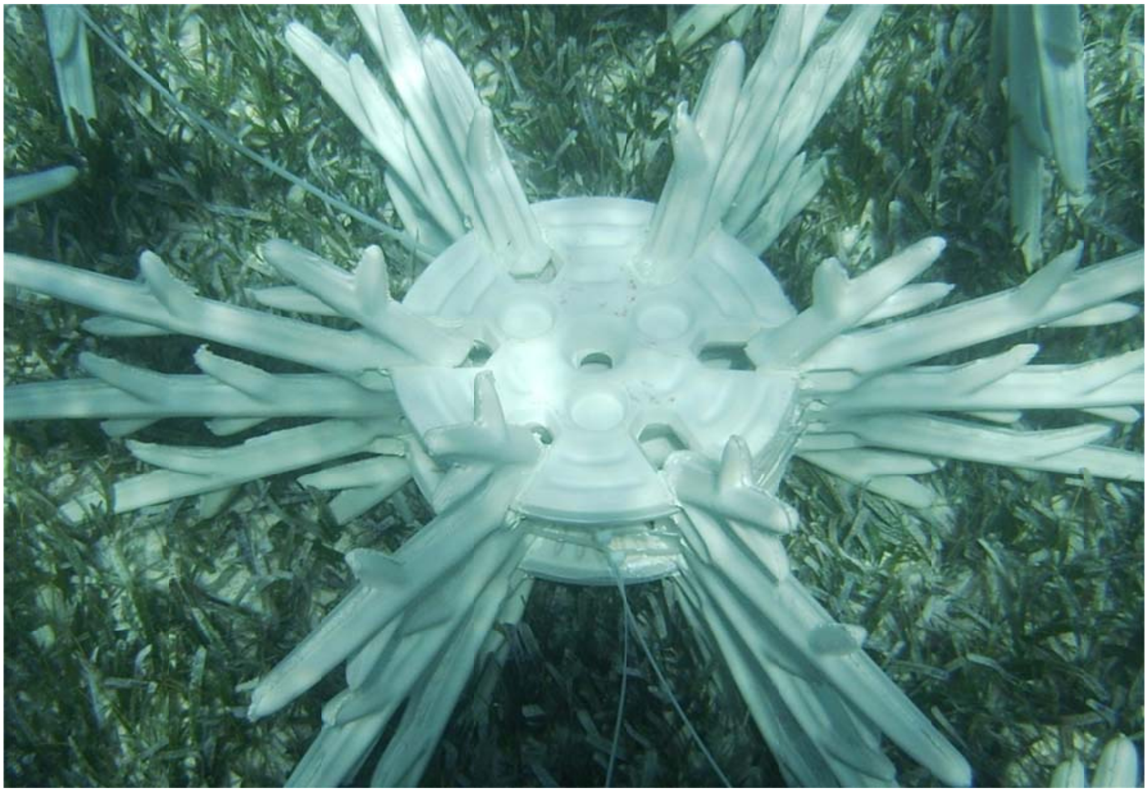
1.2 EcoReefs

EcoReefs installations have been used to create complex reef habitats of dense thickets (mimicking branching coral) over large areas using mass-produced ceramic modules (Moore and Erdmann, 2002; Kaufman, 2006; Apostolakos et al., 2007). When deployed in closely-packed arrays, the modules create habitats suitable for small and juvenile fish. Providing a habitat for juvenile fish is critical for restocking depleted fisheries (Hendry et al 2003).

Reef fish populations can be influenced by the structure of the associated coral reef, since overall 3-dimensional spatial complexity (rugosity) on the reef is correlated with fish biodiversity (Friedlander and Parrish, 1998). EcoReefs apparently have the design features to meet the needs of coral and fish recruits. This includes shaded settling plates raised off of the bottom and fluted surfaces to generate turbulence that are designed to imitate the morphology of branching coral thickets. This is important because branching corals play an integral role in the establishment of reef communities, as their high degree of 3-dimentional spatial complexity provides habitat for many species (see

Friedlander and Parrish, 1998). Branching acroporid corals can grow quickly (as much as 10 cm linear growth/year; Shinn, 1976), and form dense thickets that shelter a variety of fish and invertebrates.

EcoReefs basic design (See Photo 1) resembles that of the coral, *Acropora cervicornis* (see Photo 2). *Acropora cervicornis* is a branching coral utilized by many fish species, the shelter provided by this habitat is critical for settlement and the reduction of predation mortality among newly settled juveniles (Shulman, 1985, Ekland, 1996).



Photograph 1: Branching design of assembled Ecoreef module, the circular base is 16 cm in diameter.

Photograph 2: Example of branching coral, *Acropora cervicornis,* ~1 meter in diameter.

Following patterns observed for other artificial reef installations (Apostolakos et al., 2007.), recruitment and colonization of EcoReefs should take place quickly and the number of fish will increase for at least 6 months (Pickering and Whitmarsh, 1997); after this point, fish populations may stabilize or continue to grow. The resulting ecosystem will then theoretically build at a moderate steady rate until it equalizes and becomes a fully functional reef.

Previous studies indicate that EcoReefs installations are effective at fostering fish and coral growth resulting in good community development (Moore and Erdmann, 2002; Apostolakos et al., 2007; ; Razak, 2008), but there have not been any studies showing whether deployment of EcoReefs has any positive or negative effect on the immediate environment where they are deployed.

1.3 Statement of Purpose

The overall purpose of this study was to examine ecological changes resulting from the installation of 3 small artificial reefs, using EcoReef modules, on a mixed seagrass habitat of *Thalassia testudinum* and *Syringodium filiforme*.

The study focused on two elements of potential ecological change:

1. Changes in the seagrass in the immediate vicinity of the artificial reef, specifically:
    a. Any increase or decrease in length in seagrass blades
    b. Any increase or decrease in width in seagrass blades
    c. Any increase or decrease of epiphytic fauna cover on seagrass blades
    d. Any increase or decrease of percentage of death on seagrass blades
    e. Any increase or decrease of coverage of seagrass due to module placement

2. Changes in the fish population inhabiting the modules and surrounding seagrass, specifically:
    a. Any increase or decrease in fish populations inhabiting the modules
    b. Any changes of fish biodiversity inhabiting the modules

2.0 Methods and Materials

2.1 Location

The research sites were located on the western inshore area adjacent to Coco Cay (previously called Little Stirrup Cay), the easternmost island in the Berry island chain in the Bahamas, centered around GPS points 25º 49’ 14” N, 77º 55’ 54” (Photo 3).

The general habitat in the deployment zone was a shallow water environment (~3-4 m), consisting of a mixture of sand and seagrass (primarily *Thalassia testudinum*, with some *Syringodium filiforme*). The modules were placed directly on top of the seagrass beds and the area in which the sites were chosen had no obvious visible differences between them.

Photograph 3: Aerial Photograph of Coco Cay, showing data collection sites in the seagrass bed (dark area in center and left of the foreground): (note breakwater to the north.) experimental sites (X) control sites (C), and the old reef (O). The experimental sites and control sites are 30 meters away from each other. Water depths for data collection sites was between 3-4 m.

2.2 Artificial Reef Materials

Small artificial reefs were constructed using EcoReefs modules (Photo 4). These modules were assembled from eight component parts to form a branching coral mimic, and secured together using compression bands (later removed) and non-toxic epoxy (3M DP-605). Each module is 92 cm in diameter, 42 cm high, and has a mass of 25 kg. The modules are made of ceramic kaolinate ($Al_2Si_2O_5(OH)_4$), a non-reactive, semi-porous, pH neutral material.

Photograph 4: Experimental Reef Site consisting of 12 EcoReef modules.

2.3 Experimental Design

Seven data collection sites were used in this study: 3 experimental sites, 3 control locations, and an artificial reef that had existed at this location since 2004 (hereafter referred to as the old reef). All sites were in water of 3-4 meters depth, depending on the tide.

Each experimental site consisted of 12 EcoReef modules placed in an approximate circular shape, with the branch tips of each module slightly overlapping, and occupying a total area of approximately 12 sq. meters (Photo 4). Modules were anchored to the seafloor using stainless steel cable and sand anchors. Data on fish populations and seagrass (see following section) were collected (see section *2.4.1*) on the reef itself, and also in the "halo" area, up to 1.75 meters from the periphery of the reef (see Figure 1). Each experimental site was approximately 30 meters distant from its nearest neighbor.

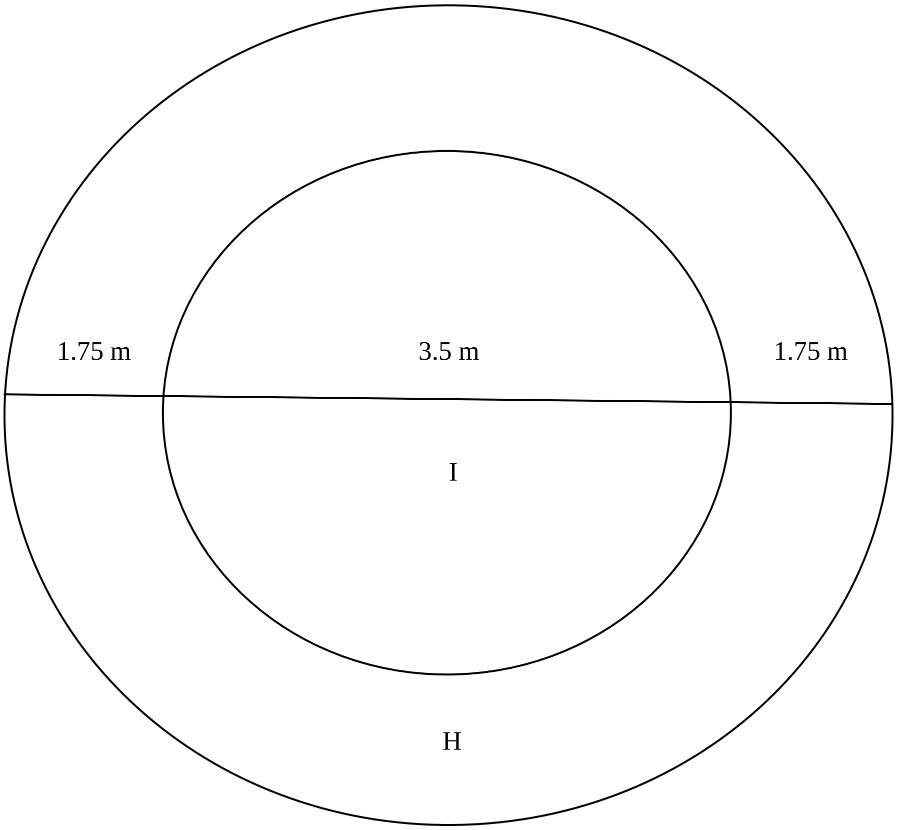


Figure 1: Diagrammatic layout of experimental and halo zones at experimental and control sites. Note that at the experimental sites, the letter I is filled with Ecoreefs whereas at the control sites this area is seagrass. The letter H stands for the halo zone.

The control sites for comparison were 30 m to the east of the experimental sites and appeared visibly indistinguishable from the experimental sites, with similar seagrass growth (potential sites in other directions has seagrass that was less dense). Within each control site, the central area (radius of 1.75 meters from the central point, marked by a pipe driven into the substrate) was designated the control area, and then the area that bordered that area for 1.75 meters was designated the “control halo” area (see Figure 1).

Data were also collected, for comparison, on an older artificial reef, first established in 2004, and subsequently expanded in 2007. This was essentially a qualitative comparison (since there is only 1 such reef) and was performed because this older reef possessed a visible halo of cleared seagrass, in order to see whether any changes noted corresponded to any observed changes in the experimental and control sites. This reef consisted of 7 ReefBalls (cement structures that resembled a half-dome with holes), and 22 EcoReefs modules, and occupied a total area of approximately 27 sq. meters (see Photo 5).

Photograph 5: Photo taken in 2009 of Old reef. The reef was initiated in 2004 (older modules can be seen to the left and right of front reefballs) and augmented in 2007 (newer modules appear stark white in photograph). Note halo zone around reef.

2.4 Data Collection

2.4.1 Sampling Periods

Sampling periods were designed to be twice a year and Royal Caribbean Cruise Lines (RCCL), who owns Coco Cay, agreed to provide island access, accommodations and food during this period. It turned out, however, that island access was limited by Royal Caribbean because of periods of construction and a high change over in management personnel who seemed completely unaware of previous RCCL commitments. Data collection periods therefore followed availability; installation and initial data collection took place in March 2009, and there were 4 additional sampling periods: August 8-11 2009, February 5-8 2010, July 7-9 2010, and December 8-10 2010.

Additional factors limited some data collection points. Delays in installation meant that no fish counts were performed during the initial installation period (except the old reef); based on the lack of fish observed, fish populations on the experimental and control sites are assumed to be zero for this period. Additionally, bad weather during the scheduled winter trip of February 2012 prevented collection of fish census data and all seagrass data with the exception of density. In both cases, RCCL would not allow additional time for data collection.

Coverage data for seagrass was taken on each of the 5 dates. Bad weather during the scheduled winter trip of February 2010 prevented collection of fish census data and all other seagrass data. Construction on Coco Cay then prevented attempts to travel to the island in the following months; the next trip was not permitted until July 2010. Hence there are 4 data collection points for all other seagrass measurements (length, width, etc.). There are 2 different measurement data factors for fish counts. Fish data was taken on the experimental and control sites for 3 dates. The installation trip had no fish on any of these sites so it was not included and the previously mentioned weather issues in February 2010 only allowed for 3 sampling periods. However, the old reef did have fish present during our installation trip. That combined with the additional fish sampling periods resulted in a total of 4 dates being used.

2.4.2 **Seagrass Measurements**

During each sampling period, 10 blades of *Thalassia testudinum* and 10 blades of *Syringodium filiforme* were randomly selected within each experimental and control area, and the following measurements taken: total length, width, percentage epiphytic cover, and percentage dead blade. Measurements were taken using a ruler on a blade of seagrass still in the sand. The blade was not removed. Measurements were taken starting at the bottom of the blade and measured to the tip for length. The amount of epiphytic fauna and dead blade were measured in the same manner. Width measurements were done by measuring the thickest part of the blade. For each sampling period, measurements were taken at each of the 3 experimental locations, at each of the 3 halo areas for those sites, at each of the 3 experimental control sites and at each of the 3 halo control sites; additionally seagrass measurements were also taken on the old reef, both at the reef and also in the halo area. Measurements were therefore collected on 140 *Thalassia* blades and 140 *Syringodium* blades each sampling period.

Additionally, coverage data was calculated for seagrass, using a photographic technique. A 0.5 x 0.5 m quadrat (i.e. 0.25 m^2) was placed randomly (note that seagrass coverage appeared uniform at collection points) within each of 14 locations noted above, and a photograph taken of the marked area using an underwater camera. Analysis of the data are described in section (e) below.

2.4.3 **Fish Data**

The primary data collection technique for fish populations was a modified version of the Bohnsack-Bannerot fish count (Bohnsack and Bannerot, 1986). In the original technique, the presence of different fish species observed in a visually estimated cylinder (radius of 7.5 m) was recorded for a period of five 5 minutes, and then subsequently the lengths and numbers of those individuals was recorded. The modified technique used here differed in two ways: (1) radius of the cylinder was dependent on where data was collected – data collected within the experimental plots, for example, was done within a ~1.75 m radius of the modules (but ~13.5 m for the old reef due to its size), while data collected within the halo zones reflected the boundaries of those zones (i.e. fish cylinder count of 1.75 m radius adjacent to the inner zones), and (2) length estimations, population numbers, and halo numbers were recorded simultaneously with presence data in the initial 5 minutes, as it was difficult to remember those data for the numerous small fish observed once a fish had swum out of sight.

All of the collection periods for fish size estimates were only for three categories: below 15 cm, between 15 and 30 cm, and above 30 cm. In order to understand distribution patterns in more detail, the parameters for the last two collection periods were amended. The original measurements mentioned above were done for consistency purposes but a count was done at the same time with amended measurements to be more specific. The size categories were expanded to six categories: below 2 cm, 2-5 cm, 5-10cm, 10-20 cm, 20-30 cm, and 30 and above.

2.5 Data Analysis

Note that the following applies to the experimental and control sites only. Since there was only 1 old site this was used for qualitative purposes.

2.5.1 **Seagrass Analysis (except coverage)**

All seagrass variables examined here (except for density) consisted of mean values taken from normally distributed data (data distributions were examined graphically), so analysis of the interaction of these variables and their effects was done using parametric ANOVA (analysis of variance) tests. Repeated measures ANOVA was used to test for the potential multivariate effects of factors (date, site, experimental sites vs. control sites, inner [experimental] area vs. halo area) on seagrass variables (*Thalassia* blade length, *Thalassia* blade width, amount of *Thalassia* epiphytes, amount of dead *Thalassia* tissue, *Syringodium* blade length, amount of *Syringodium* epiphytes, amount of dead *Syringodium* blade tissue).

2.5.2 **Seagrass Coverage Analysis**

Photographs (see 2.4.1 above) were analyzed using the program Coral Point Count (CPCe; Kohler and Gill, 2006). This program generates a series of random points on the photograph; the observer chooses the amount of points and identifies whether the points lie over seagrass or the substrate, and then the ratio of seagrass points to substrate points is a measure of coverage. A total of 20 points for each quadrat were selected as coverage appeared consistent. Statistical techniques used for the analysis of coverage were based on the pattern of results for the other seagrass variables. The ANOVA revealed there was considerable variation between sites, and that there was considerable variation due to date (see Results). Consequently the patterns of change of individual experimental sites were compared with individual control sites on the same collection date using a paired sample t-test. For convenience each experimental site was paired with the nearest control site, but any combination of experimental and control sites could have been used for this analysis. The paired sample t-test therefore resulted in the comparison of 3 mean changes per collection event (i.e. 15 total per grouping), that was performed initially as both inner (experimental) vs. inner (control) and halo (experimental) vs. halo (control). Simultaneously, the data was also analyzed (again 15 total per grouping) on the basis of paired sample t-tests within the experimental and the control sites, so therefore experimental (inner) vs. experimental (halo) and control (inner) vs. control (halo). A total of 60 comparisons were therefore made.

2.5.3 **Fish Data Analysis**

For reasons pointed out above (see 2.4.1), there were only 3 measured sets of fish population data, and the data analysis was therefore restricted to paired-sample t-tests, as this test is relatively robust (Zar, 1999), and stands up to limited sample sizes. For each paired-sample comparison, each experimental site was compared to the nearest control site, for convenience, as above.

3.0 Results

3.1 Seagrass

3.1.1 Individual factors excluding coverage

The data collected showed a strong effect for date, as this was a significant effect for all 7 factors (summarized in Table 3 [see Appendix for individual tests]; ANOVA, $p<0.0000001$ in each case). There was also considerable site variation, as Site was a significant effect for all of the factor variables except for the amount of dead *Thalassia* present (Table 3; ANOVA, $p<0.04$ except for dead *Thalassia*). This was measured to see whether the shape from the Ecoreefs caused an increase in seagrass mortality. *Thalassia* growth patterns were not any different at the experimental sites compared to the control locations (Table 3; ANOVA $p >0.05$ for *Thalassia* length, width, epiphytic fauna or dead *Thalassia*), but there was a difference in *Syringodium* lengths and the amount of dead *Syringodium* present (Table 3: ANOVA, $p<0.03$ for S*yringodium* length and dead *Syringodium*). *Thalassia* lengths and widths were different in a comparison of inner experimental sites vs. halo area (Table 3; ANOVA $p<0.02$ for both comparisons), but none of the other factors measured differed here. ANOVA tests only reveal differences without showing directionality of those differences, but a simple comparison of means showed that the *Thalassia* blades in the inner experimental areas were both shorter and less wide than in the halo areas, and the Syringodium blades were longer and there was more dead Syringodium at the control sites compared to the experimental sites (but not halo versus control)**.**

Table 1: Summary Table of mean *Thalassia* length, width, epiphytic fauna, and percentage of dead seagrass with standard deviation on 3 experimental and 3 control sites over the four sampling dates (March 2009, August 2009, July 2010, December 2010).

Date	Site	Thalassia Length (mean)	sd	Thalassia Width (mean)	sd	Thalassia Epiphytes (mean)	sd	Thalassia Dead (mean)	sd
Mar-09	Experimental Site 1 (inner)	10.28	2.72	0.67	0.13	4.69	3.61	2.30	3.34
	Experimental Site 1 (halo)	11.62	5.04	0.46	0.15	9.69	6.27	2.83	3.38
	Experimental Site 2 (inner)	15.40	4.85	0.51	0.14	13.81	5.32	2.02	2.79
	Experimental Site 2 (halo)	15.48	4.69	0.55	0.11	14.14	6.59	1.50	2.16
	Experimental Site 3 (inner)	12.61	4.73	0.57	0.15	8.97	6.53	3.31	4.32
	Experimental Site 3 (halo)	11.42	3.46	0.54	0.16	9.67	3.53	2.96	3.28
	Control Site 1 (inner)	14.83	5.61	0.73	0.20	13.91	6.81	3.83	4.90
	Control Site 1 (halo)	9.87	2.33	0.59	0.27	8.92	3.57	2.31	2.99
	Control Site 2 (inner)	13.10	2.08	0.50	0.16	12.57	1.51	3.37	3.37
	Control Site 2 (halo)	11.84	2.40	0.54	0.17	10.77	2.39	2.67	2.74
	Control Site 3 (inner)	12.24	3.01	0.55	0.11	11.02	2.64	2.23	2.50
	Control Site 3 (halo)	11.50	2.83	0.56	0.13	10.53	2.56	2.83	3.38
	Old Reef (inner)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Old Reef (halo)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Aug-09	Experimental Site 1 (inner)	11.71	1.19	2.33	0.38	0.59	0.03	0.27	0.06

	Site	Thalassia Length (mean)	sd	Thalassia Width (mean)	sd	Thalassia Epiphytes (mean)	sd	Thalassia Dead (mean)	sd
	Experimental Site 1 (halo)	12.83	4.69	0.40	0.13	12.05	4.30	2.00	2.54
	Experimental Site 2 (inner)	17.02	5.88	0.76	0.31	14.23	7.53	1.37	1.34
	Experimental Site 2 (halo)	13.88	4.72	0.50	0.20	11.27	5.66	2.52	2.62
	Experimental Site 3 (inner)	16.36	3.34	0.42	0.16	13.78	3.73	2.55	2.25
	Experimental Site 3 (halo)	14.92	4.27	0.48	0.19	11.79	5.64	1.94	1.84
	Control Site 1 (inner)	13.52	4.31	0.44	0.16	11.92	5.67	2.58	2.26
	Control Site 1 (halo)	11.88	3.73	0.47	0.14	8.80	5.80	1.29	1.41
	Control Site 2 (inner)	14.26	3.11	0.51	0.13	12.24	5.02	2.81	2.13
	Control Site 2 (halo)	13.24	2.94	0.50	0.13	8.96	5.86	2.75	2.44
	Control Site 3 (inner)	18.78	7.44	0.60	0.20	11.53	9.78	1.86	2.63
	Control Site 3 (halo)	17.62	7.21	0.60	0.24	14.04	9.89	1.68	1.93
	Old Reef (inner)	13.66	6.10	0.51	0.19	13.20	6.01	2.90	2.51
	Old Reef (halo)	11.04	3.33	0.49	0.17	9.68	4.48	1.03	1.87
Jul-10	Experimental Site 1 (inner)	18.17	7.88	0.79	0.17	13.57	11.56	0.11	0.35
	Experimental Site 1 (halo)	15.50	4.14	0.61	0.22	12.24	6.68	1.14	2.14
	Experimental Site 2 (inner)	24.65	5.11	0.83	0.24	15.37	10.55	1.04	2.86
	Experimental Site 2 (halo)	23.05	2.97	0.70	0.26	17.63	6.59	1.23	2.77

	Site	Thalassia Length (mean)	sd	Thalassia Width (mean)	sd	Thalassia Epiphytes (mean)	sd	Thalassia Dead (mean)	sd
	Experimental Site 3 (inner)	22.21	7.88	0.63	0.31	18.80	8.49	3.32	4.22
	Experimental Site 3 (halo)	18.34	5.02	0.67	0.23	16.48	7.68	1.94	2.19
	Control Site 1 (inner)	15.64	4.41	0.59	0.15	14.86	4.58	0.52	0.75
	Control Site 1 (halo)	15.20	4.69	0.56	0.18	13.64	3.97	0.38	0.57
	Control Site 2 (inner)	17.49	5.15	0.68	0.22	15.17	5.73	1.67	2.91
	Control Site 2 (halo)	15.64	3.70	0.66	0.21	13.55	3.50	0.59	0.80
	Control Site 3 (inner)	16.71	4.57	0.79	0.27	14.98	5.91	2.68	3.01
	Control Site 3 (halo)	16.34	4.06	0.69	0.28	15.44	4.44	1.95	1.63
	Old Reef (inner)	22.59	7.88	0.76	0.38	21.59	7.34	0.52	1.64
	Old Reef (halo)	12.22	6.77	0.67	0.20	12.02	6.66	1.31	2.03
Dec-10	Experimental Site 1 (inner)	16.75	4.68	0.70	0.19	11.93	8.37	2.42	2.17
	Experimental Site 1 (halo)	16.59	4.03	0.69	0.15	11.13	5.26	0.44	0.71
	Experimental Site 2 (inner)	19.14	4.11	0.83	0.18	10.15	8.49	1.98	3.17
	Experimental Site 2 (halo)	17.77	3.97	0.77	0.21	14.49	8.06	4.29	5.41
	Experimental Site 3 (inner)	17.04	6.86	0.60	0.12	9.03	10.12	1.63	2.78
	Experimental Site 3 (halo)	17.04	5.08	0.60	0.12	11.72	8.14	2.85	2.40
	Control Site 1 (inner)	18.59	4.33	0.64	0.13	17.70	4.28	0.52	0.95

	Site	Thalassia Length (mean)	sd	Thalassia Width (mean)	sd	Thalassia Epiphytes (mean)	sd	Thalassia Dead (mean)	sd
	Control Site 1 (halo)	16.60	4.72	0.64	0.12	15.67	4.38	0.49	0.82
	Control Site 2 (inner)	18.17	4.65	0.63	0.16	17.56	5.18	2.45	2.36
	Control Site 2 (halo)	17.74	4.57	0.63	0.15	17.30	4.81	1.89	2.14
	Control Site 3 (inner)	16.78	4.24	0.77	0.18	14.53	4.77	1.59	2.15
	Control Site 3 (halo)	16.75	4.30	0.65	0.17	15.70	4.28	0.88	1.30
	Old Reef (inner)	16.04	6.44	0.62	0.23	12.89	8.50	2.25	2.40
	Old Reef (halo)	13.63	6.55	0.59	0.16	10.06	8.22	2.59	4.39

Table 2: Summary Table of mean *Syringodium* length, width, epiphytic fauna, and percentage of dead seagrass with standard deviation on 3 experimental and 3 control sites over the four sampling dates (March 2009, August 2009, July 2010, December 2010).

Date	Site	Syringodium Length (mean)	sd	Syringodium Epiphytes (mean)	sd	Syringodium Dead (mean)	sd
Mar-09	Experimental Site 1 (inner)	13.21	3.37	5.25	4.63	2.56	3.51
	Experimental Site 1 (halo)	11.27	3.49	8.70	3.28	0.54	1.20
	Experimental Site 2 (inner)	14.66	6.88	2.69	2.21	3.05	3.18
	Experimental Site 2 (halo)	18.59	4.87	4.42	5.92	3.11	4.41
	Experimental Site 3 (inner)	11.51	3.48	4.29	4.15	1.13	1.74

	Site	Syringodium Length (mean)	sd	Syringodium Epiphytes (mean)	sd	Syringodium Dead (mean)	sd
	Experimental Site 3 (halo)	11.31	3.41	6.67	5.45	4.74	5.23
	Control Site 1 (inner)	13.56	4.21	8.11	5.15	0.34	0.75
	Control Site 1 (halo)	14.38	3.96	6.30	3.96	0.42	1.00
	Control Site 2 (inner)	15.85	5.46	7.81	7.81	1.86	2.88
	Control Site 2 (halo)	13.00	3.58	5.47	4.80	1.97	2.21
	Control Site 3 (inner)	13.74	3.27	8.48	6.07	2.02	2.43
	Control Site 3 (halo)	14.40	2.81	13.03	2.90	1.39	1.54
	Old Reef (inner)	n/a	n/a	n/a	n/a	n/a	n/a
	Old Reef (halo)	n/a	n/a	n/a	n/a	n/a	n/a
Aug-09	Experimental Site 1 (inner)	15.20	5.55	0.65	6.75	1.10	3.68
	Experimental Site 1 (halo)	16.68	7.52	10.50	5.86	2.60	1.94
	Experimental Site 2 (inner)	18.50	7.32	8.24	9.98	0.93	1.33
	Experimental Site 2 (halo)	15.57	4.68	8.57	6.47	1.36	1.36
	Experimental Site 3 (inner)	14.65	4.57	12.22	5.86	1.85	2.25
	Experimental Site 3 (halo)	13.89	4.51	9.58	7.73	1.30	1.05
	Control Site 1 (inner)	13.39	3.67	9.67	6.16	1.50	1.51
	Control Site 1 (halo)	14.95	4.64	8.43	6.16	1.58	1.80

	Site	Syringodium Length (mean)	sd	Syringodium Epiphytes (mean)	sd	Syringodium Dead (mean)	sd
	Control Site 2 (inner)	15.56	4.41	9.71	6.59	2.90	2.84
	Control Site 2 (halo)	14.00	4.08	10.55	6.73	2.13	2.09
	Control Site 3 (inner)	18.54	6.47	11.60	9.61	0.80	1.07
	Control Site 3 (halo)	16.95	6.23	10.26	9.50	0.56	0.87
	Old Reef (inner)	12.36	3.87	9.90	4.82	1.63	2.34
	Old Reef (halo)	12.66	3.45	11.26	3.77	1.65	4.77
Jul-10	Experimental Site 1 (inner)	18.65	6.15	6.72	8.34	0.32	0.98
	Experimental Site 1 (halo)	13.54	3.99	5.79	6.01	0.44	1.01
	Experimental Site 2 (inner)	18.97	5.34	0.00	0.00	0.01	0.02
	Experimental Site 2 (halo)	16.73	5.26	0.26	0.56	0.01	0.02
	Experimental Site 3 (inner)	20.24	7.69	0.87	1.91	1.12	2.33
	Experimental Site 3 (halo)	17.50	3.89	4.22	7.32	0.52	0.96
	Control Site 1 (inner)	17.06	5.82	10.30	9.25	1.38	2.50
	Control Site 1 (halo)	17.45	6.49	8.70	8.14	0.47	0.81
	Control Site 2 (inner)	16.18	4.39	11.20	8.29	0.46	0.62
	Control Site 2 (halo)	17.24	5.01	10.91	8.15	0.53	0.81
	Control Site 3 (inner)	17.59	4.81	12.70	5.77	0.54	0.62

	Site	Syringodium Length (mean)	sd	Syringodium Epiphytes (mean)	sd	Syringodium Dead (mean)	sd
	Control Site 3 (halo)	17.94	4.63	13.81	6.37	0.53	0.62
	Old Reef (inner)	17.47	4.59	13.53	8.71	0.82	2.23
	Old Reef (halo)	15.61	5.20	11.72	7.33	1.64	2.20
Dec-10	Experimental Site 1 (inner)	17.08	4.68	0.00	0.00	0.64	1.07
	Experimental Site 1 (halo)	16.02	4.66	0.00	0.00	0.45	0.73
	Experimental Site 2 (inner)	16.64	3.28	0.00	0.00	0.63	1.61
	Experimental Site 2 (halo)	15.22	5.49	0.00	0.00	0.91	1.89
	Experimental Site 3 (inner)	16.36	5.40	0.02	0.03	0.61	0.85
	Experimental Site 3 (halo)	18.21	5.88	0.94	2.97	0.28	0.58
	Control Site 1 (inner)	16.24	3.44	12.73	5.89	0.56	1.00
	Control Site 1 (halo)	15.82	4.09	13.93	5.49	0.77	1.06
	Control Site 2 (inner)	16.80	2.84	12.20	5.60	1.78	2.38
	Control Site 2 (halo)	16.29	3.82	11.24	4.39	1.31	1.40
	Control Site 3 (inner)	14.71	2.68	10.45	5.74	0.98	1.16
	Control Site 3 (halo)	16.50	4.18	11.92	8.05	1.08	1.31
	Old Reef (inner)	14.34	3.00	0.67	1.63	0.23	0.46
	Old Reef (halo)	15.62	6.42	1.52	2.56	2.13	3.77

Table 3: Summary table showing ***ANOVA*** significance values for factors (listed vertically) affecting seagrass variables (listed horizontally) – prefixes T and S refer to variables for *Thalassia testudinum* and *Syringodium filiforme*, respectively. Len = Length, Wid = Width, Epi = percentage epiphytes, Dead = percentage dead blade, ns = p value < 0.05.

	T Length	**T Width**	**T Epi**	**T Dead**	**S Length**	**S Epi**	**S Dead**
Date	0.0000001	0.0000001	0.0000001	0.0000001	0.0000001	0.000022	0.000001
Site	0.000001	0.0002	0.04	n.s.	0.0117	0.003	0.033
Exp/Con	n.s.	n.s.	n.s.	n.s.	0.003	n.s.	0.032
In/Halo	0.003	0.018	n.s.	n.s.	n.s.	n.s.	n.s.

3.1.2 Seagrass Coverage

Table 4: Summary table representing the percent coverage of both species of seagrass as they correspond to date and site.

Date	Site	% of total coverage by seagrass
Mar-09	Experimental Site 1 (inner)	85%
	Experimental Site 1 (halo)	75%
	Experimental Site 2 (inner)	65%
	Experimental Site 2 (halo)	80%
	Experimental Site 3 (inner)	55%
	Experimental Site 3 (halo)	75%
	Control Site 1 (inner)	75%
	Control Site 1 (halo)	80%
	Control Site 2 (inner)	80%
	Control Site 2 (halo)	70%

Date	Site	% of total coverage by seagrass
	Control Site 3 (inner)	65%
	Control Site 3 (halo)	60%
Aug-09	Experimental Site 1 (inner)	60%
	Experimental Site 1 (halo)	85%
	Experimental Site 2 (inner)	95%
	Experimental Site 2 (halo)	85%
	Experimental Site 3 (inner)	100%
	Experimental Site 3 (halo)	80%
	Control Site 1 (inner)	100%
	Control Site 1 (halo)	100%
	Control Site 2 (inner)	100%
	Control Site 2 (halo)	90%
	Control Site 3 (inner)	95%
	Control Site 3 (halo)	100%
Feb-10	Experimental Site 1 (inner)	50%
	Experimental Site 1 (halo)	80%
	Experimental Site 2 (inner)	60%
	Experimental Site 2 (halo)	60%
	Experimental Site 3 (inner)	55%
	Experimental Site 3 (halo)	65%
	Control Site 1 (inner)	75%
	Control Site 1 (halo)	75%
	Control Site 2 (inner)	65%
	Control Site 2 (halo)	65%
	Control Site 3 (inner)	70%
	Control Site 3 (halo)	65%
Jul-10	Experimental Site 1 (inner)	100%
	Experimental Site 1 (halo)	100%

Date	Site	% of total coverage by seagrass
	Experimental Site 2 (inner)	100%
	Experimental Site 2 (halo)	100%
	Experimental Site 3 (inner)	90%
	Experimental Site 3 (halo)	100%
	Control Site 1 (inner)	95%
	Control Site 1 (halo)	100%
	Control Site 2 (inner)	100%
	Control Site 2 (halo)	100%
	Control Site 3 (inner)	100%
	Control Site 3 (halo)	100%
Dec-10	Experimental Site 1 (inner)	65%
	Experimental Site 1 (halo)	80%
	Experimental Site 2 (inner)	70%
	Experimental Site 2 (halo)	85%
	Experimental Site 3 (inner)	60%
	Experimental Site 3 (halo)	80%
	Control Site 1 (inner)	75%
	Control Site 1 (halo)	80%
	Control Site 2 (inner)	80%
	Control Site 2 (halo)	75%
	Control Site 3 (inner)	80%
	Control Site 3 (halo)	75%

For parametric comparisons (Table 5) coverage was a significant variable, as there was significantly more seagrass coverage in the halo zones compared to the inner experiment zones ($p < 0.001$, Paired sample t-test, $p < 0.005$; Table 5), and more coverage on the control sites compared to the experimental sites ($p < 0.0025$, Paired sample t-test, $p < 0.0005$; Table 5), but not more coverage on the halo experimental zone vs the halo control zone (Paired sample t-test, $0.05 < p < 0.010$; Table 5).

Table 5: Summary Table showing significance values for parametric (paired sample t-tests) comparisons of seagrass [both species lumped] coverage, for 4 categories; experimental coverage (**EC(I)**) vs. control coverage (**CC(I)**) (inner zone), experimental coverage (**ED(H)**) vs. control coverage (**CC(H)**) (halo zone), halo coverage (**HC(E)**) vs. inner coverage (**IC(E)**) (experimental zone), and halo coverage (**HC(C)**) vs. inner coverage (**IC(C)**) (control zones). Note all parametric comparisons are one-tailed (i.e. p values are insignificant over 0.025); sign values are retained (for clarity). For density measurements see text.

	CC(I)>EC(I)	CC(H)>EC(H)	HC(E)>IC(E)	HC(C)>IC(C)
Parametric	p<0.0005	n.s.	p<0.0005	n.s

3.2 Fish populations

3.2.1 General Population Patterns - overall numbers and species diversity

For all 3 fish data collection periods, there were more fish present (i.e. in terms of overall numbers) on the inner EcoReef sites than on the halo sites (Table 7; t-test, $p<0.001$). At the same time, there were more fish present of the inner EcoReefs sites than on the inner control sites (Table 7; t-test; $p < 0.007$), and there were more fish present of the EcoReef halo sites than on the control halo sites (t-test; $p<0.008$). There was no difference between the number of fish present on inner vs. halo sites at the control locations (Table 7; t-test; $p=0.29$). Similarly, there were more species of fish present on inner EcoReef sites that on halo sites (Table 7; t-test; $p<0.0004$), there were more species on the inner EcoReef sites than on the inner control sites (Table 7; t-test, p<0.00001), and there were more species on the experimental halo sites than on the control halo sites (Table 7; t-test, p<0.002). As with overall numbers, there was no difference in the number of species found in the inner control sites vs. the halo control sites (Table 7; t-test, no p value could be calculated because all differences equated to zero).

Table 6: Summary table of total fish count, species count, and species identification on the 3 experimental sites, 3 control sites, and the old reef. Includes 3 sampling periods on the experimental and control sites and 4 sampling periods on the old reef.

Date	Site	Total Fish Count	Total Species Count	Species ID
Mar-09	Experimental Site 1 (inner)	n/a	n/a	n/a
	Experimental Site 1 (halo)	n/a	n/a	n/a
	Experimental Site 2 (inner)	n/a	n/a	n/a
	Experimental Site 2 (halo)	n/a	n/a	n/a
	Experimental Site 3 (inner)	n/a	n/a	n/a
	Experimental Site 3 (halo)	n/a	n/a	n/a
	Control Site 1 (inner)	n/a	n/a	n/a
	Control Site 1 (halo)	n/a	n/a	n/a
	Control Site 2 (inner)	n/a	n/a	n/a
	Control Site 2 (halo)	n/a	n/a	n/a
	Control Site 3 (inner)	n/a	n/a	n/a

Date	Site	Total Fish Count	Total Species Count	Species ID
	Control Site 3 (halo)	n/a	n/a	n/a
	Old Reef (inner)	239	17	a,b,c,d,h,j,k,l,n,o,p,t,u,w,x
	Old Reef (halo)	37	5	a,b,c,d,h,o,p,
Aug-09	Experimental Site 1 (inner)	143	12	b,e,f,g,h,l,k,q,v,x,z,aa
	Experimental Site 1 (halo)	45	7	b,e,l,g,q,v,aa
	Experimental Site 2 (inner)	139	8	e,g,h,l,m,n,u,aa
	Experimental Site 2 (halo)	22	5	e,g,l,n,aa
	Experimental Site 3 (inner)	51	8	b,e,f,g,l,s,z,aa
	Experimental Site 3 (halo)	11	4	f,i,s,aa
	Control Site 1 (inner)	0	0	n/a
	Control Site 1 (halo)	2	1	i
	Control Site 2 (inner)	0	0	n/a
	Control Site 2 (halo)	0	0	n/a
	Control Site 3 (inner)	0	0	n/a
	Control Site 3 (halo)	1	1	f
	Old Reef (inner)	228	10	a,b,e,h,j,l,m,q,z,aa
	Old Reef (halo)	68	6	a,b,e,m,q,aa

Date	Site	Total Fish Count	Total Species Count	Species ID
Jul-10	Experimental Site 1 (inner)	35	8	a,e,j,k,m,y,aa,ee
	Experimental Site 1 (halo)	5	2	aa,e
	Experimental Site 2 (inner)	30	7	a,c,e,g,h,z,aa
	Experimental Site 2 (halo)	22	6	a,c,e,g,h,aa
	Experimental Site 3 (inner)	36	8	a,f,g,h,l,o,z,aa
	Experimental Site 3 (halo)	6	4	f,h,o,aa
	Control Site 1 (inner)	0	0	n/a
	Control Site 1 (halo)	0	0	n/a
	Control Site 2 (inner)	0	0	n/a
	Control Site 2 (halo)	0	0	n/a
	Control Site 3 (inner)	0	0	n/a
	Control Site 3 (halo)	1	1	o
	Old Reef (inner)	416	17	a,b,c,e,g,h,j,k,l,m,u,z,aa,bb,cc,dd,ee
	Old Reef (halo)	91	5	a,b,c,aa,bb
Dec-10	Experimental Site 1 (inner)	69	6	a,c,h,r,u,ff
	Experimental Site 1 (halo)	1	1	c
	Experimental Site 2 (inner)	153	7	a,b,g,h,i,x,aa

Date	Site	Total Fish Count	Total Species Count	Species ID
	Experimental Site 2 (halo)	14	1	aa
	Experimental Site 3 (inner)	79	6	a,b,i,j,o,aa
	Experimental Site 3 (halo)	3	2	o,aa
	Control Site 1 (inner)	0	0	n/a
	Control Site 1 (halo)	0	0	n/a
	Control Site 2 (inner)	0	0	n/a
	Control Site 2 (halo)	0	0	n/a
	Control Site 3 (inner)	0	0	n/a
	Control Site 3 (halo)	1	1	o
	Old Reef (inner)	251	12	a,b,c,e,f,g,h,k,l,z,aa,ff
	Old Reef (halo)	32	3	b,c,aa

Legend for fish species for table 6:

ID	Common Name	Species Name
a	Blue Striped Grunt	*Haemulon sciuris*
b	White Grunt	*Haemulon plumierii*
c	Stoplight Parrotfish	*Sparisoma viride*
d	Redtail Parrotfish	*Sparisoma chrysoptarum*
e	Striped Parrot	*Scarus iserti*
f	Redband Parrot	*Sparisoma aurofrenatum*
g	Yellowhead Wrasse	*Halichoeres gamoti*
h	Blue Head Wrasse	*Thalassoma bifasciatum*
i	Blackear Wrasse	*Halichoeres poeyl*
j	Sharpnose Puffer	*Canthigaster rostrata*
k	Beaugregory Damsel	*Stegastes leucostictus*
l	Bicolor Damsel	*Stegastes partitus*
m	Sgt Major	*Abudefduf saxatilis*
n	Spotted Goatfish	*Pseudupeneus maculatus*
o	Great Barracuda	*Sphyraena barracuda*
p	Gray Angel	*Pomacanthus arcuatus*
q	French Angel	*Pomacanthus paru*
r	Queen Angel	*Holacanthus ciliaris*
s	Yellow Jack	*Caranx bartholomaei*
t	Cleaning Goby	*Gobiasoma genie*
u	Nassau Grouper	*Epinephelus striatus*
v	Southern Stingray	*Dasyatis americana*
w	Harlequin Bass	*Serranus tigrinus*
x	Four Eye Butterfly	*Chaetodon capistratus*
y	Spotfin Butterfly	*Chaetodon ocellatus*
z	Blue Tang	*Acanthurus coeruleus*
aa	Yellow Tail Snapper	*Ocyurus chrysurus*
bb	Almaco Jack	*Seriola rivoliana*
cc	Bar Jack	*Caranx ruber*
dd	Spanish Hogfish	*Bodianus rufus*
ee	Blue Hamlet	*Hypoplectrus nigricans*
ff	Peacock Flounder	*Bothus lunates*

Table 7: Statistical comparison of means (one-tailed t-test) for fish numbers and number of species (all sampling periods pooled together). Abbreviations are as follows **EI –** experimental inner zone, **EH –** experimental halo zone. **CI –** control inner zone, **CH –** control halo zone.

	EI > EH	**EH > CH**	**EI > CI**	**CI > CH**
Fish Numbers	p<0.007	p<0.008	p<0.001	n.s
No. of Species	p<0.0004	p<0.002	p<0.00001	n.s

3.2.2. Seasonal Patterns

Although since there are only 3 data sampling periods, any conclusions drawn can only be tentative, there was no significant difference in the number of total fish counted in the 2 summer periods (August 2009 and July 2010, paired sample t-test, $P>0.05$) for either the inner or halo experimental areas, or between July 2010 and December 2010 (paired sample t-test, $p>0.05$)**.** However, there was a significant different between the number of fish counted in August 2009 and July 2010 (paired sample t-test, $p<0.05$ and 0.02 for experimental inner and halo areas, respectively. Note that these comparisons were not done for the controls, as there were virtually no fish (only 4) present during all sampling periods. The total changes in fish counts over time, for both the experimental sites and the Old Reef, are shown in Figure 2. (Note: that these comparisons are between the total number of fish observed summed for all data collection points.)

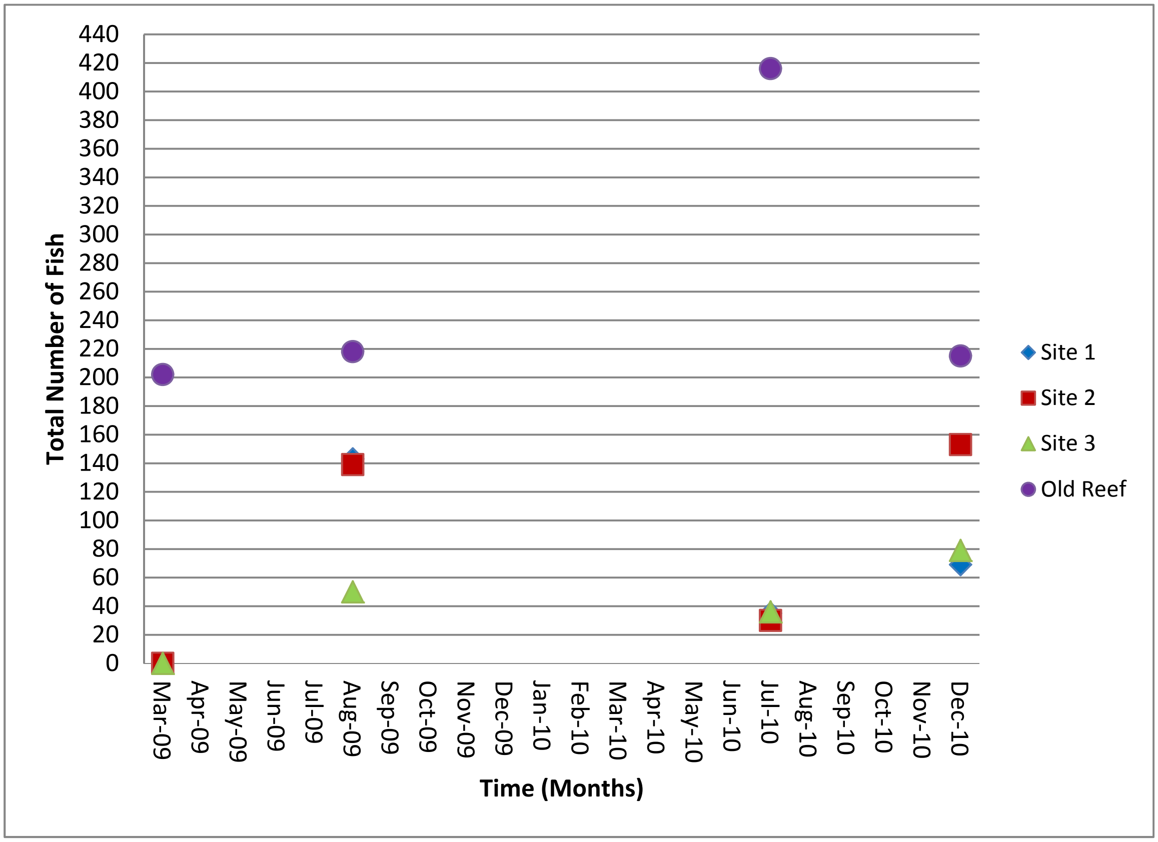


Figure 2: The total number of fish counted on the three experimental sites and the old reef over time.

3.2.3. **Size distributions and comparison with the Old Reef**

Size distributions were measured in two ways (see Methods). Using the initial 3 size categories, ~84% of fish observed on the experimental sites (for both inner and halo zones), were less than 15 cm in length (Figure 3), whereas fish counts on the old reef were roughly equal ranging between 80 and 100 individuals for all 3 size categories (Figure 4). More detailed size estimates collected over the last 2 sampling periods showed that most of the small fish on the experimental sites were between 2 and 5 cm in length (Figure 5), whereas the most abundant size category on the old reef was for fish over 30 cm in length (Figure 6).

There was a difference in both species numbers and species biodiversity on the experimental sites. At site 1 approximately 53% of the fish at site 1 were parrotfish (Figure 7), at site 2 there was a more even distribution of several different species (Figure 8), and at site 3 more than 65% of the fish observed were haemulids (i.e. grunts; see Figure 9). Similar to site 3, more than 67% of the fish observed on the old reef were also grunts (Figure 10), although much bigger, as noted above.

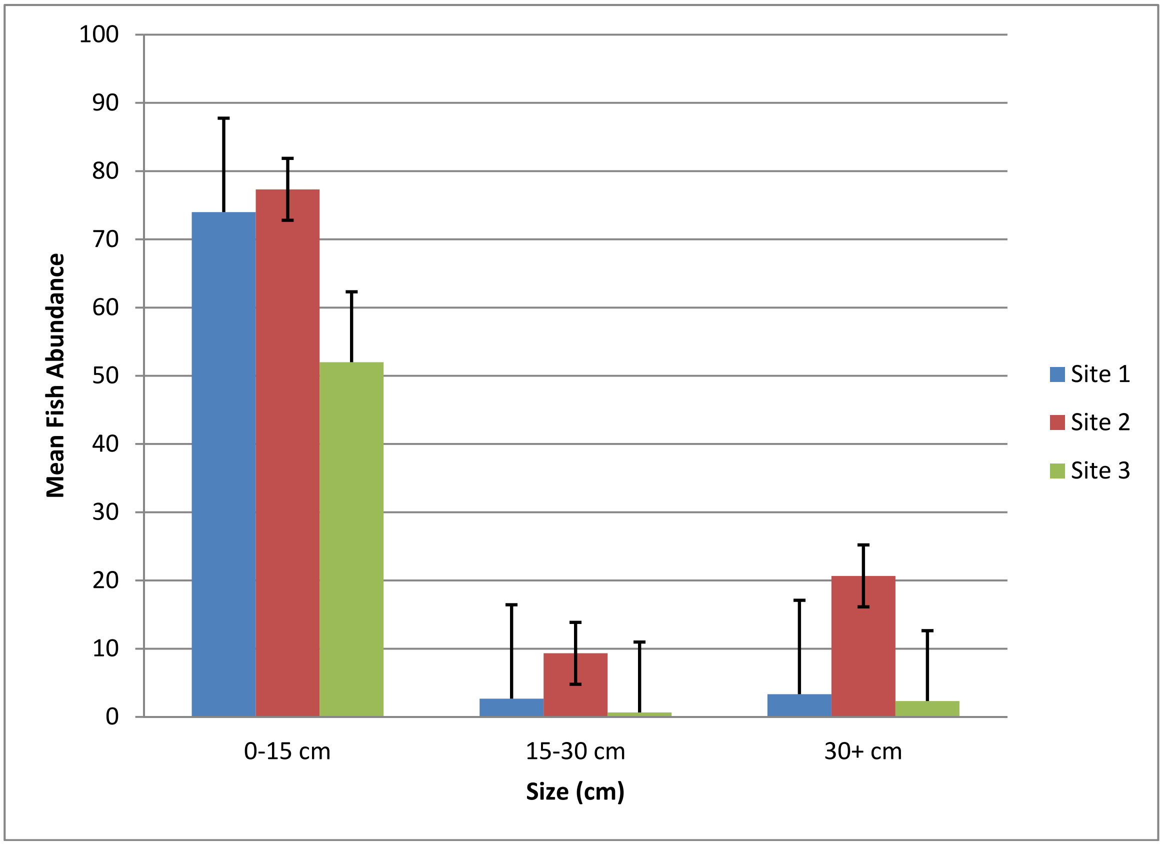


Figure 3: Mean fish abundance of three experimantal sites using designated size (cm) categories averaged over 3 sampling periods (August 2009, July 2010, December 2010) with SD bars.

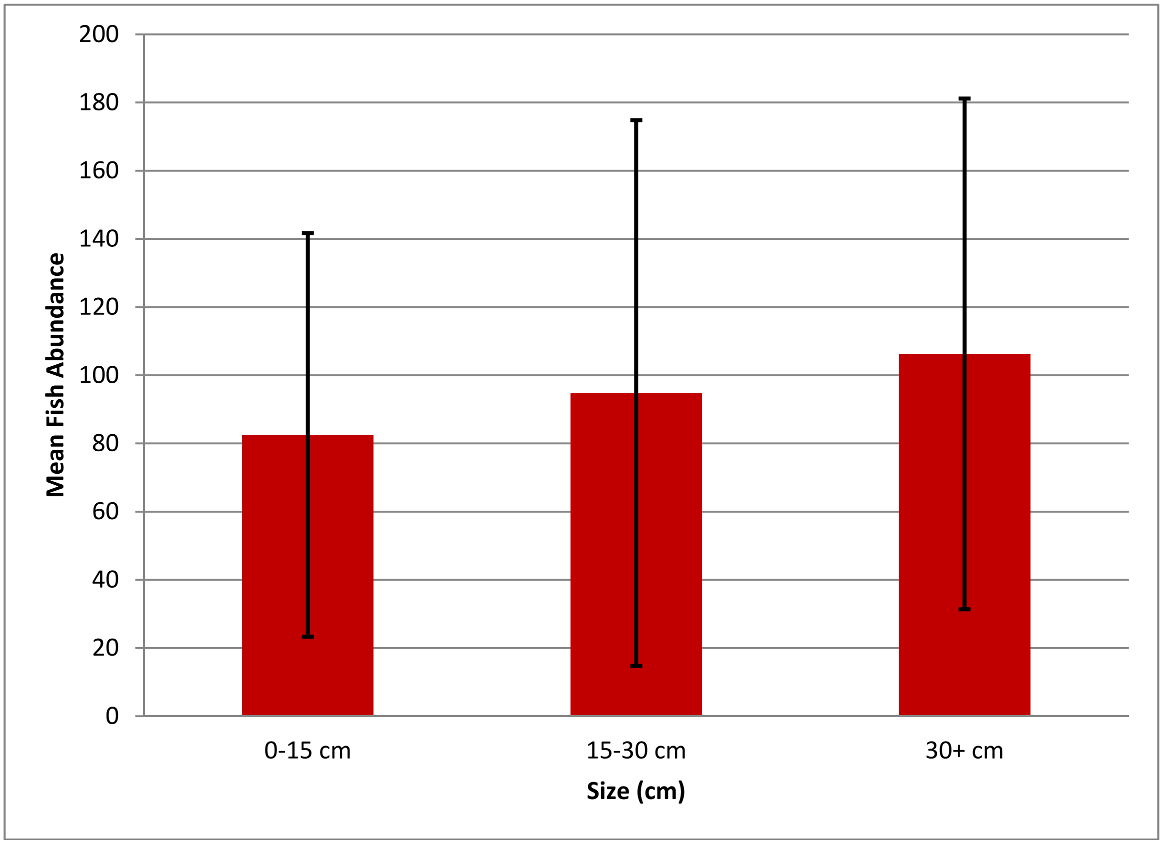


Figure 4: Mean fish abundance using originally designated size (cm) categories on the Old Reef averaged over 4 sampling periods with SD bars (March 2009, August 2009, July 2010, December 2010).

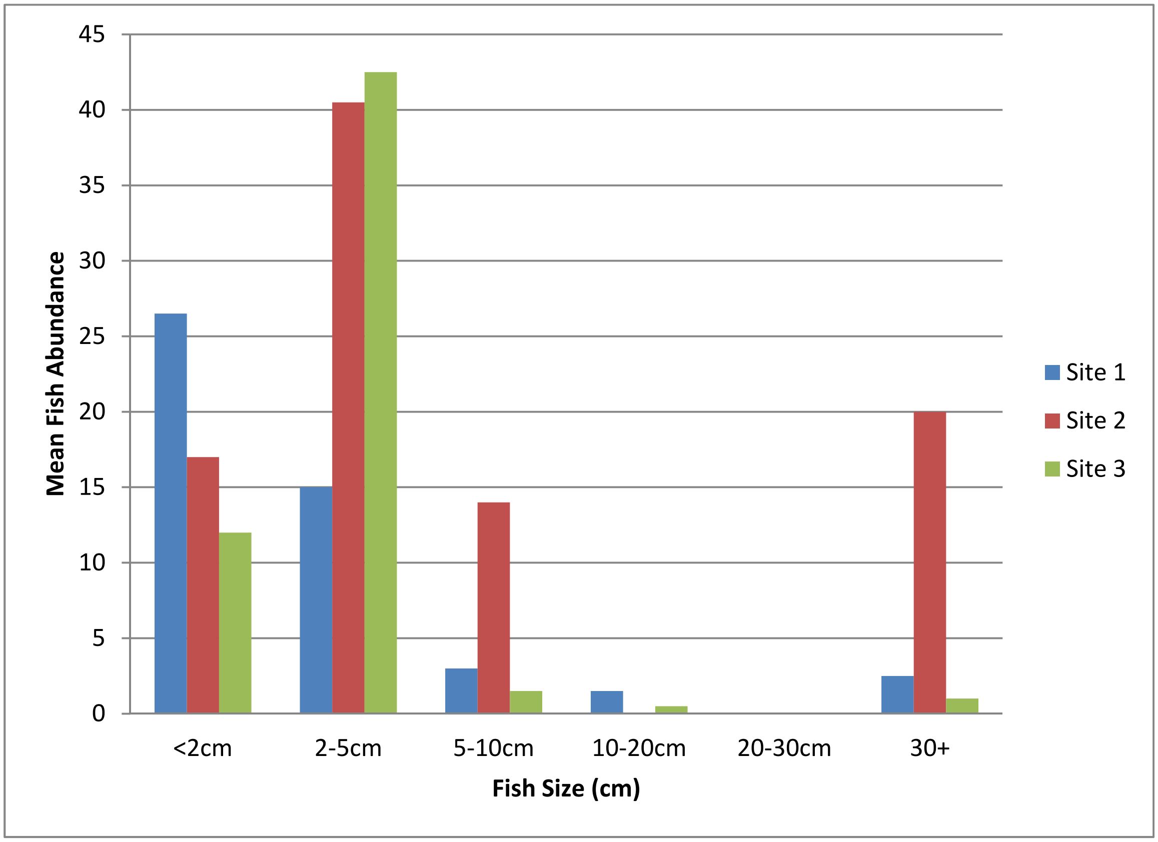


Figure 5: Mean fish abundance using modified size (cm) categories on experimental sites averaged over 2 sampling dates (July 2010, December 2010). SD bars are not included because there are only 2 collection dates.

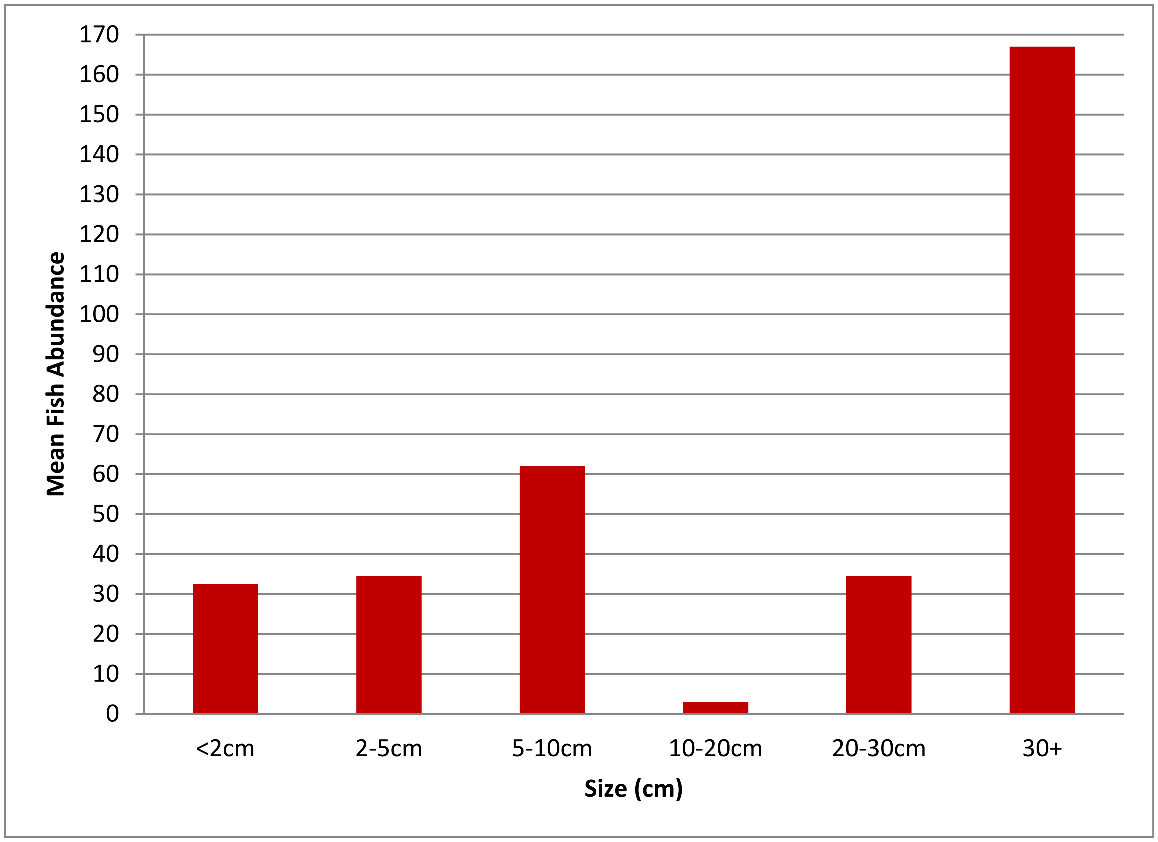


Figure 6: Mean fish abundance using modified size (cm) categories averaged over 2 sampling periods on the Old Reef (July 2010, December 2010). SD bars are not included because there are only 2 collection dates.

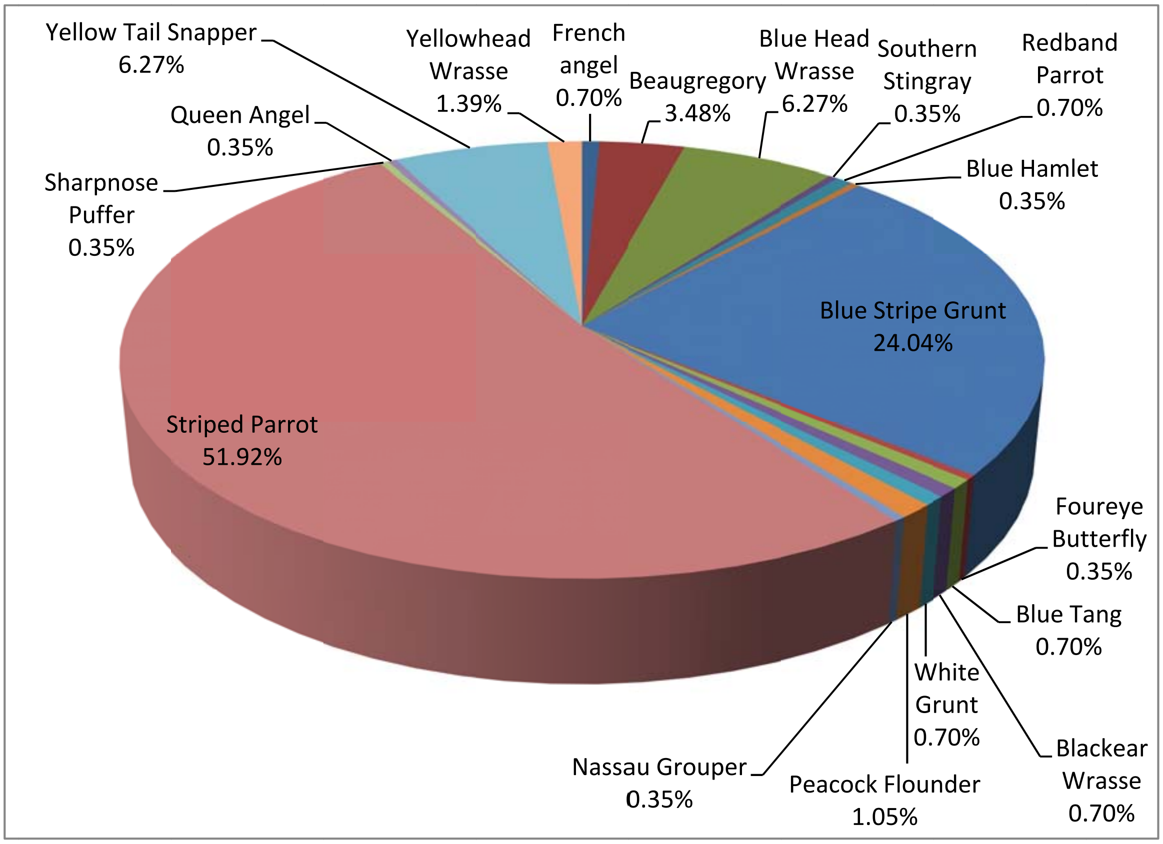


Figure 7: Percentage values for fish biodiversity on experimental Site 1 averaged over three sampling periods. Total abundance = 292 fishes

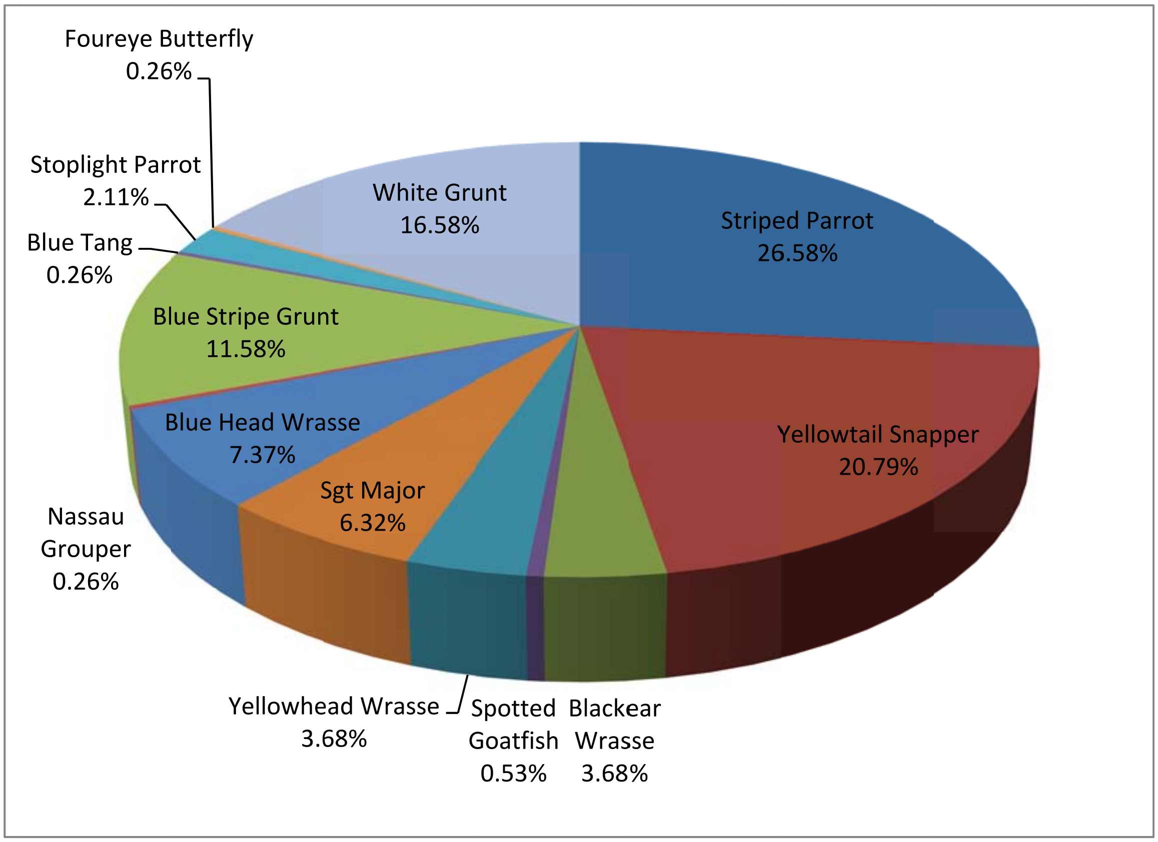


Figure 8: Percentage values for fish biodiversity on experimental Site 2 averaged over three sampling periods. Total Abundance = 380 fishes.

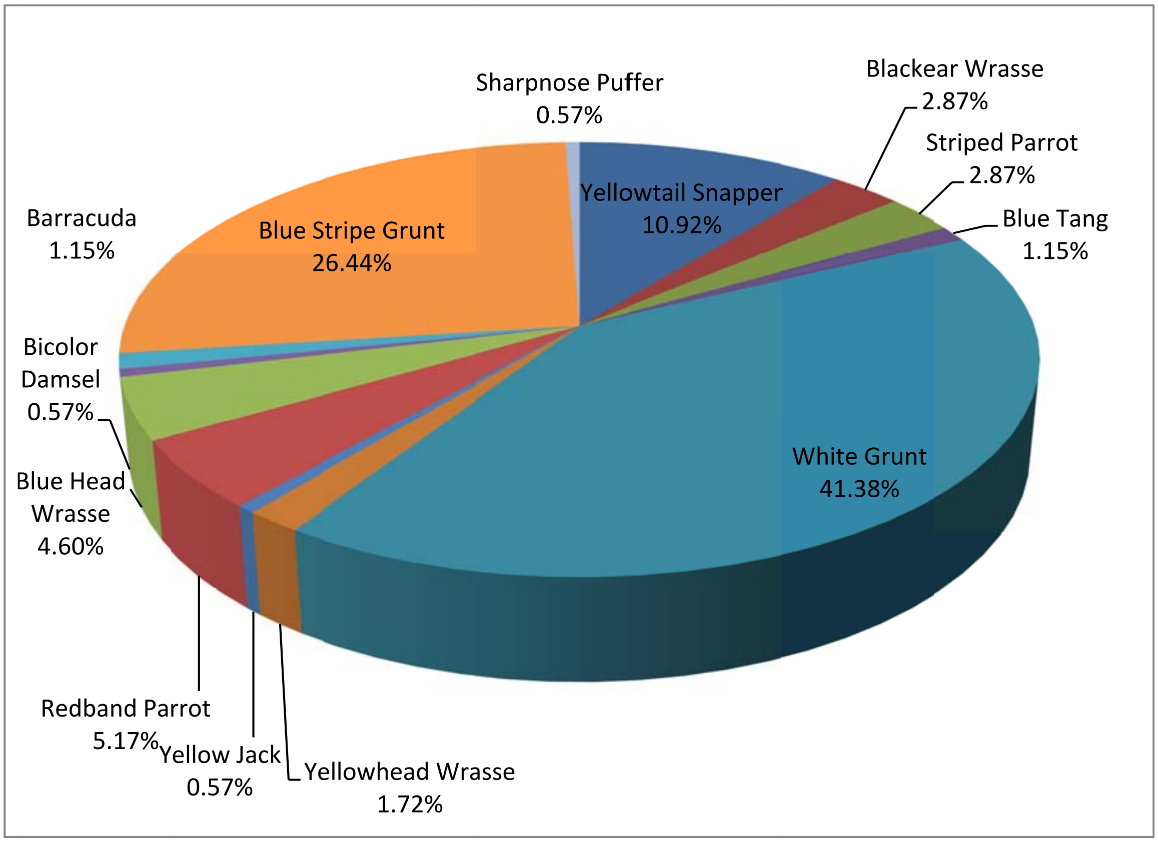


Figure 9: Percentage values for fish biodiversity on experimental Site 3 averaged over three sampling periods. Total Abundance = 174 fishes.

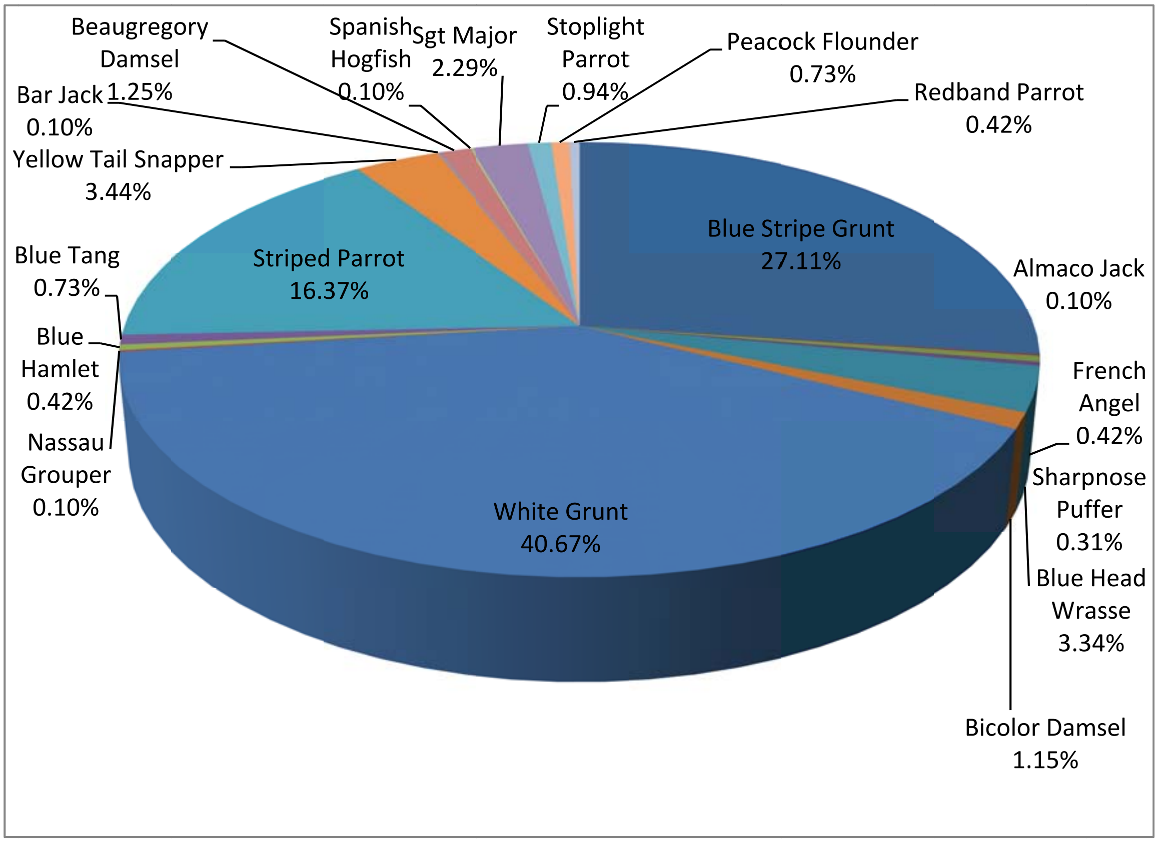


Figure 10: Percentage values for fish biodiversity on the Old Reef averaged over three sampling periods. Total Abundance = 971 fishes.

Note: No figures shown for control sites due to the low number of fish, if any, at the sampling dates.

4.0 Discussion

4.1 Effects of Ecoreefs on Seagrass

In this study, placing EcoReef modules over seagrass has some effect on the growth and coverage of both *Thalassia testudinum* and *Syringodium filiforme,* although this effect was different for the two species of seagrass. Over the two year study period, *Thalassia* blades length and widths were smaller in the experimental area compared to the experimental halo area but not compared to control sites, while the opposite was true for *Syringodium*; lengths were less in the experimental area compared to the control site but not compared to the experimental halo areas. Coverage was reduced in the experimental area for both comparisons with both species.

These reductions and changes, however, were considerably less in scope than the overall variation due to both site variation and sample date in almost all factors measured (Table 3). Although the fact that there were only 4 sampling periods makes it difficult to state categorically that there are seasonal effects, the strong statistical variation due to date indicates that seasonal effects may be likely. A longer monitoring period would have shown definitely whether this was the case.

The overall conclusion, therefore, is that the presence of EcoReef modules does have a minor effect in reducing coverage and seagrass length and widths. What was striking, however, is that there was no reduction in length or coverage of seagrass in the halo zones immediately around the EcoReef installations, in marked contrast to the older mixed reef in the same area, which has a halo zone of cropped or non-existent seagrass that extends ~3 m or so past the reef structures (see Tables 1, 2 for length and 4 for coverage).

It seems reasonable to suggest that the difference in halo zones between the older larger reef and the experimental installations studied here has to do with the difference in the fish communities. Fish communities in the experimental installations were mostly very small (76**%** smaller than 5.0 cm) where as in the older reef more than 80**%** of the fish were greater than 5.0 cm. The larger parrotfish (*Sparisoma viride* and *Scarus iserti*) observed present on the larger reef are most likely helping to maintain the halo zone by eating seagrass, but it is difficult to judge the extent of their herbivory since their numbers vary so much (ranging from 4 to 102 *S. iserti* in different sampling periods, for example). Parrotfish tend to range widely while feeding in mixed species groups on algae, substrate, and surrounding seagrass (Ogden and Buckman, 1973; Itzkowitz, 1977), so the fact that they were not the most common species on the larger reef may not be indicative of the real pattern of herbivory; it could easily be that larger schools move through periodically and maintain the halo.

Seagrass herbivory, however, may be more widespread among fish species than previously thought (Valentine and Heck, 1999), and it could be that the mixed school of 130 to 200 or more adult (>5 cm) grunts (White, *Haemulon plumeirii*, and Blue-striped, *H. sciurus*), present on the older reef and not present on the experimental installations, are also contributing to the creation and maintenance of the halo area. This could be a by-product of their mostly invertebrate diet (see Hargrove et al., 2012), and perhaps having to do with a strategy of maximizing low predation risk by staying close to the reef (Pennings, 1998; Hammershlag et al., 2010). Ogden et al., (1973) have shown that black spined sea urchins (*Diadema antillarum*) also contribute to halo formation, but these were not observed on the large reef.

The fact that there was no halo zone effect for any of the experimental installations of EcoReefs effectively demonstrates that the (mostly) small fish present are not consuming seagrass, either directly or indirectly. Even though large numbers of small herbivorous fish were sometimes observed (e.g.140 striped parrotfish, *Scarus iserti* in August 2009), it seems that they were not feeding on either the *Thalassia testudinum* or *Syringodium filiforme* present, either directly or indirectly. *S. iserti* feeds mostly on algae (Clifton, 1995), and the lack of herbivorous damage to the seagrass on the experimental sites implies that at this size range (<2.5 cm), their algal grazing does not cause damage to the seagrass blades. In larger size ranges, however, (i.e. above 2.5 cm) their foraging technique of rapid consecutive nips at the substrate (Itzkowitz, 1977) probably damages the seagrass and helps to maintain the halo zone. It may be that in future years, the fish populations on the experimental sites will become large enough to create and maintain separate halo zones, but there were no indications in the current study that this was about to take place.

4.2 Effects of EcoReefs on Fish Populations

Seagrass beds are a significant habitat within the overall coral reef environment, together with mangrove communities and coral reefs themselves, and as such function chiefly as a nursery for some fish species that later move to the adjacent communities. In Bonaire, Nagelkerken, et al., (2000) noted that these species included *Haemulon flavolineatum*, *H. sciurus*, *Ocyurus chrysurus*, *Acanthurus chirurgus* and *Sparisoma* *viride*; most of these species were observed in the experimental sites in this study, but the Bohnsack-Bonnerot technique revealed almost no fish on the seagrass beds themselves.

The reasons for the number of low fish may have to do with the specific nature of the sampling sites at Coco Cay. Although the seagrass beds were extensive (see Photo 3), there were 2 differences between these beds and those elsewhere in the Berry chain of islands. In the first place, there were no mangrove habitats nearby; the nearest locations for mangroves was on the island of Great Harbour Cay 5 km to the Southeast, and the seagrass beds here may harbor larger populations of these fish. More importantly, however, Coco Cay has extensive amounts of shallow water rock habitat that can provide greater protection and shelter for these species (see, for example, rock breakwater in Photo 3).

The fact that these species (see Table 6) as well as others, occupied the experimental EcoReefs sites quickly, and were found at the first sampling period 6 months subsequent to installation, implies that these species move through the seagrass beds searching for available habitat or their could possibly be direct settlement from larvae onto the reefs..

A significant number of the juvenile fish (see Table 5) found episodically on the EcoReefs were grunts (both *Haemulon sciurus* and *H. plumieri*), and it seems reasonable to suggest that these juveniles may be, at least in part, offspring of the grunts present in the large school on the old reef. Bluehead wrasse (*Thalassoma bifasciatum*), one of the most numerous fish species found on Caribbean reefs were also common on the experimental reefs, and this may reflect the lack of any clearly defined home range and their constant exploratory behavior (DeLoach, 1999). The other species noted (Table 5) were also common coral reef residents.

4.3 Comparison to other artificial reefs

In comparison with artificial reefs built with specifically engineered components, those built with “materials of opportunity” (tires, plastic) generally support a smaller and less diverse biological community. Reefs built with old car tires like the Osborne Tire Reef in Ft. Lauderdale, and others like it around the world, have been known to attract fish and increase fish abundance (Capmos and Gamboa, 1989; Haughton and Aiken, 1989.) However, in the long term using tires as reef materials are generally acknowledged to be an ecological disaster (FDEP, 2007).

Reefs built with structures specifically designed to function as artificial reefs generally do much better. Probably the most widely used purpose designed artificial reef structures are ReefBalls, which are hemispherical hollow concrete structures. Although comparisons are difficult because the spacing and design of different artificial reefs are usually completely different, Sherman et al., (2002) showed that individual ReefBalls deployed over sand substrate (spaced 30-35m apart) would each recruit about 20 individuals of 6 or 7 different species over a 2 year monitoring period, although these numbers were basically doubled (50+ individuals of around 11 different species) if the internal void spaces (1 m+ diameter) had concrete blocks placed within them, and the ReefBalls with concrete blocks also had significantly more juvenile fish. Similar results have been found in Brazil (Brotto et al., 2006).

These results are consistent with the data collected here. The creation of small void spaces, either within the ReefBalls with concrete blocks, or around the 30 branches of each EcoReefs module, seems to attract juvenile fish (note that EcoReefs fish counts on experimental sites ranged from 30 to 150 individuals of 7 or 8 species, and most of these fish were of the smallest size class). Similar results have been found in other studies (e.g. Ogden and Ebersole, 1981, West et al., 1994).

Larger void spaces attract fewer fish of fewer species (Sherman et al., 2002), but the combination of large void spaces with small spaces, as with the older, larger reef monitored here, seems to attract the largest number of fish with the greatest diversity (up to 416 individuals of 17 different species). No firm conclusions or robust statistical analyses can be drawn from a single example, but this result is not surprising. It makes sense that a larger reef with a greater variety of void spaces available for shelter should attract more individuals of more species. This reasoning is also consistent with the fact that shipwrecks, with their diversity of void spaces, often attract a diverse and abundant fish aggregation (Fowler and Booth, 2012; Arena et al., 2007).

The fish communities attracted to shipwrecks in SE Florida are also similar to the results collected here in that the fish communities are dominated by the Haemulid grunts (46% of total fish abundance; Arena et al., 2007). Large schools of grunts can also be seen on other artificial reefs, although in many cases the dominant species is the TomTate *Haemulon aurolineatum* (Arena, 2007) and not Blue-striped and White grunts as it is in this study. Arena et al., (2007) have suggested that the reason for this grunt predominance on some Florida artificial reefs has to do with the structures deflecting underwater currents upwards, allowing the planktivorous grunt juveniles to feed above the artificial structures with ready access to shelter, and, since, grunts usually show strong site fidelity (e.g. Ogden and Ehrlich, 1977), even when the adults switch to feeding on sessile invertebrates and have to forage further afield at night in seagrass beds (Ogden and Quinn, 1989; Appeldorn et al., 2009), they may continue to use the artificial reef as a home base and shelter during the day. The results collected here are consistent with this explanation; when initially placed in the water in 2004, there were no grunts observed around the older reef (Haley, personal communication), but if juveniles started to collect around this reef at that time that would explain why 5 years later a large school of up to 200 individuals has become resident. Since the experimental reefs have started to accumulate grunt juveniles, it may be that in subsequent years schools of adult grunts may be present around these reefs as well.

The results here show that the EcoReefs functioned primarily as juvenile habitat (Table 6) for the fish species that are found nearby (on the larger reef and elsewhere) as adults. The smaller fish consisted mostly of blue-striped and white grunts, yellow tail snappers, and striped parrots. All of these fish are found in abundance on the larger reef as adults except striped parrots; striped parrot juveniles are often found in small roving schools before they become adults and move to deep water (see Ogden and Buckman, 1973).

This study was only short-term that encompassed a 2 year period, and showed a high degree of fluctuation in the fish populations. Even though casual observations on the larger older reef prior to the present study indicate that the fish aggregation on this reef has been relatively stable since 2005, one year post-installation (Haley, personal communication), it is not clear whether the populations of fish on the smaller installations will stabilize over time, as they will likely fluctuate with recruitment events, as is the case in other studies (Danilowicz, 1997; Jordan et al., 2005). It is also possible that as corals and other forms of marine life settle on the new EcoReef modules and grow (the older reef had a lot of *Millipora alcicornis* present on the modules) that the increasing structural complexity will support a larger community of adult herbivores, which would then result in the emergence of a halo around each installation.

The results of this study make it difficult to predict what will happen on these installations in the future. Some of this unpredictability may be due to fluctuations in recruitment events, and some to the differential response of different size fish to different scales of rugosity. Knudsby and LeDrew, (2007) pointed out that the degree of three dimensional complexity on coral reefs can be considered at several different spatial scales, and the scale at which fish and other forms of marine life may be responding may be, in many cases, different to those perceived by humans doing research. They argue that future research will relate fish body size to the scale of reef structural complexity, and the results of this study are consistent with this framework; that is, that smaller fish respond to different levels of structural complexity compared to adult fish (since the fish on the structurally more complex old reef included many more adults), but additional time would be necessary to show this more clearly.

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Appendix A

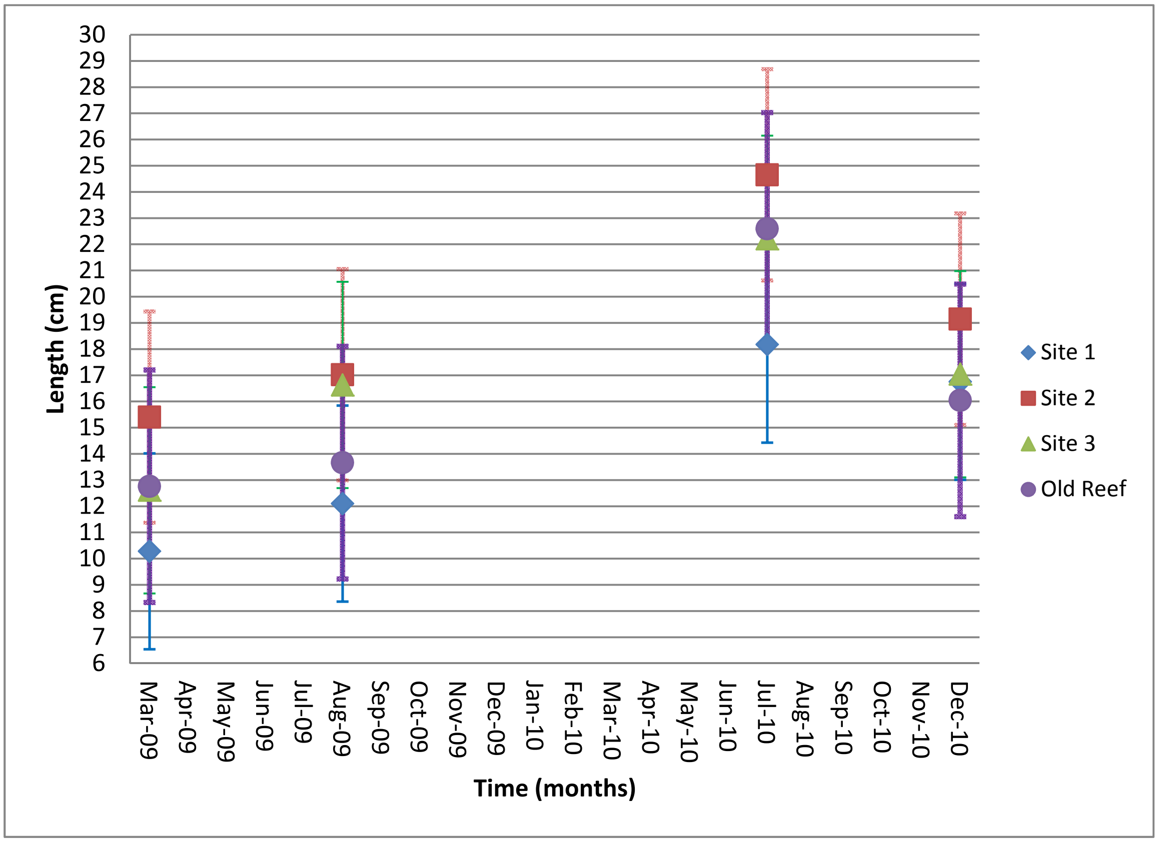

Figure 11: Average changes in the length of *Thalassia* blades measured around the three experimental sites and the old reef over time. The color of SD bars correspond with the color of each site.

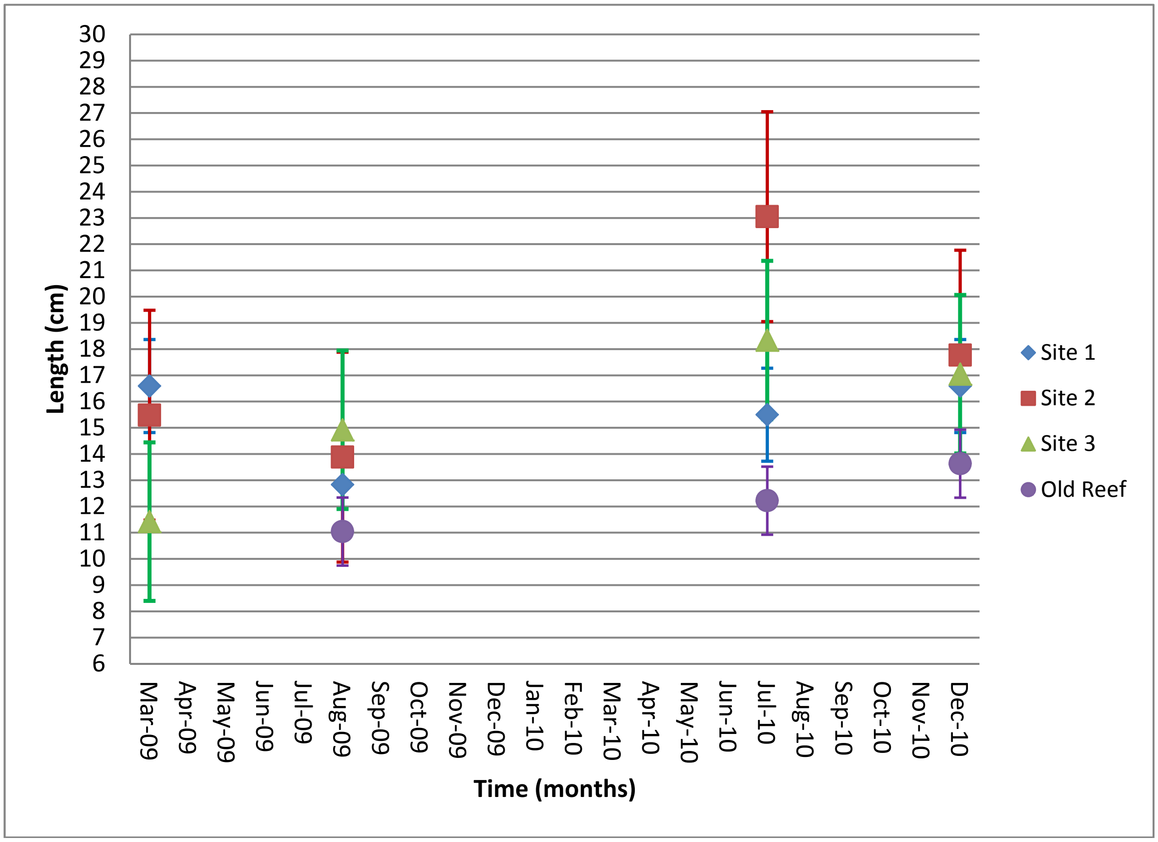

Figure 12: Average length changes of *Thalassia* blades measured around the halo area of the three experimental sites and the old reef over time. The color of SD bars correspond with the color of each site.

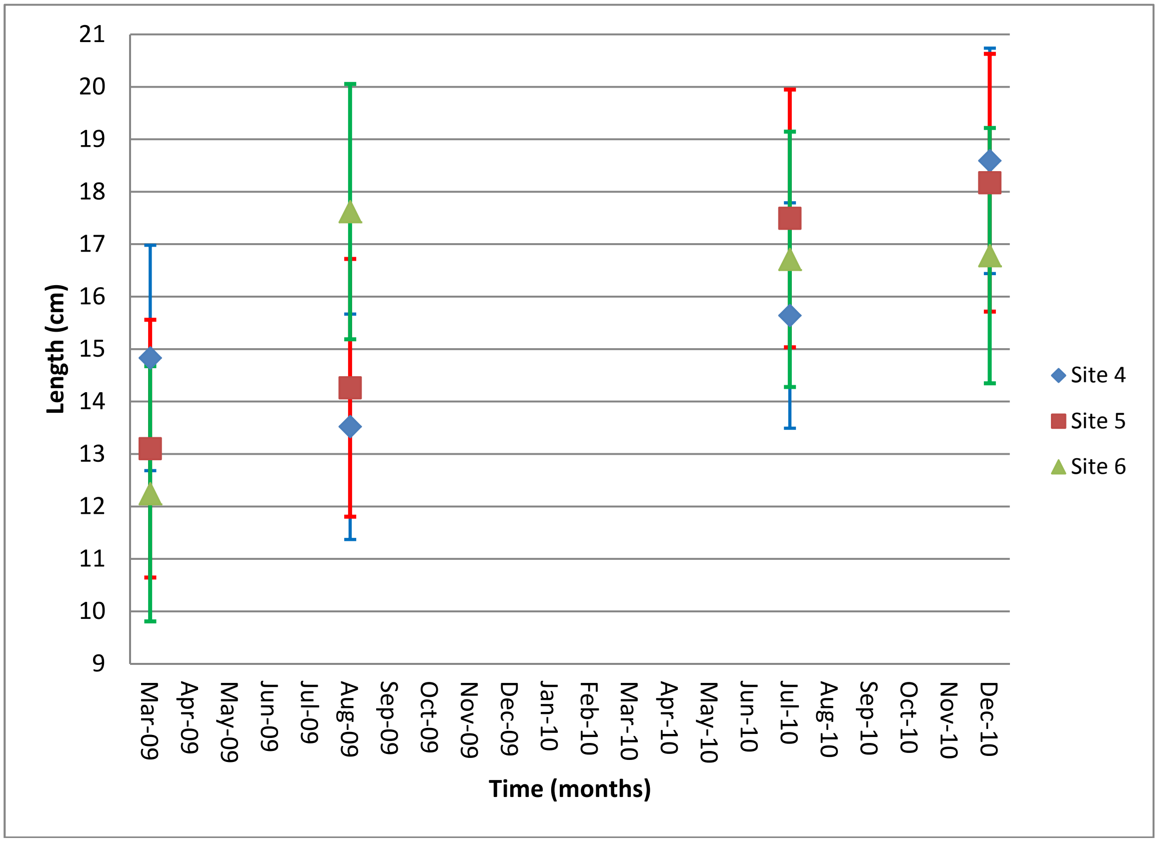

Figure 13: The average length changes of *Thalassia* blades measured on the control sites over time. The color of SD bars correspond with the color line of each site.

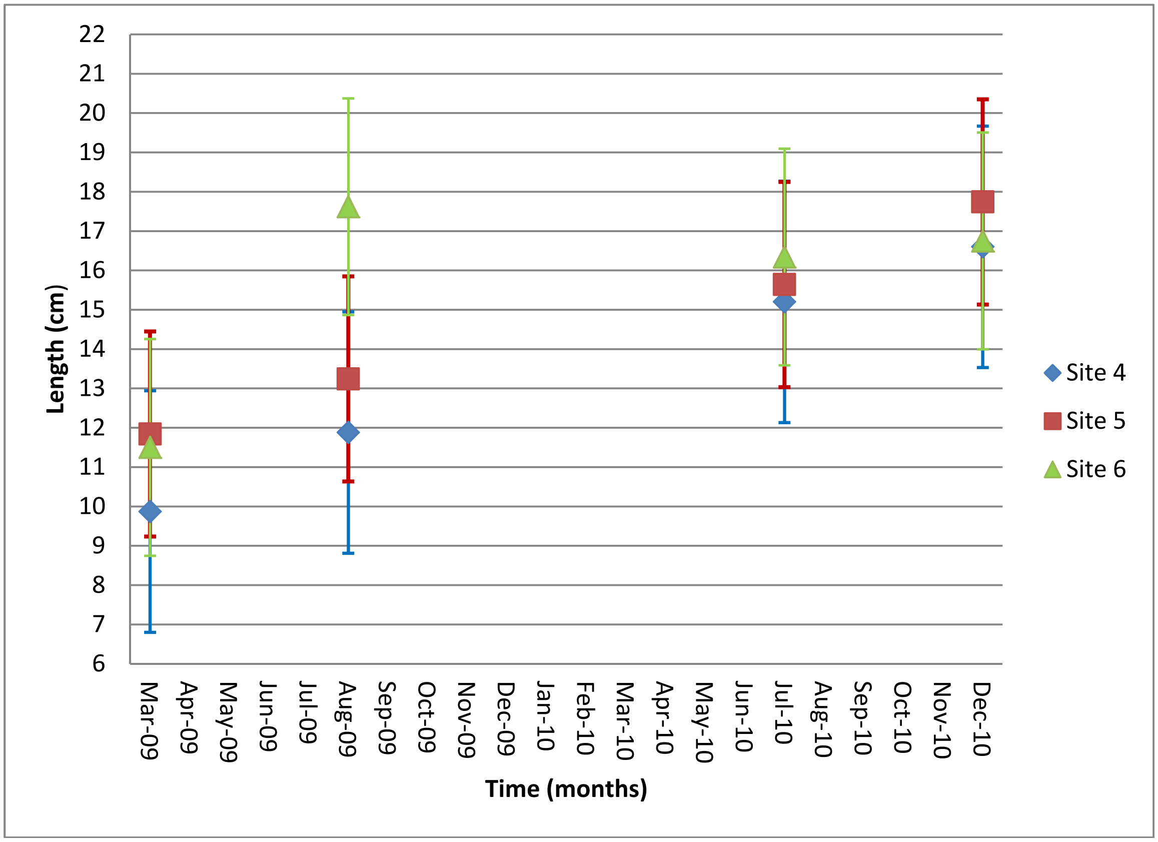

Figure 14: The average length changes of *Thalassia* blades measured in the halo area around the control sites over time. The color of SD bars correspond with the color line of each site.

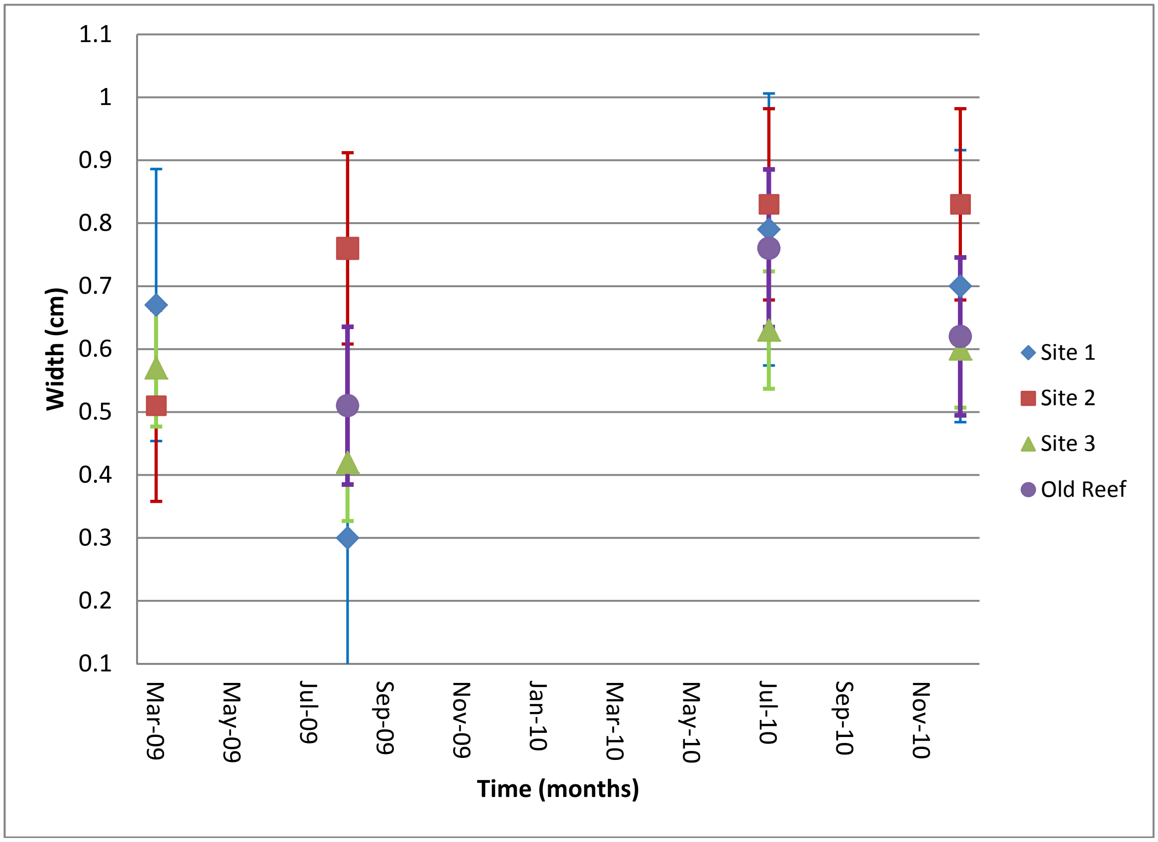

Figure 15: The average changes in width of individual *Thalassia* blades measured on the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

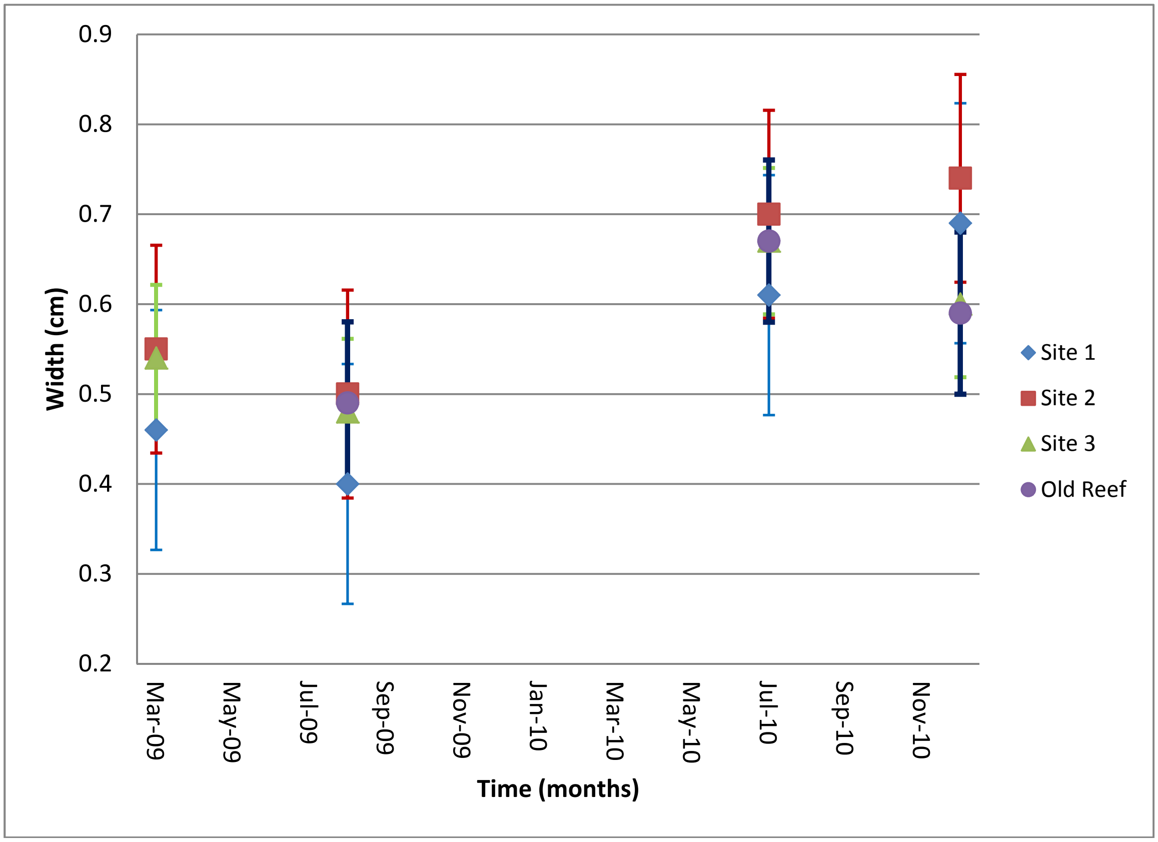

Figure 16: The average changes in width of individual *Thalassia* blades measured in the halo area around the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

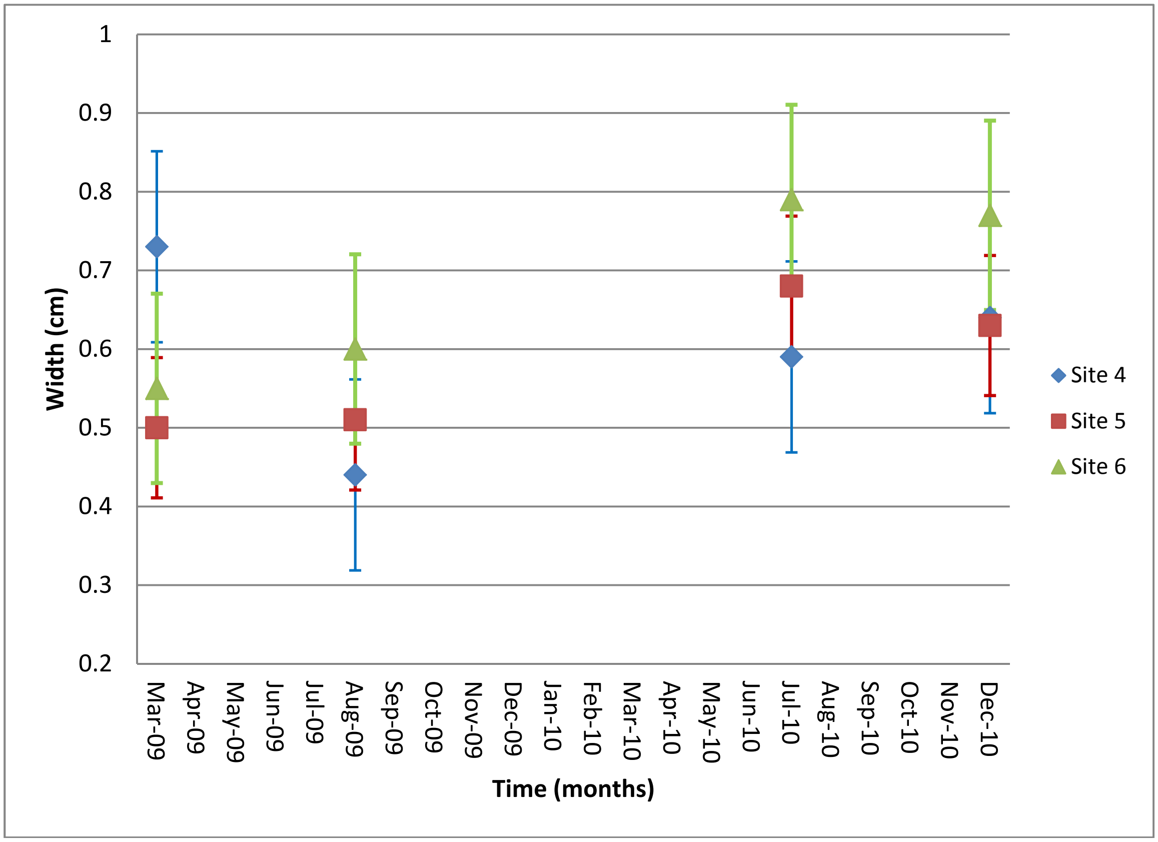

Figure 17: The average changes in width of *Thalassia* blades measured on the control sites over time. The color of SD bars correspond with the color line of each site.

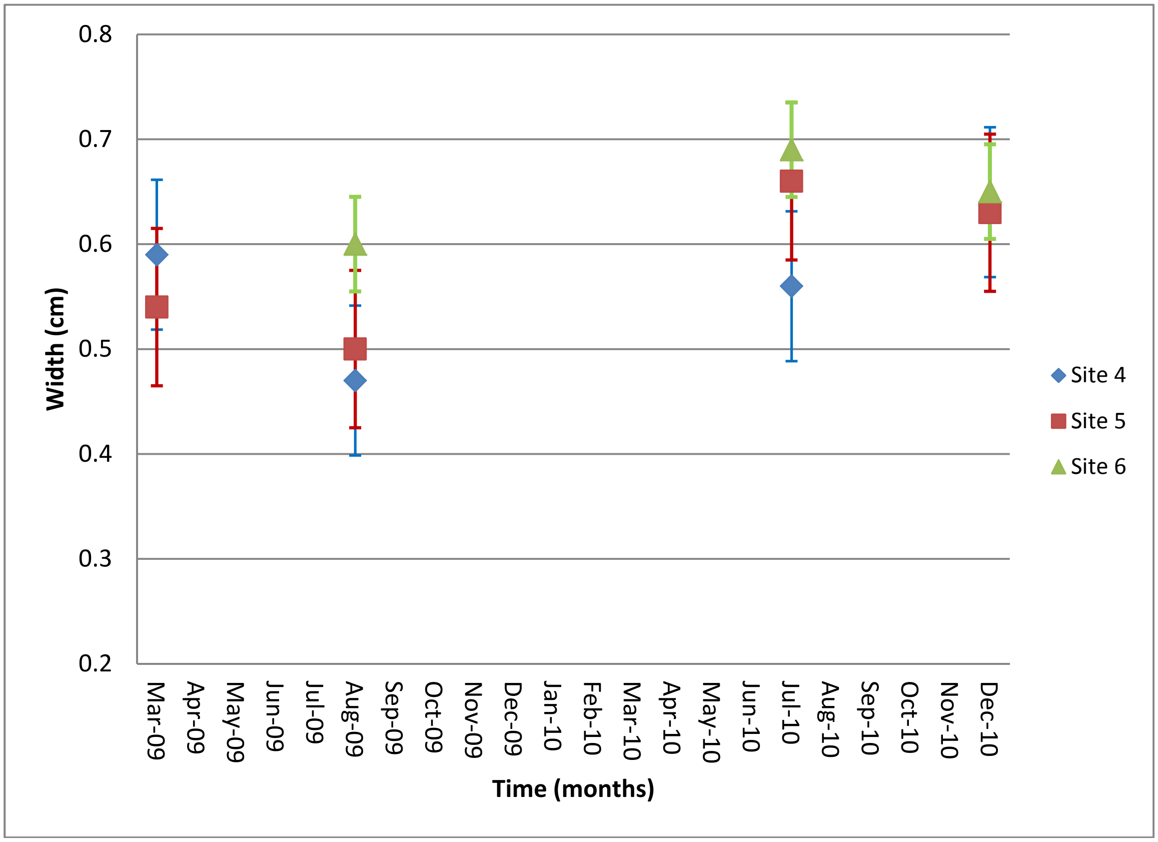

Figure 18: The average changes in width of *Thalassia* blades measured in the halo area around the control sites over time. The color of SD bars correspond with the color line of each site.

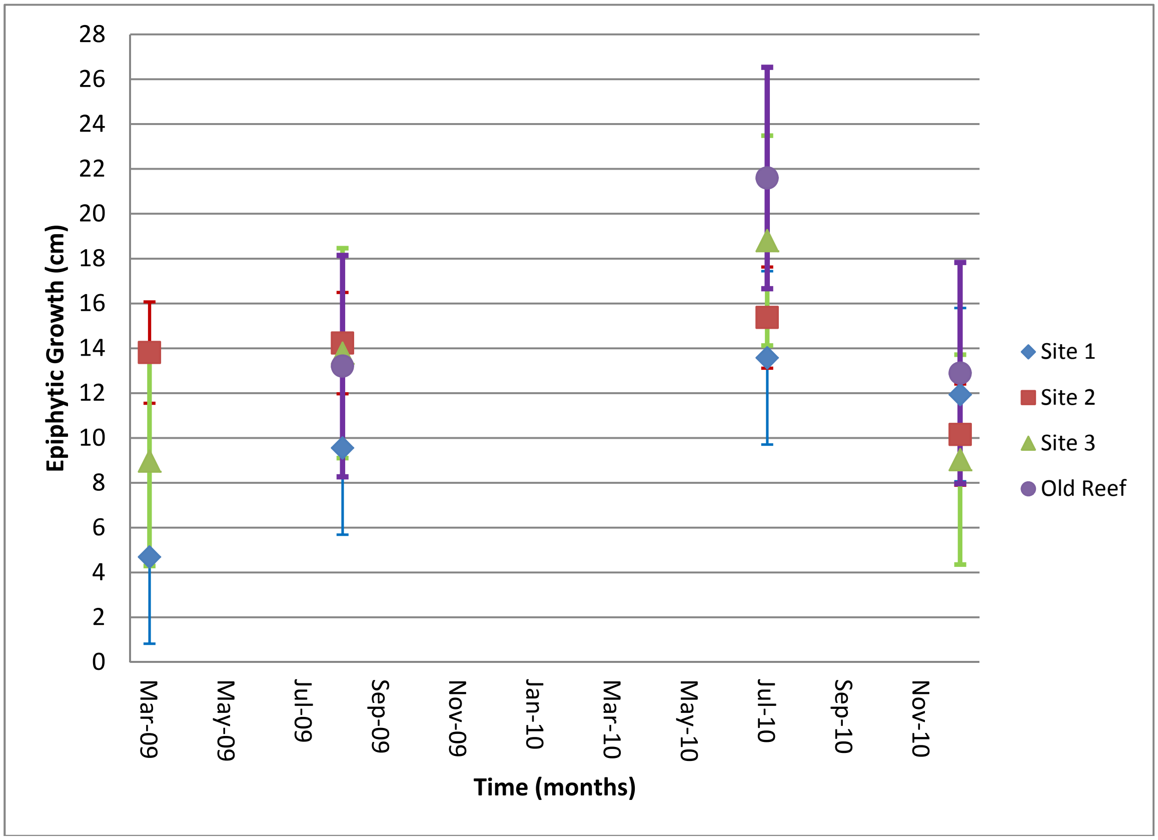

Figure 19: The average changes in epiphytic fauna growth measured on individual blades of *Thalassia* on the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

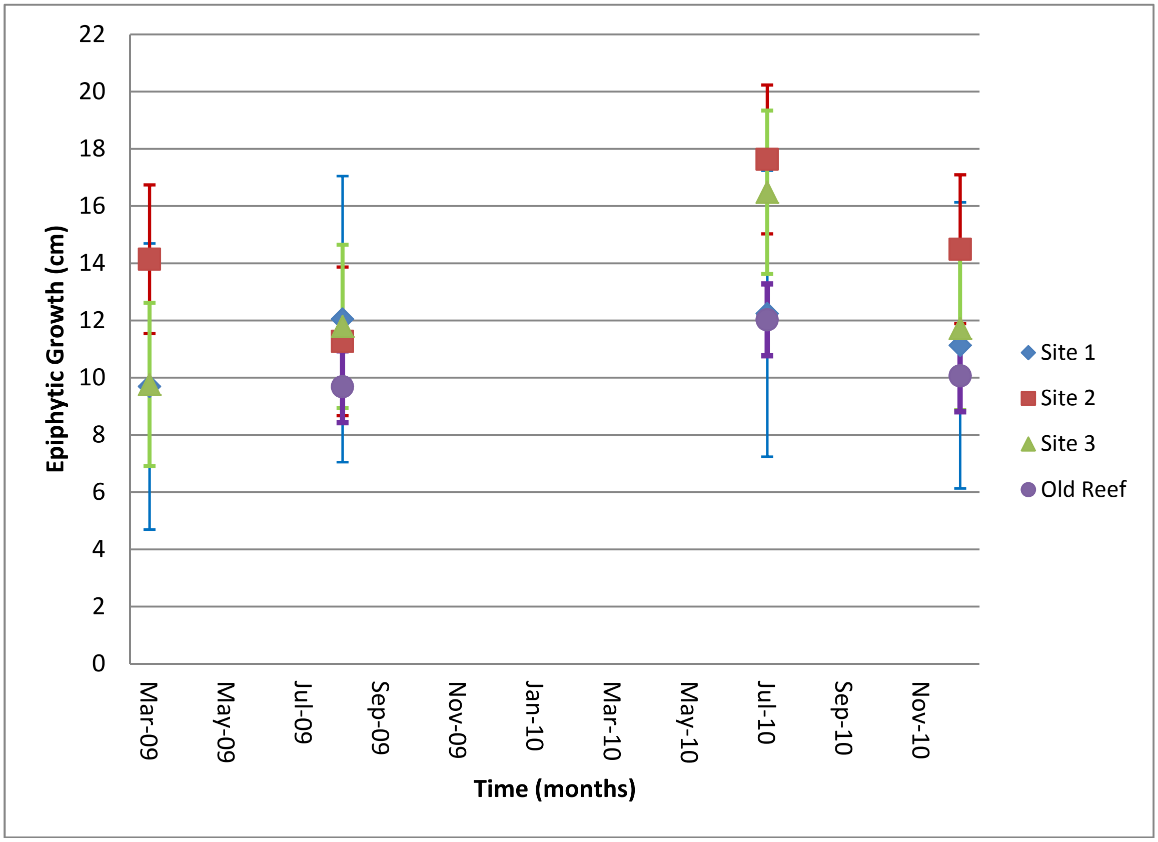

Figure 20: The average changes in epipytic fauna growth measured on individual blades of *Thalassia* around the halo area of the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

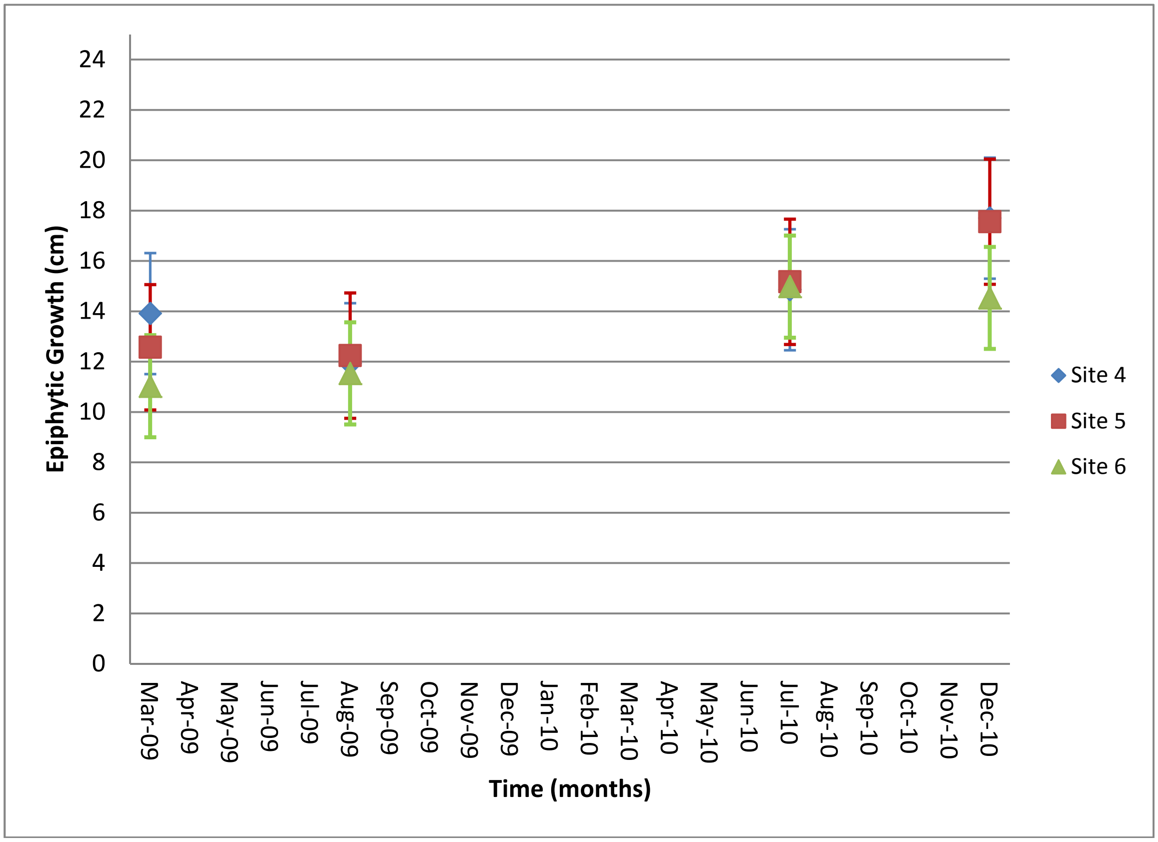

Figure 21: The average changes in epiphytic fauna growth measured on individual blades of *Thalassia o*n the control sites over time. The color of SD bars correspond with the color line of each site.

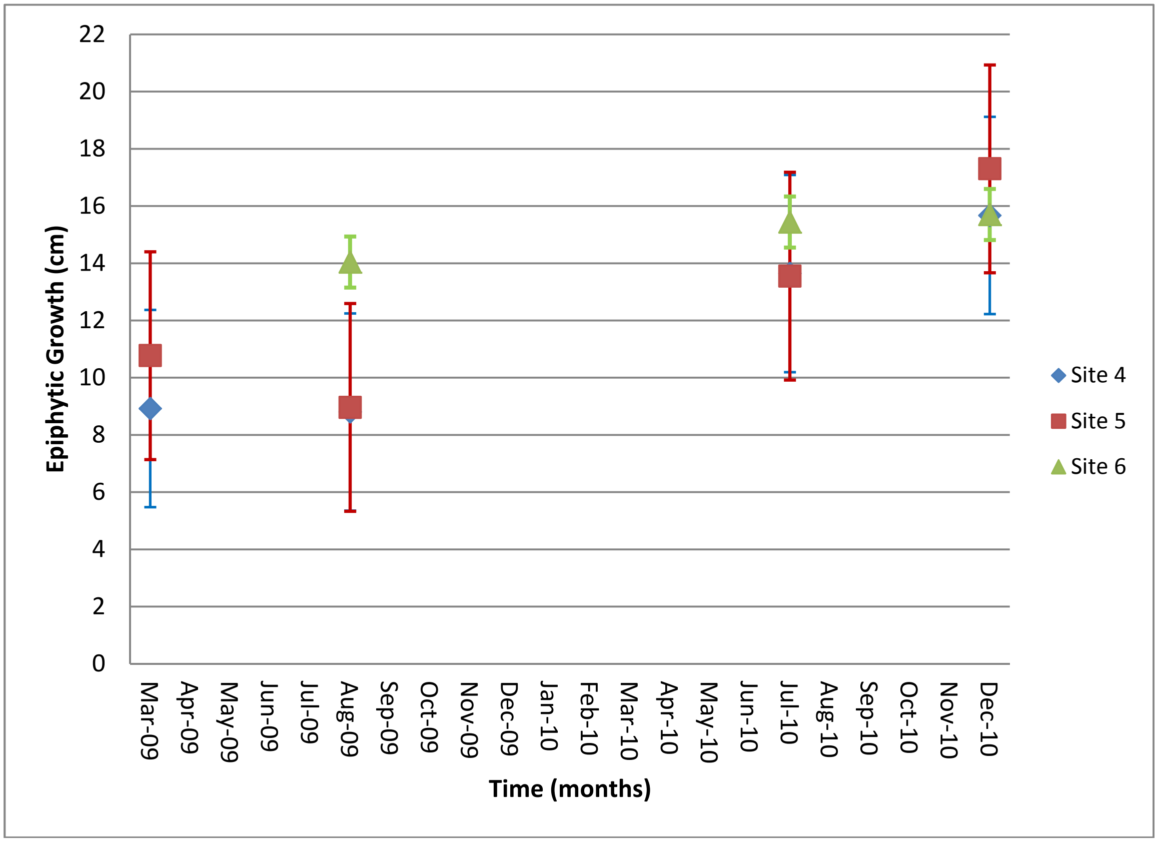

Figure 22: The average changes in epiphytic fauna growth measured on individual blades of *Thalassia* in the halo area of the control sites over time. The color of SD bars correspond with the color line of each site.

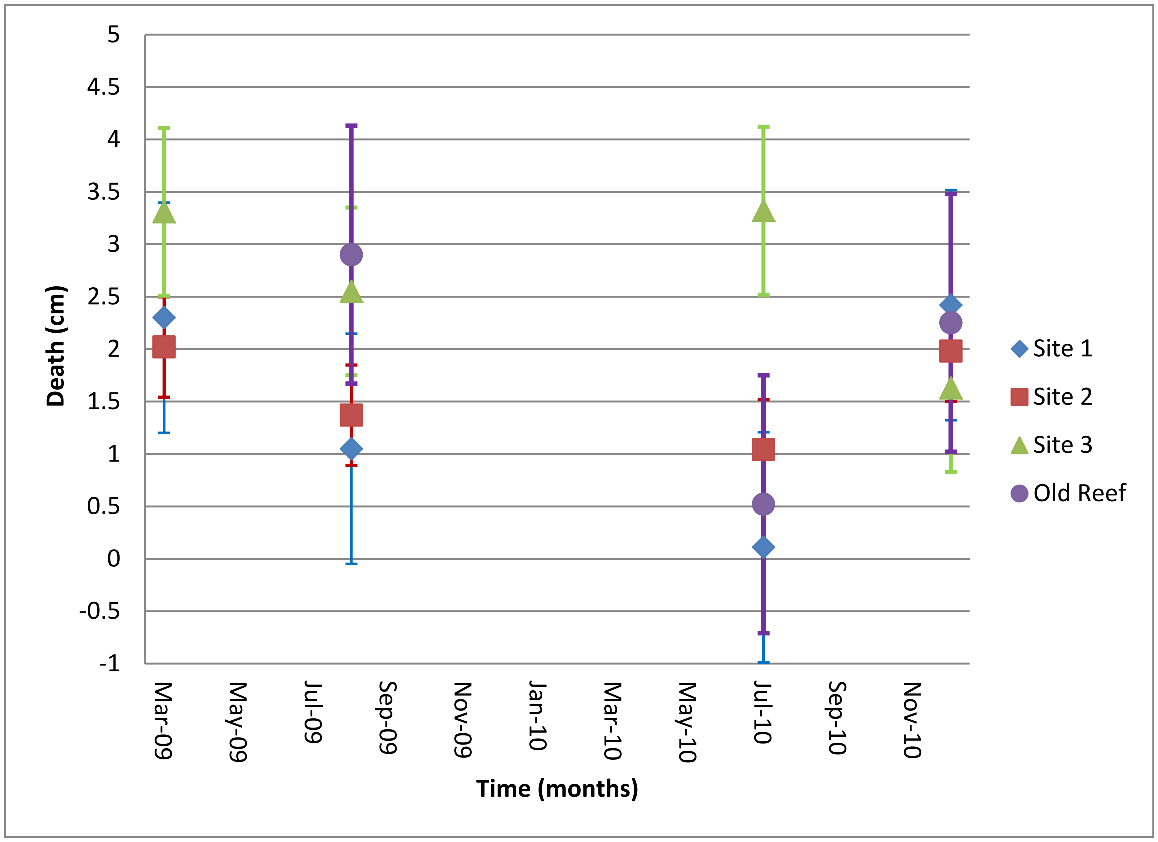

Figure 23: The average changes in the amount of dead seagrass measured on individual blades of *Thalassia* on the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

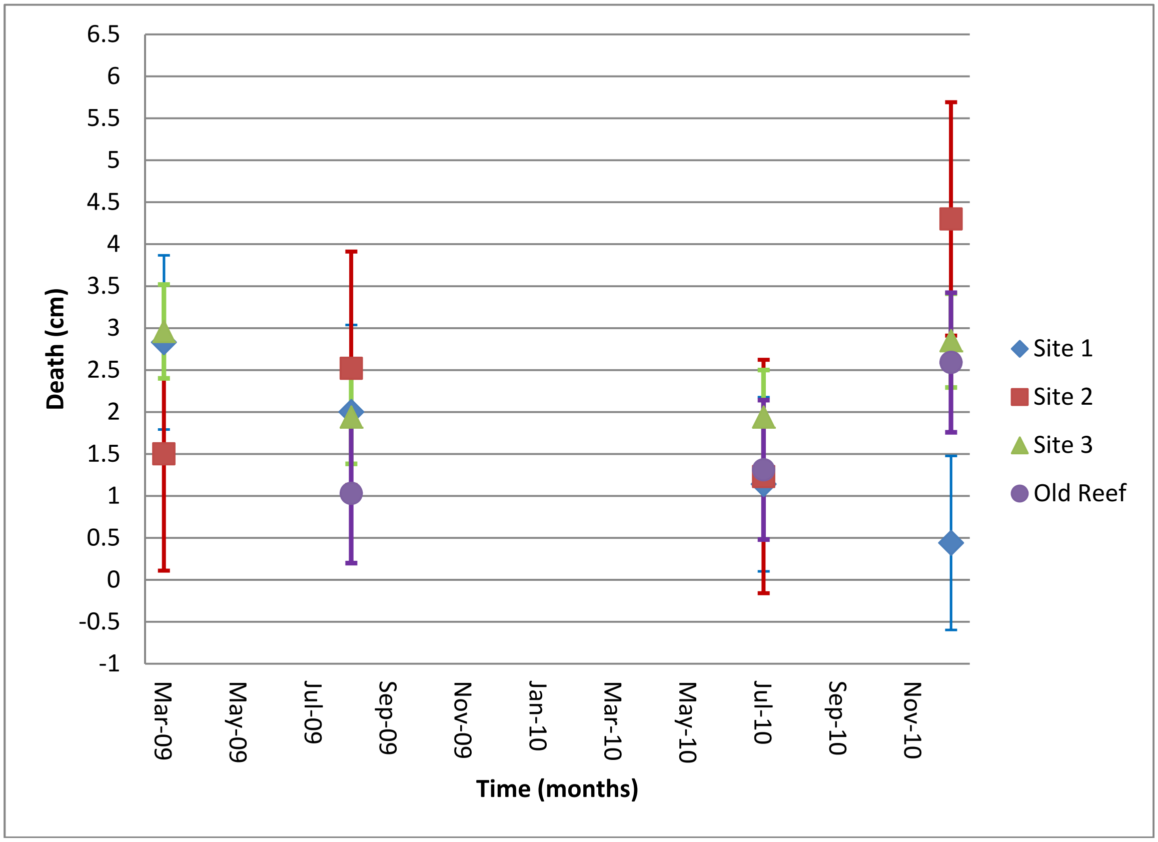

Figure 24: The average changes in the amount of dead seagrass measured in the halo area of individual *Thalassia* blades on the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

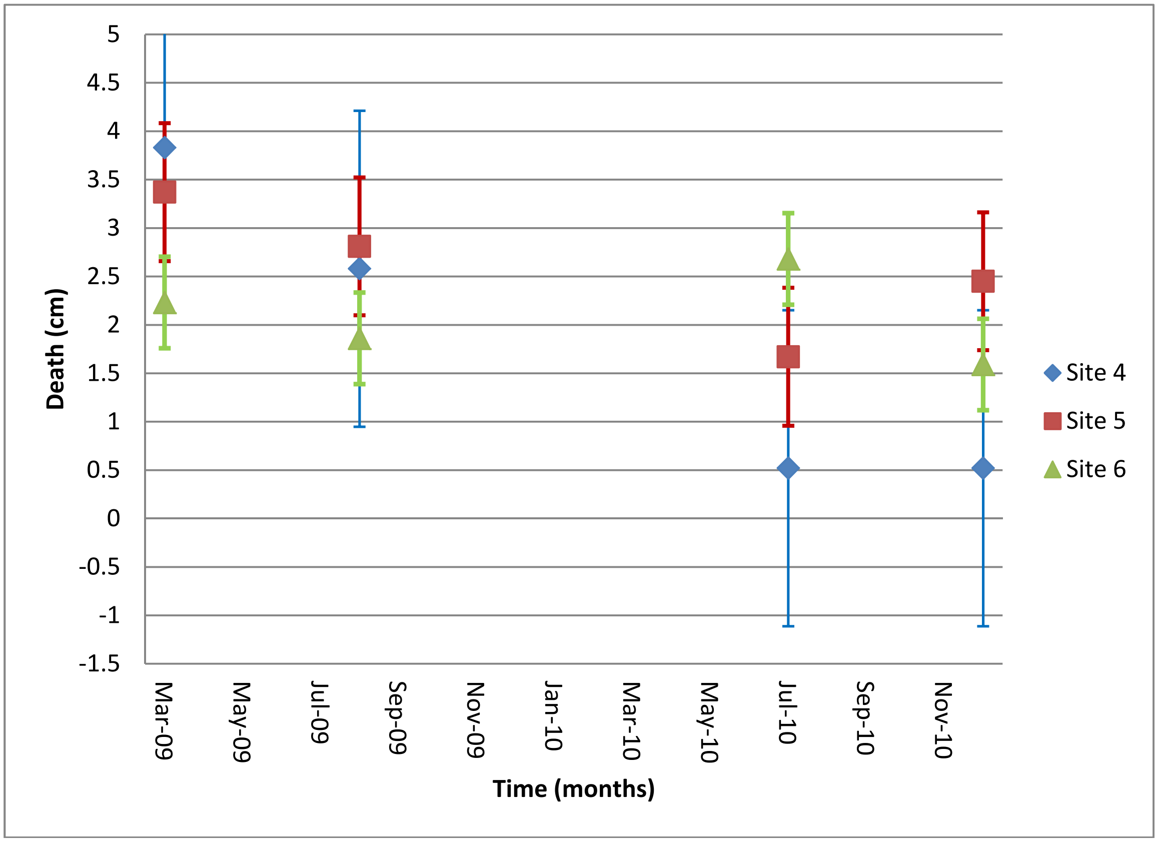

Figure 25: The average changes in the amount of dead seagrass measured on individual blades of *Thalassia* on the control sites over time. The color of SD bars correspond with the color line of each site.

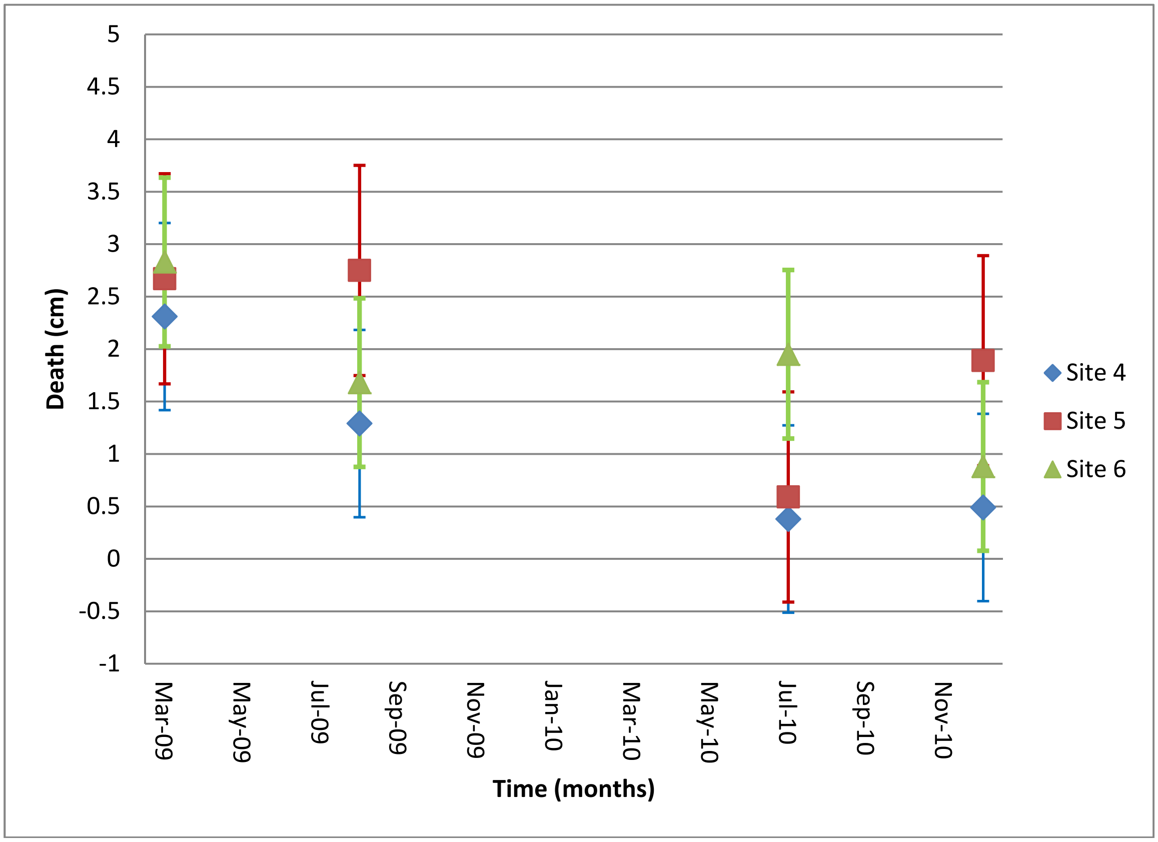

Figure 26: The average changes in the amount of dead seagrass measured on individual *Thalassia* blades around the halo area of the control sites over time. The color of SD bars correspond with the color line of each site.

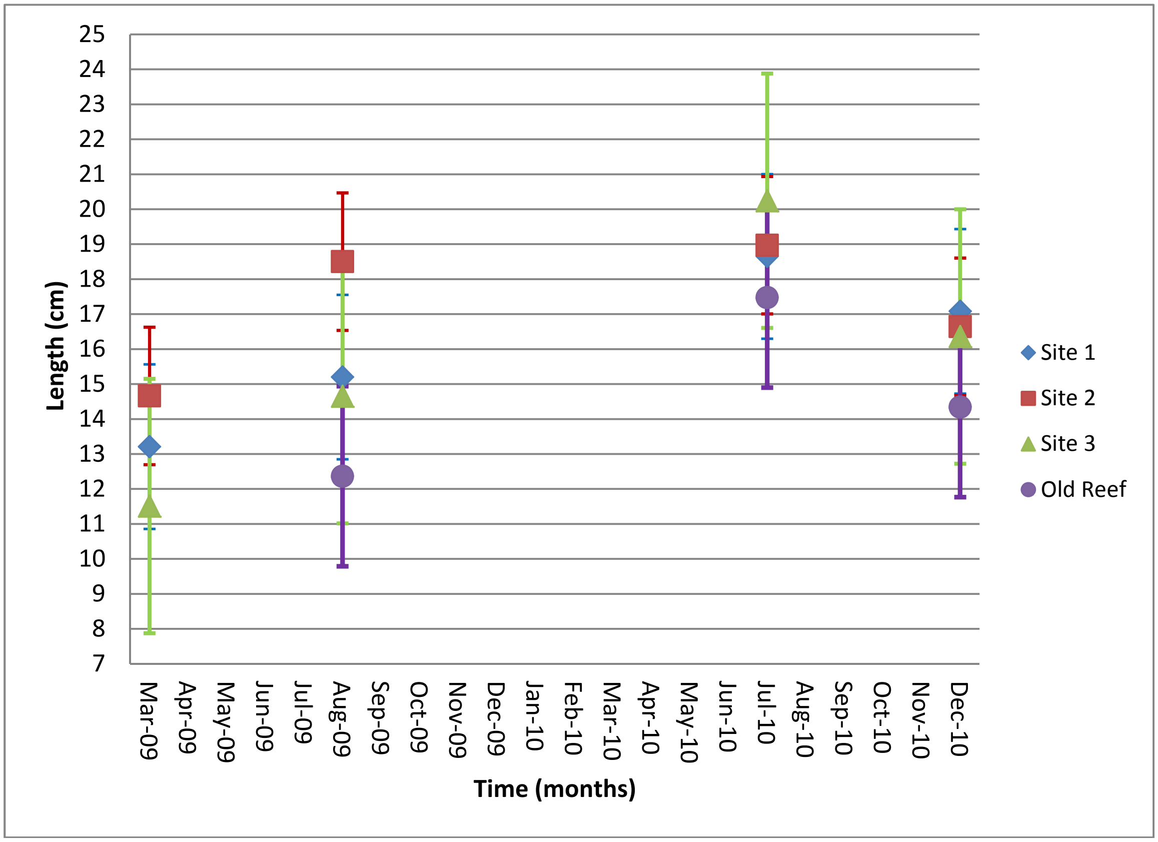

Figure 27: The average changes in length of *Syringodium* blades measured around the three experimental sites and the old reef over time. The color of SD bars correspond with the color of each site.

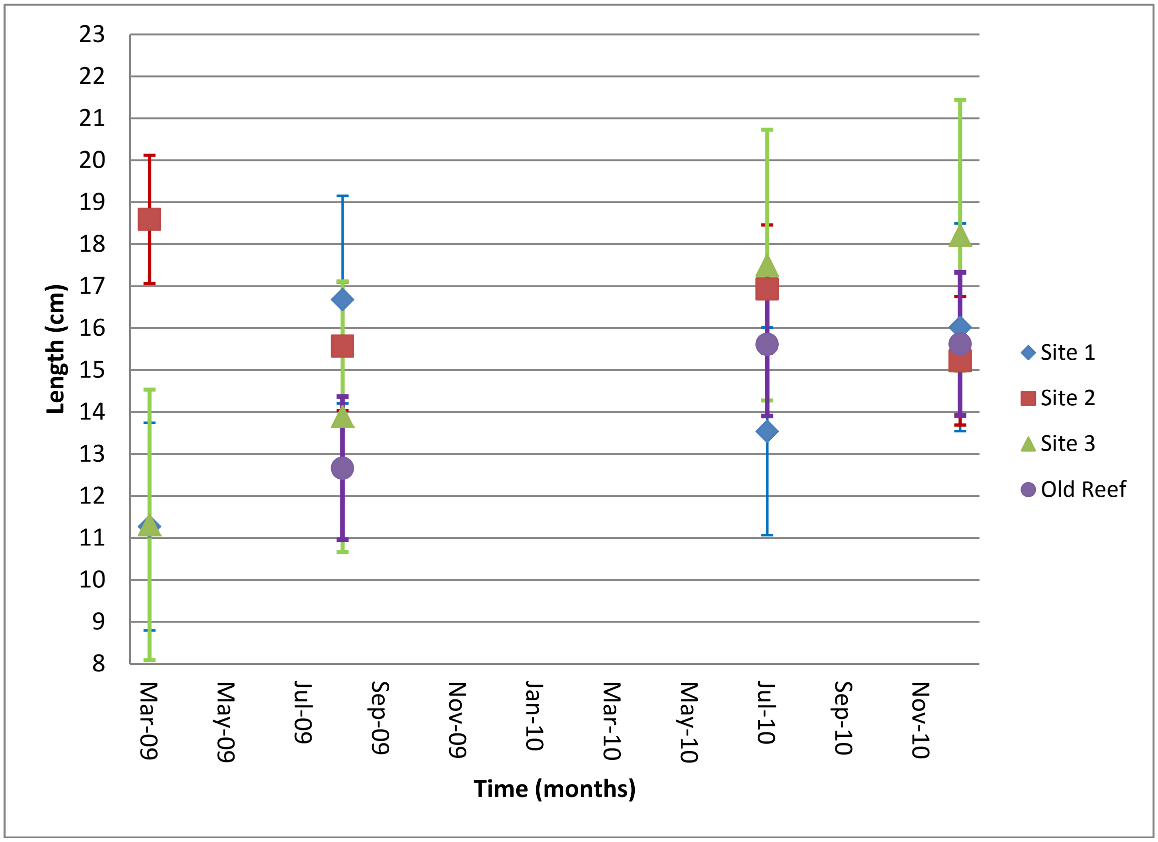

Figure 28: The average length changes of *Syringodium* blades measured in the halo area of the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

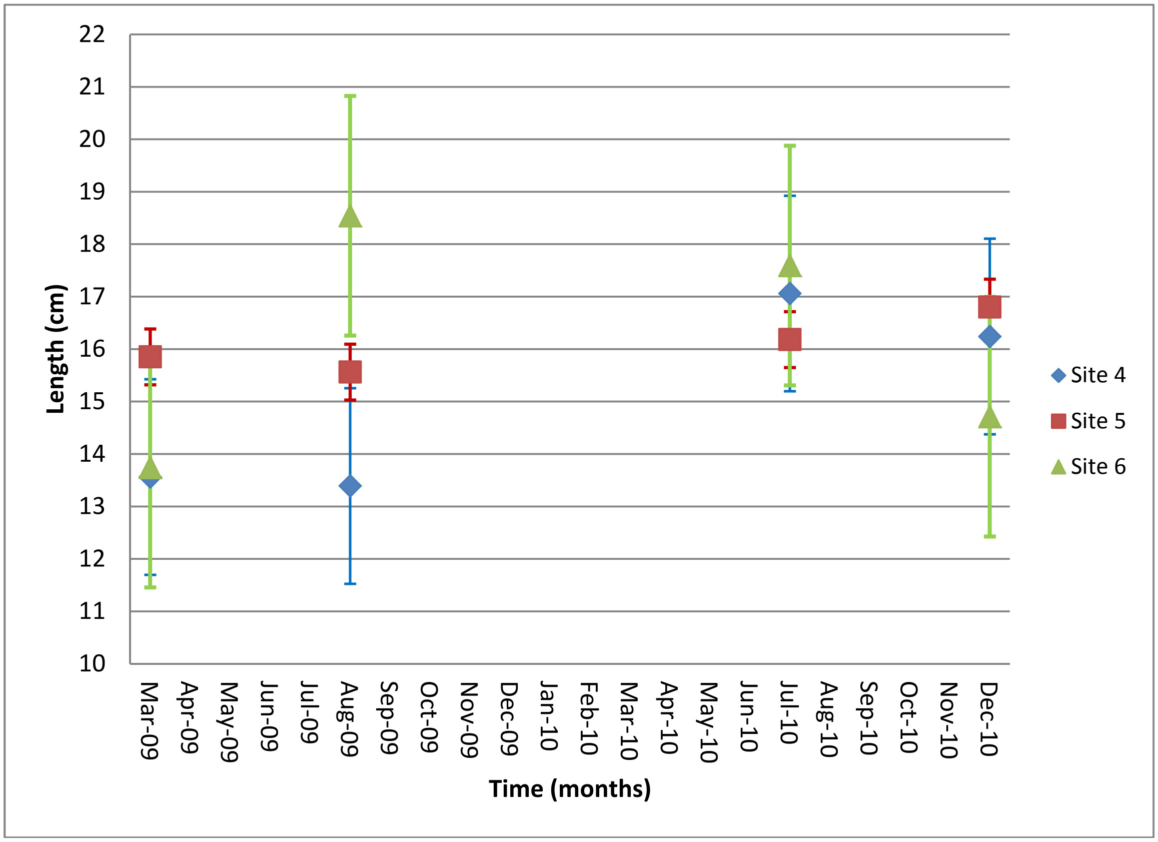

Figure 29: The average length changes of individual *Syringodium* blades measured on the control sites over time. The color of SD bars correspond with the color line of each site.

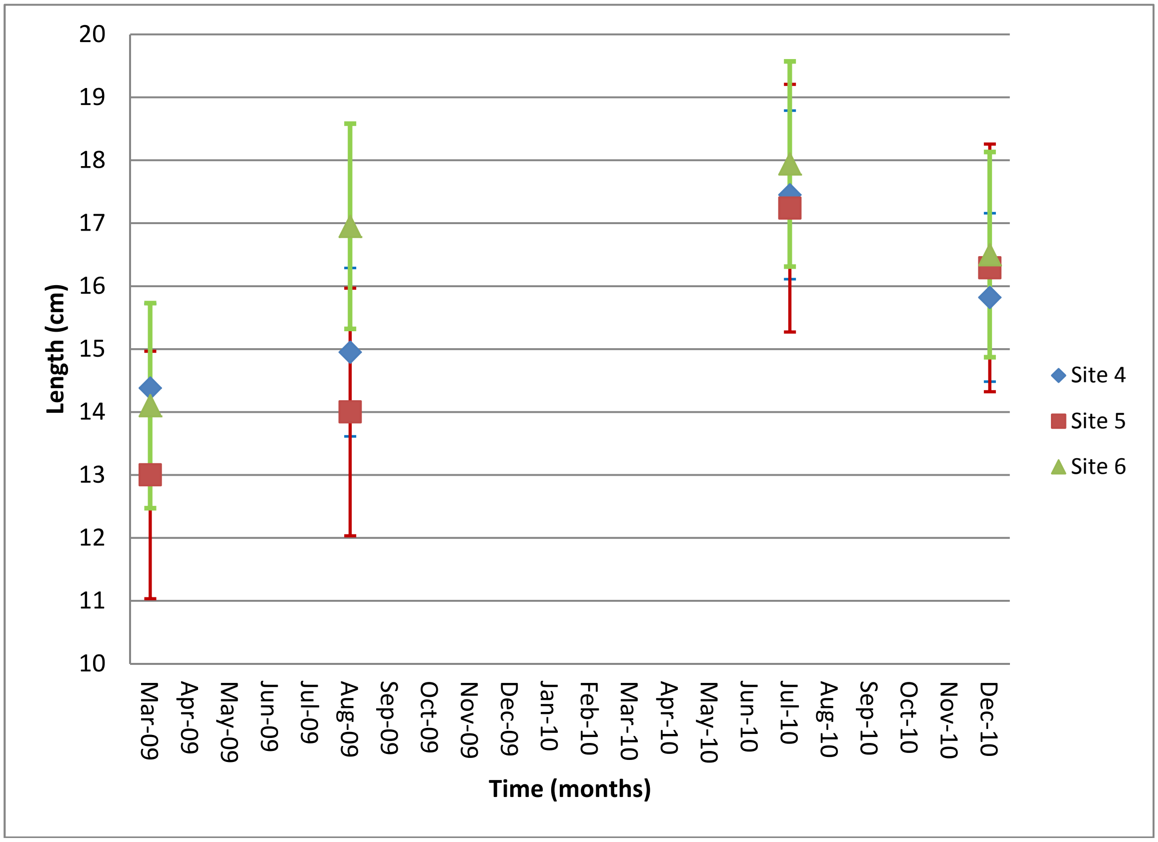

Figure 30: The average length changes of individual *Syringodium* blades measured in the halo area of the control sites over time. The color of SD bars correspond with the color line of each site.

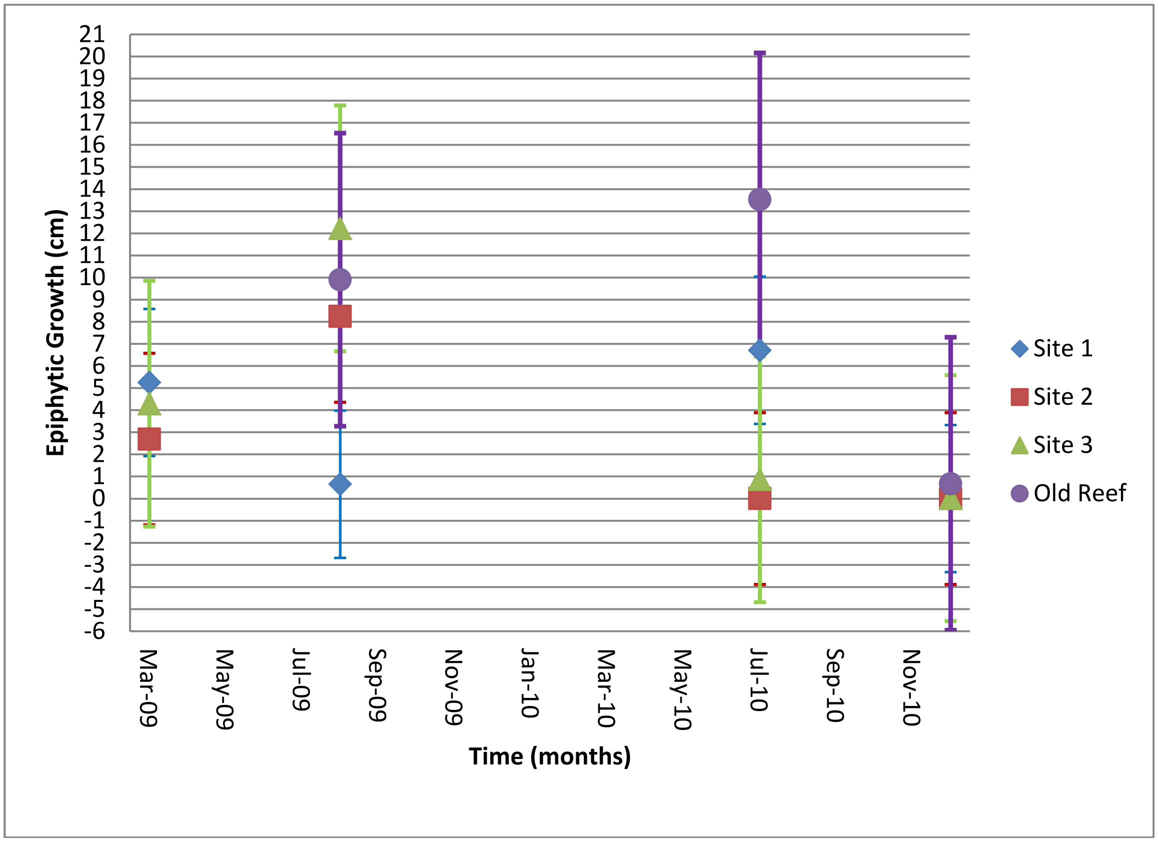

Figure 31: The average changes in epiphytic fauna growth on individual blades of *Syringodium* on the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

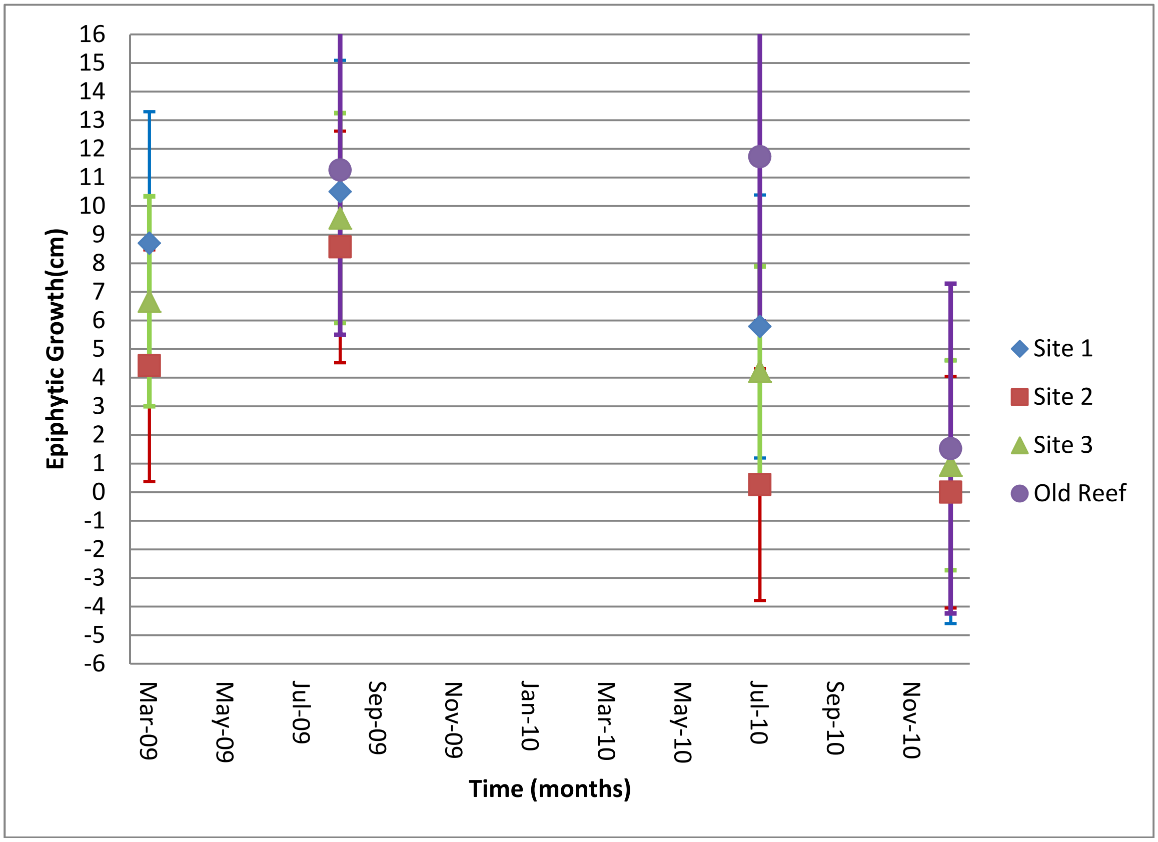

Figure 32: The average changes in epiphytic fauna growth on individual *Syringodium* blades around the halo area of the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

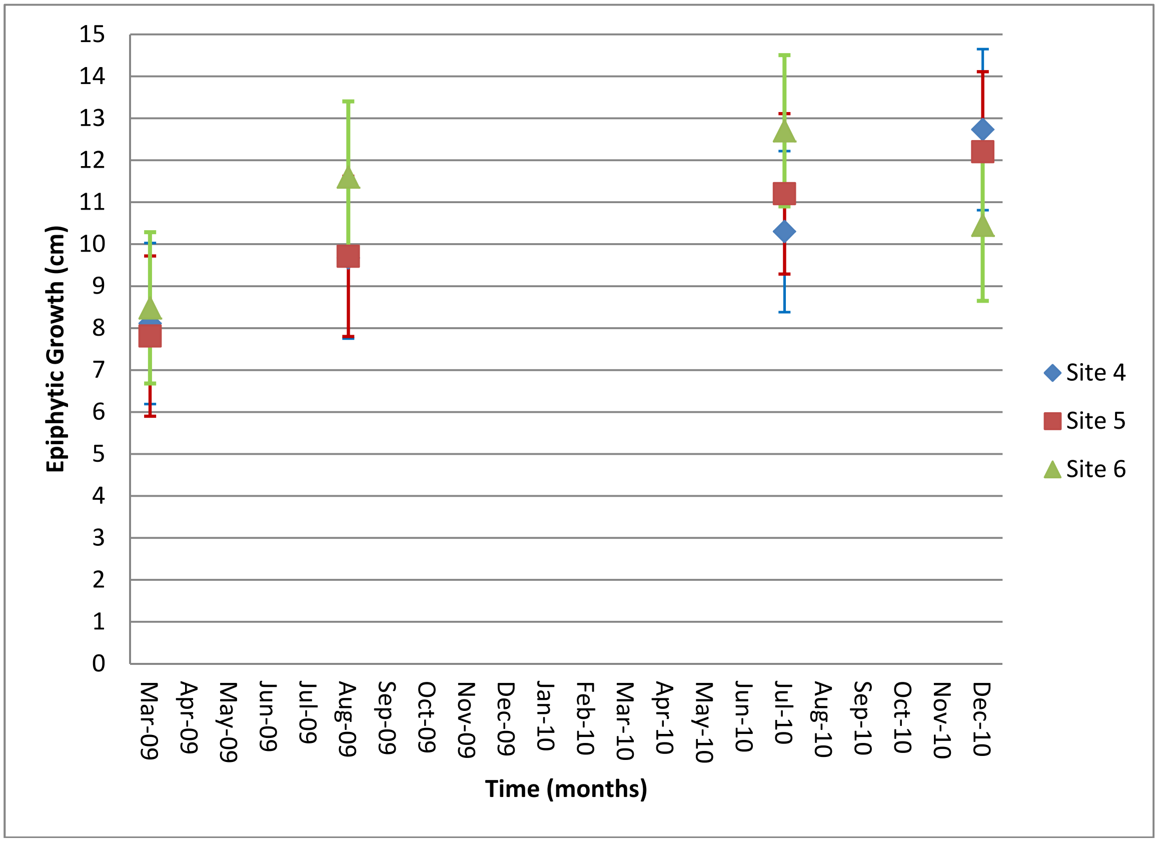

Figure 33: The average changes in epiphytic fauna growth measured on individual *Syringodium* blades on the control sites over time. The color of SD bars correspond with the color line of each site.

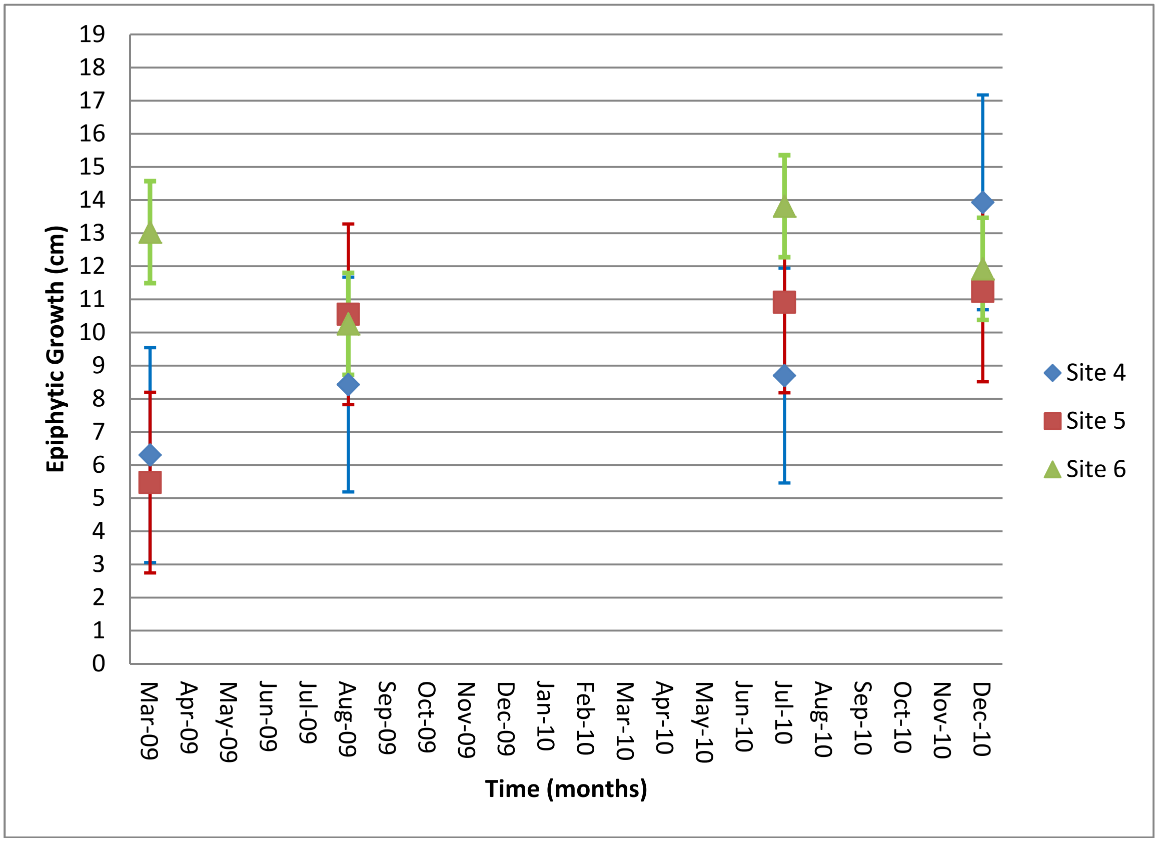

Figure 34: The average changes in epiphytic fauna growth measured on individual blades of *Syringodium* in the halo area of the control sites over time. The color of SD bars correspond with the color line of each site.

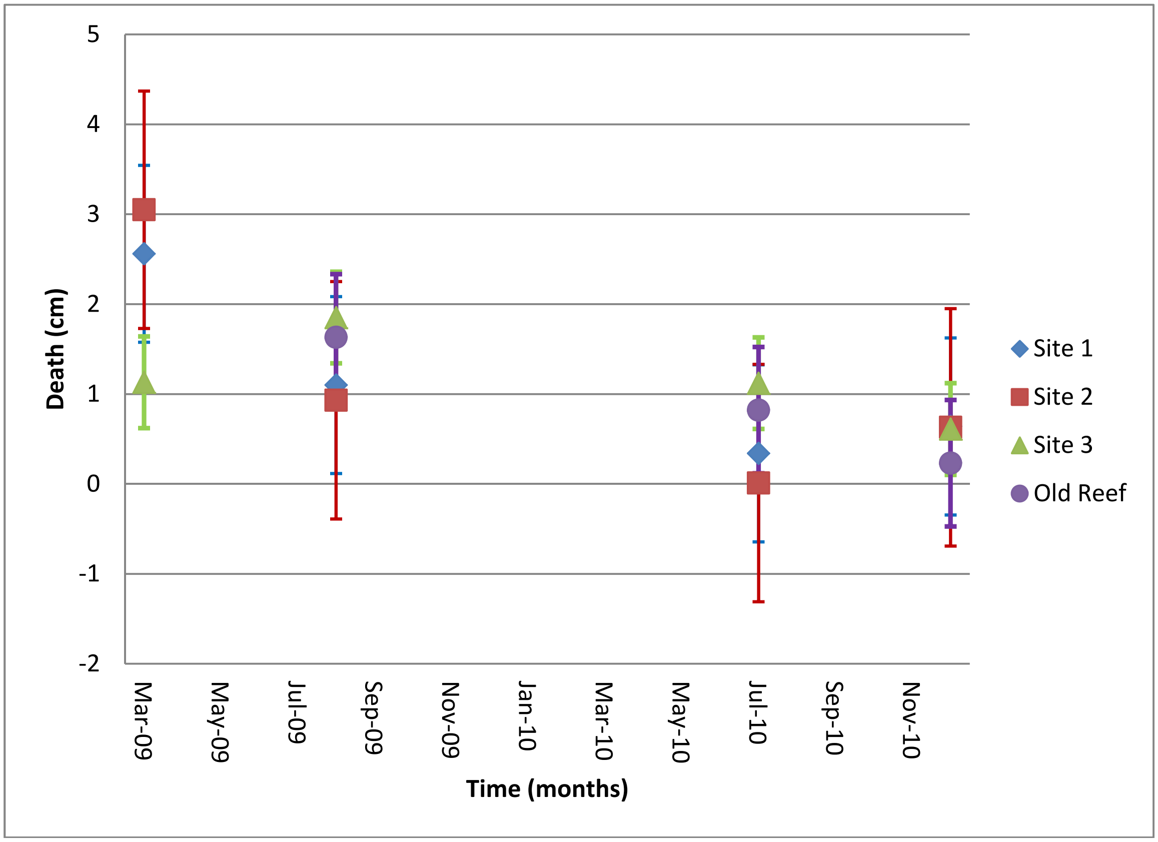

Figure 35: The average changes in the amount of dead seagrass measured on individual *Syringodium* blades on the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

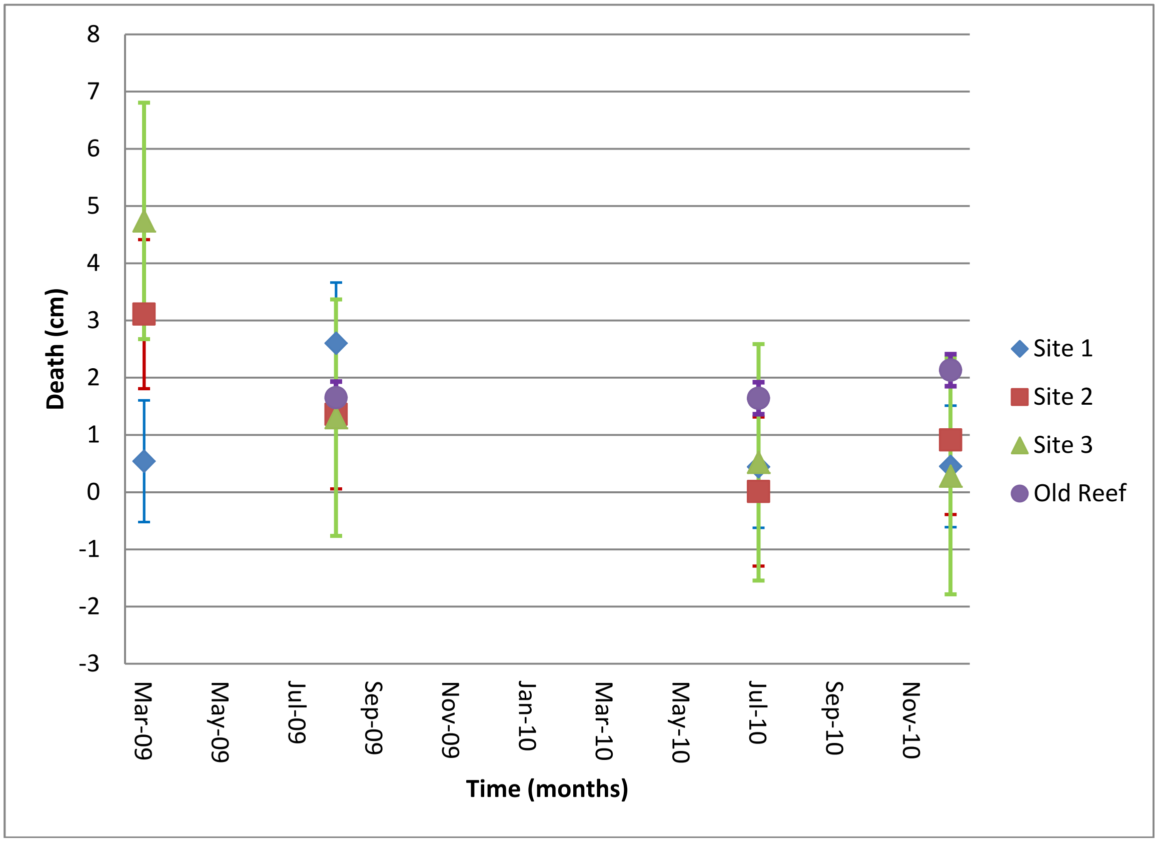

Figure 36: The average changes in the amount of dead seagrass measured in the halo area on individual *Syringodium* blades on the experimental sites and the old reef over time. The color of SD bars correspond with the color line of each site.

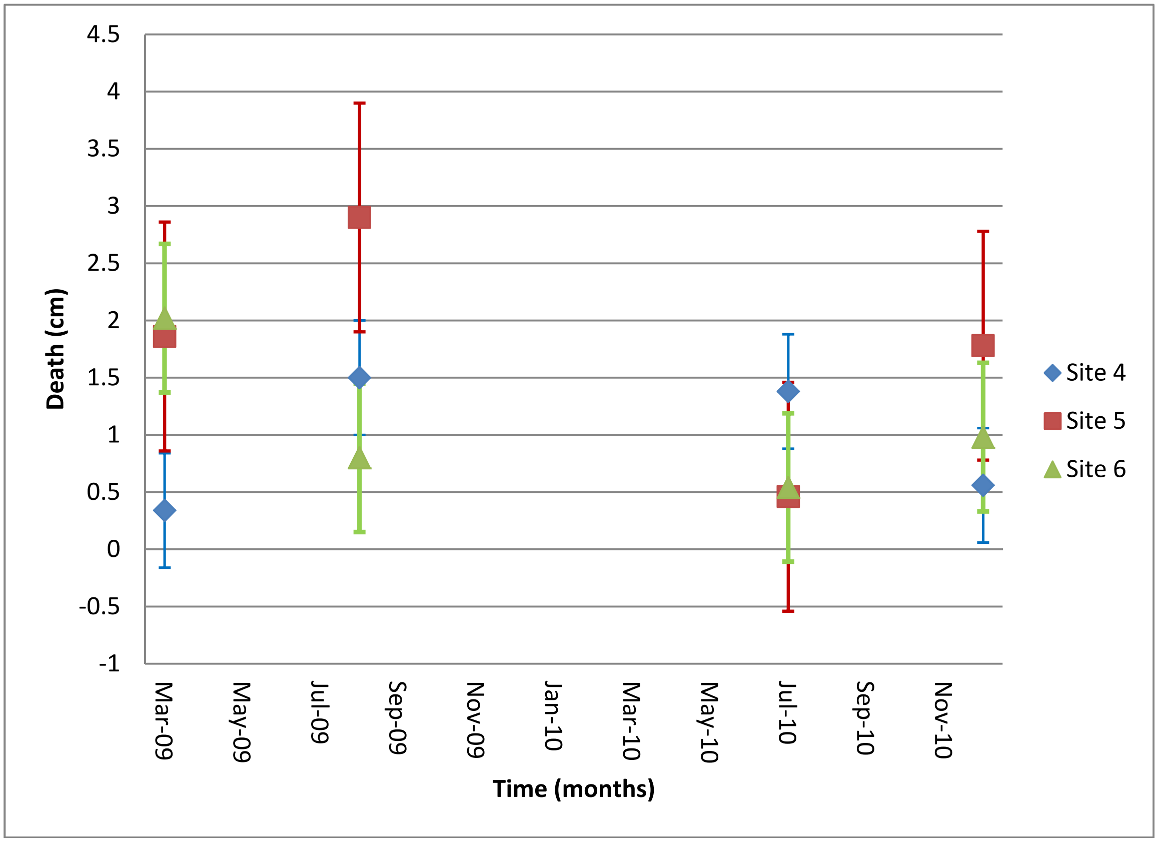

Figure 37: The average changes in the amount of dead seagrass measured on individual *Syringodium* blades on the control sites over time. The color of SD bars correspond with the color line of each site.

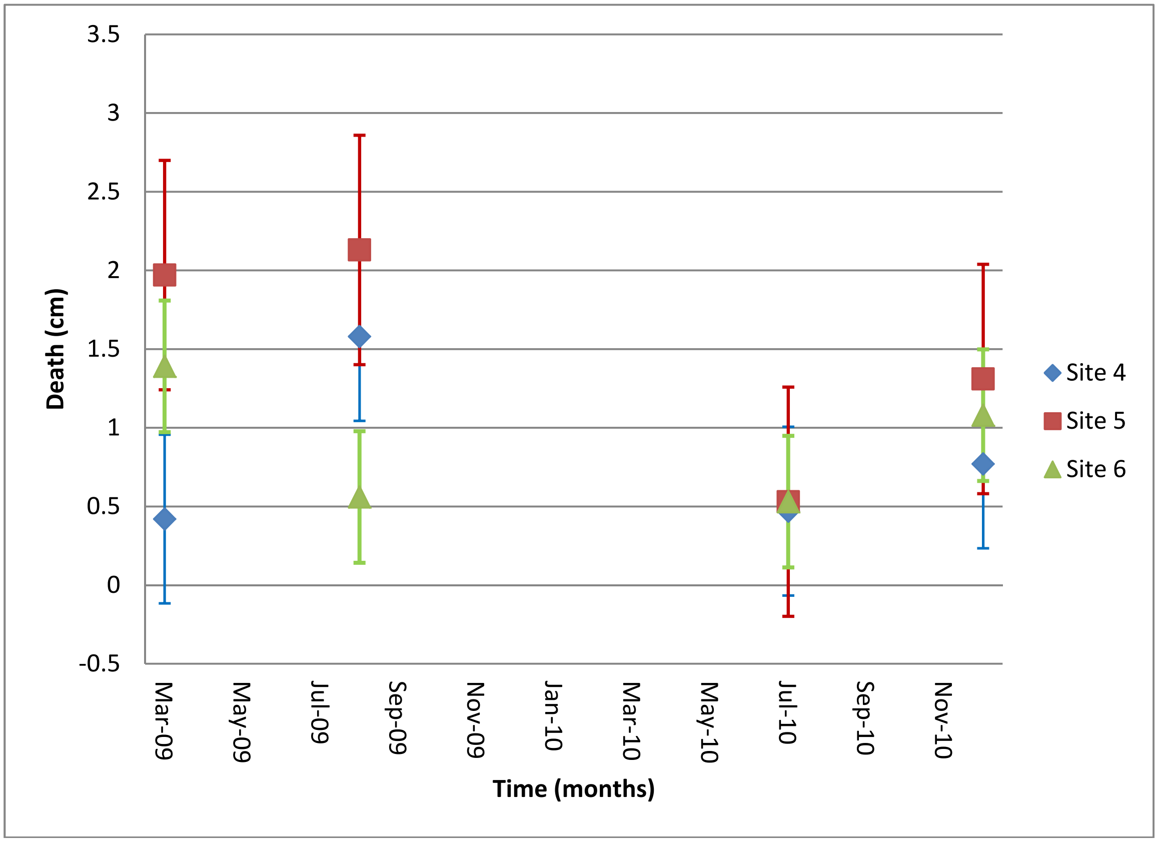

Figure 38: The average changes in the amount of dead seagrass on individual *Syringodium* blades measured in the halo area of the control sites over time. The color of SD bars correspond with the color line of each site.