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The relationship between live coral and macroalgae in South Caicos as influenced by herbivorous fishes

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by

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ABSTRACT:

Marine life is the basis for most industries in the Turks and Caicos Islands, located on the outskirts of the Caribbean Sea. Few studies have been carried out to assess the current status of reefs in this region, especially those off the shore of South Caicos Island. The AGRRA v.4.0 methodologies were employed create baseline assessments of stony corals, macroalgae and associated fishes and to explore the relationships between these key reef organisms. This study was based on 10 different locations both inside and outside of Marine Protected Areas (MPAs) and including exposed and sheltered reefs in proximity to South Caicos. Findings were highly variable, although a statistically significant positive correlation was found between macroalgal cover and herbivorous fish abundance, namely Acanthuridae and Scaridae. No significant relationships were found between macroalgal cover and coral cover or between coral cover and herbivore abundance. Minimal differences were found between exposed and sheltered reefs or between protected and unprotected areas. The findings of this study indicate a need for further reef assessments at additional locations.

INTRODUCTION:

Coral reefs are valued throughout the world as a unique habitat for a wide variety of marine organisms. Stony corals are characterized by their ability to produce a hard calcareous layer which expands providing the foundation for the diverse reef ecosystem. Nearly all scleractinion, or reef building corals, contain zooxanthellae, symbiotic algae that capture the sun's energy through photosynthesis and serve as the main source of food for reef corals (Castro & Huber 2005). Several other species of algae, particularly macroalgae (i.e. *Penicillus* sp., *Halimeda* sp., *Dictyota* sp), exist within the reef ecosystem and also engage in photosynthesis. Therefore algae regularly compete for light and space with reef corals (Bellwood *et al.* 2004; Francini-Filho *et al.* 2009).

Another type of organism to call the coral reef home falls under the category of herbivore, feeding largely on algae, plankton, and detritus (Bellwood *et al.* 2004). Reef fish from the families Acanthuridae (surgeonfish) and Scaridae (parrotfish) act as roving herbivores and consume the largest quantities of algal biomass (Francini-Filho *et al.* 2009). Because the intense feeding of herbivores reduces the presence of algae on the reef, these organisms are key players in the dynamics of coral reef health (Bellwood *et al.* 2004; Francini-Filho *et al.* 2009). Therefore this project also aims to explore the relationship between the abundance of herbivores and algae along the reef and its impact on live coral cover.

The balance among coral cover, algal presence and herbivore abundance is a delicate relationship crucial to reef health. It is predicted that areas with higher algal coverage will also support more herbivorous reef organisms, because of the abundance of available food. Thus it may also be true that a decrease in live coral cover, which competes directly with algae for space and light will correlate with an increase in herbivorous fishes. This trend has been observed in

several previous studies such as Lirman's 1999 study of Reef fish communities in Florida and the US Virgin Islands. Additionally, Jamaica's coral reef ecosystem demonstrates the compounding effects of a disruption of balance regarding the relative levels of coral, algae and herbivores along a reef. The island of Jamaica was struck by widespread sea urchin disease in the 1980s, in addition to extensive continual overfishing of herbivores and Hurricane Allen in 1980, taking a devastating toll on the reef dynamics. During this time coral cover dropped from an average of 52% to 3% and macroalgae cover rose from a mere 4% to 92% (Hughes 1994). Although Jamaica's reef is now on the road to recovery, this example illustrates the dramatic role herbivorous fishes play in the balance of the coral reef ecosystem and also demonstrates the indirect correlation between coral and algal cover.

As increasing nutrient pollution gives way to a rise in algal coverage, herbivores become increasingly essential to reef health (Bellwood *et al*. 2004). Currently, market demand for herbivorous fishes is on the rise. Although some herbivores are being caught and sold as food, demand for live herbivorous reef fishes is rising particularly in China, Singapore, and Taiwan (Bellwood *et al*. 2004). Studies around the world including Zanzibar Island off the coast of Tanzania and the Solomon Islands near Papua New Guinea have recorded declines in Scaridae population levels (Thyresson *et al*. 2011 and Aswani & Sabetian 2009). In a ten day provisional study of South Caicos fisheries, it was estimated that herbivorous reef fish compose only a very small portion, approximately 5%, of the total fish caught by local fishermen (SFS 2010). Although this minimal level of fishing is sustainable, substantial future rises in this figure if a new market for live herbivores were to develop could be cause for alarm. Continual research on the status of current reefs, the characteristics of each reef habitat and the abundance and diversity

of associated organisms is essential to the preservation of these sites from rising destructive influences.

Research on marine habitat complexity has historically utilized a wide variety of different evaluation methodologies. The Atlantic and Gulf Rapid Reef Assessment (AGRRA) methodology features a multivariate reef assessment of stony corals, algal presence and fish communities of an associated area so that many sites can easily be compared (Kramer *et al.* 2005). In a 2005 comparison of the methods used to estimate coral cover within the Hawaiian Islands, it was found that a large number of general reef appraisals, such as the AGRRA methodology which includes a multivariate assessment, will produce a better estimate of reef habitats than a few, high-quality appraisals (Jokiel *et al.* 2005)

South Caicos Island, located on the fringe of the Caribbean Sea, consists of eight square miles of land which sit upon a limestone platform whose margins eventually end in a 'drop-off' to oceanic abyss (Linton *et al.* 2002). Prior to the 'drop-off' regions, marine areas skirting South Caicos Island contain an abundance of both fringing and patch reefs which supported an average 18% coral coverage in 1999 (Linton *et al.* 2002). Since this time there has been little active or published monitoring of the health of the reef, however a rise in tourist developments, a potential for passing cruise ships and an increase in fishing pressure suggest that the reefs of South Caicos Island may be at risk in upcoming years (Linton *et al.* 2002). No specific marine conservation policy exists within the Turks and Caicos Islands (TCI), nevertheless several MPAs are present along the South Caicos coast (Linton *et al.* 2002). Further and consistent monitoring of the South Caicos reef and MPA systems is necessary to ensure future reef ecosystem conservation.

While several previous studies have explored the role of herbivores within the reef ecosystem, no research has addressed this topic with a specific focus on South Caicos, an island

whose main industry is fisheries. In 1999 an AGRRA study conducted on 28 sites throughout the

Turks and Caicos Islands found no correlation between herbivore density and macroalgal

biomass or live stony coral cover (Hoshino *et al.* 1999). Because this study was conducted over a

decade ago and reef dynamics are constantly changing due to various outside pressures, an

assessment of the current state of the reef by means of an AGRRA-based survey is necessary to

form the basis for future marine policies on South Caicos Island and prevent future reef

deterioration, especially if compared to yearly data.

Additionally, this project will aim to explore the relationship between live coral coverage

and algal coverage on various exposed, sheltered, protected and non-protected reefs surrounding

South Caicos. This relationship is worthy of investigation because in recent years a rise in

several anthropogenic factors such as nutrient runoff, anchor damage, destructive fishing and

SCUBA diving tourism as well as many geomorphic factors like disease, climate change and

severe weather have led to a deterioration of the reef and the development of algal blooms

(Linton *et al.* 2002). If rising algal concentrations subsequently decrease the presence of live

coral then the reefs surrounding South Caicos will be especially vulnerable to damage by future

nutrient runoff caused by increasing human developments. Additionally, fringing and/or exposed

reefs will be especially susceptible due to their proximity and/or accessibility to human impacts.

By publicizing this relationship while the Island's infrastructure is in its infancy, we may be able

to prevent the threat of nutrient runoff from arising in the future.

MATERIALS AND METHODS

Ten different reef locations surrounding South Caicos Island, including both exposed and

sheltered reefs and protected and non-protected areas, were chosen based on previous research as

well as shallow overall depth (max 6m) and weather-related limitations such as strong currents.

Testing and data collection was conducted from November 15th, 2010 through November 26th, 2010.

The methodologies were based on the Atlantic Gulf and Rapid Reef Assessment (AGRRA) v. 4.0 2005 program, which include a rapid, multi-scale assessment of fishes, stony corals and algae (Lang 2003). Twelve different surveyors gathered data for this project. To minimize observer biases four training transects were conducted with all surveyors prior to the start of the study. Additionally, some elements of the original AGRRA program, as described below, were simplified for use in this project.

First, three 50m belt transects were haphazardly laid at each site, while also ensuring that the line was taut and secure because many sites featured strong currents (Kramer *et al.* 2005). During this time a snorkel team consisting of two researchers swam along each transect recording each fish species and the corresponding size class observed within a 5m diameter of the transect. Fishes were divided into the following size classes: 0-5cm, 6-10cm, 11-20cm, 21-30cm, 31-40cm and >40cm. Every day, including the two training days at the start of the project, prior to conducting the study all roving snorkelers received size class estimation training within a pool to help minimize inter-rater variability. Each snorkel team conducted an initial pass along the transect to log larger, transient fishes and then immediately followed with a second pass to identify more cryptic fishes. Afterwards, each snorkel team conducted a 30min roving diver REEF survey of the reef site, recording each observed fish species and estimating its abundance along the reef (Kramer *et al*. 2005). The fish abundance data recorded along the 50m transect for Acanthuridae and Scaridae was used to estimate the presence of herbivores at each reef location.

Also along each transect teams of two SCUBA divers surveyed the benthos area with modified AGRRA techniques. One diver laid a 25cm by 25cm quadrate every five meters along

the transect beginning at zero meters. Within this quadrate percent substrate coverage was recorded, categorized as either pavement (rock), live stony coral, dead stony coral, rubble or sand; maximum relief was noted; and any macroalgae present was identified and measured for maximum height. Additionally, any coral recruit species (<2cm) were also be documented.

Using the chain and tape method for surface complexity, rugosity of the substrate immediately below the transect line was measured and recorded from 0-1m, 10-11m, 20-21m, 30-31m and 40-41m. The line intercept method was used to categorize the substrate located immediately beneath the transect line. The second diver swam along the line and recorded the amount in centimeters of live stony coral, sand, rock, fleshy macroalgae, calcareous macroalgae, crust coral and other organisms (e. g. sponges, gorgonians) observed. Any live corals found to be greater than ten centimeters beneath the transect were identified and measured, recording maximum width, length and height as well as the corresponding length along the transect line (Kramer *et al*. 2005). Because multiple different divers conducted this surface complexity analysis the original AGRRA methodology was simplified to encourage greater inter-rater reliability. For example dead coral was not classified by potential source of death nor was dead coral found beneath the transect line identified or recorded. Finally, the number of *Diadema antillarum* and *Panulirus argus* found within a 5m diameter of the transect line were recorded by the dive team.

Subsequently appropriate data were analyzed in terms of both live coral and macroalgal coverage, height and species diversity as well as abundance of herbivorous fishes, namely Acanthuridae and Scaridae. The mean coverage of live coral and macroaglae along the reef was determined as a measure of length under the 50m transect. Average algal height and species richness was determined from algal species observed within the 25cm by 25cm quadrates.

Average live coral height and species richness was determined from coral colonies $\geq$10cm found directly below the 50m transect. A Pearson correlation coefficient (r) was calculated to determine if there was a linear relationship between variables. To determine the significance of results coefficient correlation tables were employed (Bakus 2007).

RESULTS:

This study examined a total of 138 stony coral colonies, representing 14 distinct species, found beneath 30 different 50m transects, laid at 10 distinct locations. An overall mean colony height of 30$\pm$20cm was found. Species richness for live corals was fairly consistent across all sites. *Montastrea annularis* was the most common coral species recorded, with 60 separate colonies of the 138 total stony coral colonies recorded. *Millepora alcicornis*, *Montrastrea cavernosa, Porites astreoides, Porites* sp. and *Siderastrea siderea* and were fairly common with more than 10 colonies found for each species. Finally, fewer than 10 colonies of the following stony corals were found based on all visited locations: *Agaricia agaricites, Dendrogyra cylindricus, Diploria strigosa, Eusmilia fastiagata, Madracis aurenra, Madracis mirabilis*, *Meandrina meandrites,* and *Millepora complanata*.

A total of 8 distinct species of macroaglae were observed within the 300 different 25cm by 25cm quadrates laid over 10 different locations. Macroalgae had an overall mean height of 4$\pm$3cm with species richness fairly consistent across all sites. *Dictyota* sp. was the most common algal species, as it was observed at every site. Other observed algal species include, listed in order of decreasing abundance: *Halimeda* sp., *Turbinaria* sp., *Sargassum* sp., *Padina* sp., *Udotea* sp., an unidentified species of Rhodophyta and *Penicillis* sp. Acanthuridae and Scaridae were equally represented along all reefs with an average of 11$\pm$7 individuals per 100m^2 and 12$\pm$11

individuals per 100m^2, respectively. Overall an average of 24$\pm$21 herbivorous fish individuals per 100m^2 were found across all sites.

Live coral cover was found to vary from 1.1$\pm$0.9% to 5.4$\pm$6.2% over all locations. The mean live coral cover over all sites was found to be 3.2$\pm$3.2%. Macroalgal cover was found to vary from 0% to 61$\pm$24% over all locations. The mean cover of macroalgae over all sites was found to be 20$\pm$21%. Mean coverage for coral and algae were found to be generally consistent on both exposed and sheltered reefs (*Table 1*). The abundance of herbivores were also found to be consistent both in exposed and in sheltered reef locations (*Table 1*). When collected data was divided by site protection status average coral cover, average coral height, average algal height and average herbivore abundance were also found to be relatively consistent across all zones as shown in *Table 1*. The exception to this trend was average algal cover which was extremely high in unprotected areas and much lower in protected areas, the specific coverage values (*Table 1*).

A low, negative correlation (Pearson's r = -0.582) was found between live stony coral cover and macroalgal cover (*Figure 1*). A positive statistically significant relationship (Pearson's r = 0.864, df = 8, CI = 95%) was found between algal cover and herbivore abundance (*Figure 2*). An almost negligible correlation was found between live coral cover and herbivore abundance (Pearson's r = 0.025, df = 8, CI = 95%) (*Figure 3*).

DISCUSSION:

The major findings of this study include few overall differences between exposed and sheltered reefs or between protected and unprotected area. Overall macroalgae was considerably more prevalent over all reef locations than live coral. Herbivores were found in consistent abundance across all locations with Acanthuridae and Scaridae equally represented. Finally, the

only statistically significant relationship observed was a positive correlation macroalgal coverage and herbivore abundance.

The abundance of *Montastrea annularis* was supported by the 1995 AGGRA survey of Turks and Caicos reefs (Riegl *et al*. 1995). Additionally, the average coral colony height of 30±20cm falls within the average range recorded in 1995 of 16.5cm to 66cm. The mean coral cover over all sites was found to be 3.2±3.2%, which is alarmingly less than the average 18% coral coverage reported in 1999 and the 10% to 20% reported in 2006 (Linton *et al*. 2002; Goreau *et al*. 2008). It is possible that bleaching caused a rise in coral mortality, however this influence cannot account for such a dramatic decline, indicating that this assessment failed to accurately record all present corals. There were many occasions when additional coral species were observed very close to but not underneath the transect. Other stony coral species such as *Favia fragam* were located under the transect but never exceeded 10cm in length. Therefore the data collected in this study represents the stony coral species that composed the greatest proportion of reef area however failed to provide an accurate measurement of coral species diversity and live coral coverage, a major limitation in this study. In future studies coral species, coral coverage and algal coverage should be recorded via quadrates using the same methodology as implemented to determine algal species abundance.

Algal cover was found to dominate coral cover at nearly every location. The 1995 study of TCI reefs found mean macroalgal height to be <2cm (Reigl *et al*. 1995). This is a notable difference from the findings in this study in which average macroalgal height was 4±3cm suggesting a rise in algal growth in recent years. However, a rise in macroalgal growth is generally correlated with a decline in overall reef health (Reigl *et al*. 1995), a trend was not noted by this study. Because *Dictyota* sp. was the most abundant species of macroalgae observed

and this species is typical in regions of low to moderate nutrient levels, it is unlikely that significantly rising nutrient levels due to sewage runoff or other sources are the cause of this rise in algal height, however it may be a contributing factor (Goreau *et al*. 2008). Further studies should be conducted to further confirm this result and investigate ocean nutrient levels; at which point actions would need to be taken to prevent and combat rising algal growth.

The recorded abundance of Acanthuridae, 11 ± 7 individuals per $100m^2$, is slightly lower than that found in the 1999 AGRRA study of TCI reefs which recorded 15 individuals per $100m^2$, while the recorded abundance of Scaridae, 12 ± 11 individuals per $100m^2$, is nearly equivalent to that of the 1999 study which recorded 11 individuals per $100m^2$ (Hoshino *et al*. 1999). Because recorded abundance values from both studies fall within the standard deviation of the calculated values, results suggest that herbivorous fish populations have remained relatively constant over the last decade and rising fishing pressures have not impacted herbivorous populations.

All averaged values carry a very large standard deviation often equal to that of the value itself. For example in *Table 1* the standard deviations calculated for average coral cover values represent 50% or greater of the average value. This suggests an extremely high variability among recorded data points. Although training transects and fish size training sessions were carried out to reduce inter-rater variability, further steps need to be taken in the future to ensure that all surveyors follow the same standard procedure. It is suggested that future studies clearly define the terms and units of data collection because this was an obvious weakness of this study. Additionally, data variability may be a reflection of strong wave currents during some days of data collection which made laying quadrates and recording accurate measurements extremely difficult.

The wide variability in live coral coverage over all locations, ranging from $1.1\pm0.9\%$ to $5.4\pm6.2\%$, is demonstrated by *Figures 1* and *2*. However, when sites were divided into exposed and sheltered reefs and into protection status no trends could be determined. Other studies have found that exposed and sheltered reefs in Turks and Caicos differ in the percentage of live coral cover which was found to be higher in moderately exposed reefs than in sheltered reefs (Reigl *et al.* 1995). This result was only just significant therefore overall coverage differences between exposed and sheltered reefs are historically very minimal. It is possible that if additional sites were tested to present a more cumulative representation of different types of reef systems a similar relationship could be observed. Therefore a limitation to this study is the few overall number of sites and inability to accurately represent differences between exposed and fringing reefs as well as the effects of marine protected areas on coral coverage. If coral has in fact adapted equally as well to growth on exposed and on sheltered reefs then both of these reef systems should receive equal attention in future coral conservation efforts.

The wide variability of macroalgal abundance between locations, ranging from zero to $37\pm5.8m^2$ per $100m^2$, is demonstrated by *Figures 1* and *2*. However when sites were divided into exposed and sheltered reefs no trends could be determined. The 1995 study of TCI reefs found average macroalgal heights to be greater in moderately exposed reefs than in sheltered reefs, (Reigl *et al.* 1995). Once again, although this relationship was not observed in this study, as shown by the similar macroalgal heights for exposed and sheltered reefs detailed in *Table 1*, a relationship may develop if more sites were tested. When sites were divided by protection status, it was found that unprotected areas carried a higher coverage of macroalgae. Other studies have also found unprotected marine areas to support higher levels of macroalgae than protected areas (Mumby & Harborne 2010). However, this trend was observed with an increase in live coral

cover within protected areas and in regions with low coverage of macroalgae (Mumby &
Harborne 2010). Neither of these relationships was supported by this study. Thus additional
protected and unprotected areas should be tested to further confirm the result that algal growth is
increased in unprotected areas.

The positive, statistically significant relationship found between algal cover and
herbivore abundance indicates that herbivores do prefer regions with a higher abundance of food.
The 1999 AGRRA study of Turks and Caicos Reefs did not find any correlation between
herbivore abundance and macroalgal cover. However a relationship was noted between
Acanthuridae and macroalgal cover (Hoshino *et al*. 1999). This information could be useful in
future efforts to conserve herbivorous fishes if their populations ever decline from rising fishing
pressures.

Finally, there was a slight correlation between live coral cover and herbivore abundance.
Because no statistically significant relationship was found between algae and live coral, although
algae and coral have been shown to directly compete for light and space, it follows that no
correlation would be observed between herbivores and live coral which would carry an indirect
relationship because herbivores feed on algae and not on corals (Francini-Filho *et al.* 2009). A
direct relationship between herbivores and live corals would be possible if increasing habitat
complexity due to greater live coral cover presented more sources of refuge for herbivores
(Wilson *et al*. 2009). However, this direct relationship would include all reef fishes not merely
herbivores. Previous studies display conflicting results regarding this relationship. A study in the
lagoon of Mataiva Atoll in French Polynesia found overall fish abundance to increase with
increasing live coral cover; however this study did not look specifically at herbivorous fishes
(Bell & Galzin 1984). The 1999 TCI reef fish assessment as well as a 1987 study on habitat

complexity in the Red Sea found no correlation between herbivore abundance and live coral cover, which support the findings of this study (Hoshino *et al*. 1999; Roberts & Ormond 1987). If the status of South Caicos reefs were to decline considerably in future years it may be possible that a relationship would emerge however in its present state no such finding was evident.

Because the results of this study were variable based on research observers and are not entirely supported by previous historical findings, further studies at additional locations should be conducted to provide a more accurate assessment of South Caicos reefs. Additionally, steps should be taken to reduce observer bias and ensure standard methods for data collection. It is also important to note that only herbivore abundance and not herbivore biomass was considered in this study. If herbivore biomass was instead considered and found to vary considerably among locations it may be possibly that a relationship with macroalgal cover and/or coral cover would emerge. This study was valuable in that it provided a baseline assessment of South Caicos reefs and indicated a need for continual future assessments.

TABLES AND FIGURES:

Table 1. Influence of reef location and protection status on corals, algae and herbivores

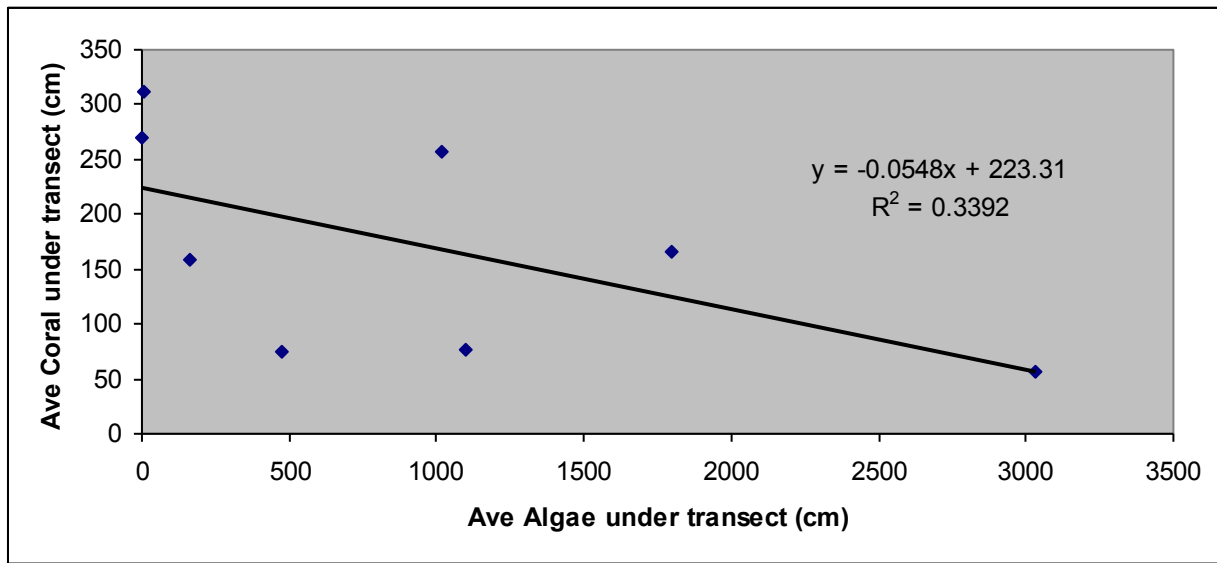|		Coral Cover	Algal Cover	Coral Height (to nearest cm)	Algal Height (to nearest cm)	Herbivore (# of individuals per 100m2)
Location:	**Exposed Reef**	2.4+3.4%	20+27%	23+17	4+2	20+15
	Sheltered Reef	3.8+3.0%	20+16%	34+20	5+3	28+15
Protection:	**None**	2.0+2.8%	40+19%	23+17	6+3	28+16
	EHCLR	4.8+3.2%	1.7+1.9%	44+20	3+2	25+10
	ACLSNP	2.0+2.1%	10+11%	25+17	3+1	22+20

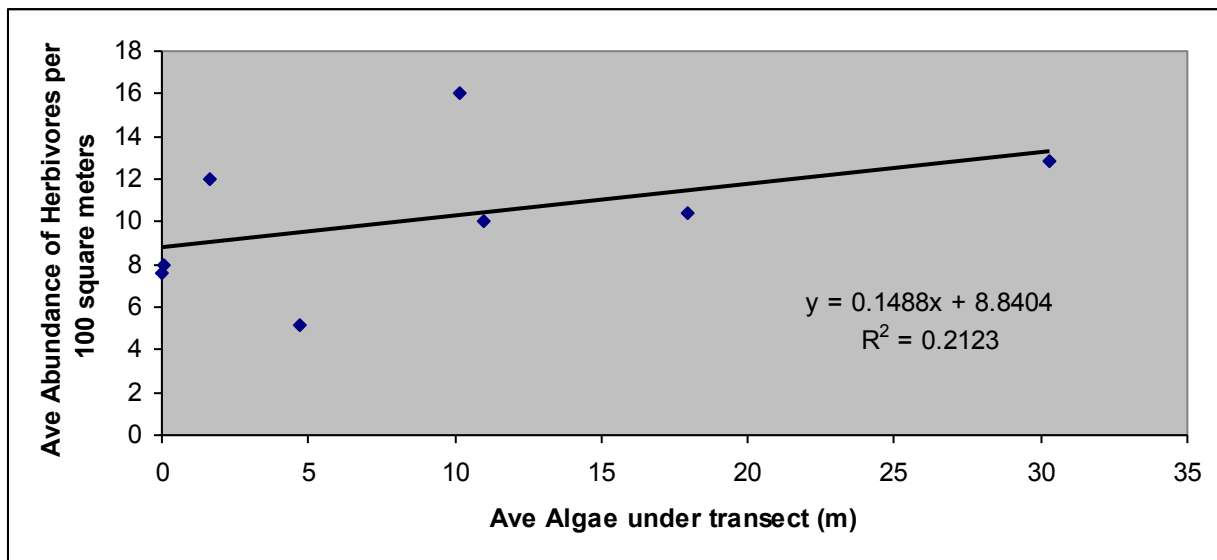*Figure 1. Relationship between algal and coral cover* (Pearson's r = -0.582, df = 8, CI = 95%)

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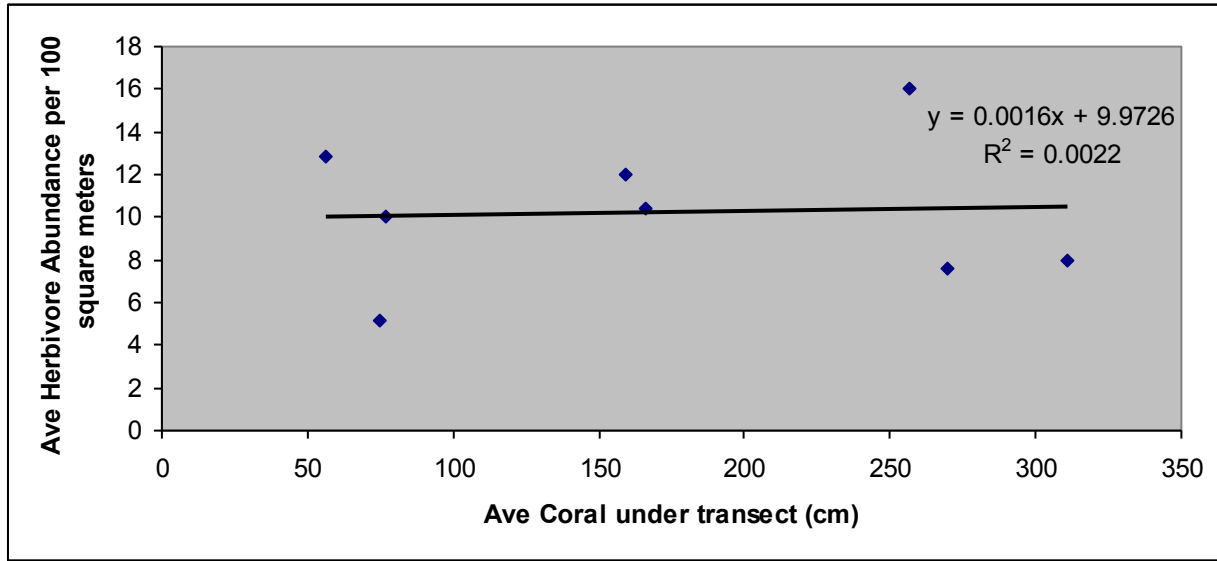*Figure 2. Relationship between algal cover and herbivore abundance* (Pearson's r = 0.864, df = 8, CI = 95%)

$$y = 0.0016x + 9.9726$$
$$R^2 = 0.0022$$

Figure 3. Relationship between coral cover and herbivore abundance (Pearson's r = 0.025, df = 8, CI = 95%)

APPENDIX A:

Site	Exposed/Sheltered Reef	Protection Status
Channel Reef	Exposed	None
S.W. End of Long Cay	Sheltered	Admiral Cockburn Land and Sea National Park (ACLSNP)
S. side of Dove Cay	Exposed	ACLSNP
Tucker's Reef 1	Exposed	ACLSNP
Tucker's Reef 2	Exposed	ACLSNP
Timm's Reef	Sheltered	None
Patch Reef	Sheltered	E. Harbour Conch and Lobster Reserve (EHCLR)
HDL	Sheltered	EHCLR
Dryer's Reef 1	Sheltered	None
Dryer's Reef 2	Sheltered	None

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