Spatial investigation on coral-turf algae interactions in fringing reefs of the Jordan Gulf of Aqaba- Red Sea

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ABSTRACT
Declines in coral cover are generally associated with increases in turf algae abundance- thus often termed a *phase-shift* from coral reef to an algae-dominated system. Turf algae coverage on the reef was measured at seven sites affected to varying degrees by industrial and recreational activities along the Jordanian coast of the Gulf of Aqaba (GoA). Using SCUBA to conduct transect surveys at two depths of each site, turf algae incidence was calculated in relation to total reef area (all live and dead reef) and in comparison to bare, algae-free dead coral reef. At every site, levels of turf algae were higher in the shallower depth (8 m), and more live reef was determined at the deeper depth (15 m). The two sites with the most turf algae, and least live reef coverage, are within close proximity to heavy industrial developments, while the site with the least turf algae and most live reef cover lies within a public beach, inside the Marine Park, which prohibits fishing. The average turf algae cover in relation to total reef area for all the sites and both depths is 28%, while bare dead coral to total reef proportion is a greater percentage: 40%. This may indicate that the potential phase-shift from coral reef to turf algae is not yet incurable, but with significant action, can be slowed, halted, or even reversed especially at sites in close proximity to anthropogenic influences such as construction and nutrient (i.e. Phosphorus and Nitrogen) over-enrichment.

KEYWORDS: Turf algae, coral reef, phase shift, Gulf of Aqaba

INTRODUCTION

Coral reefs are among the most biologically diverse ecosystems on earth, yet have worldwide been a recipient of the most destructive human activities over the years. Worldwide coral reefs have been suffering a prolonged decline in abundance, diversity, and habitat structure due to diverse adverse causes, notably over-exploitation, habitat destruction, pollution and climate change (Wilkinson 2002; Pandolfi et al. 2003). In many areas the loss of coral cover and diversity is coupled with an increase in algal biomass and shift in algal community structure (Szmant 2002; McManus and Polsenberg 2004).

The coral reefs of the GoA, as with many other reefs in the world, are currently experiencing slight deviation toward coral-algae phase shift—from reefs dominated by coral, toward turf algae-dominated reefs (Bahartan et al. 2010). The GoA's coral reefs are greatly jeopardized by such expansion of this phase shift, as the ailing reef becomes overgrown by bushy algal turfs that trap sediment and do not serve as healthy habitat for marine life, or many of the various other advantages provided by live coral reefs. Thus, the coral reefs of the GoA might be considered to be in critical condition, where "critical" is defined as being severely damaged and in imminent danger of collapse or extermination (Wilkinson, 1992).

Despite the ecological and conservation significance of the phase-shift phenomenon and the socio-economic implications for the thriving tourism industry and local fisheries in the GoA, little is known about the factors responsible for the appearance and proliferation of the turf algae on the GoA reefs. As coastal tourism continues to increase in the unique sea gate of Jordan, there is a need to maintain and sustain the coral reef ecosystem in this region. The main objective of this study is to survey and analyze turf algae proliferation on coral reefs at seven sites, each affected to a varying degree by industrial and recreational activities, along the Jordanian coast of the GoA (Fig. 1) in order to grasp whether or not turf algae is taking over Jordan's coral reefs. The GoA is 180 km by 16-25 km, and reaches depths of 800 m between Jordan and the Sinai Peninsula. The Jordanian coast along the GoA is only 27 km in length, and is bordered by fringing coral reefs.

Fig. 1 Survey sites along the 27 km of Jordanian coast of the GoA.

The Clinker port, just north of a container port and ferry port, is the most northern survey site.

There are no areas of live reef habitat large and intact enough for this survey north of the Clinker Port. The Saudi Arabian Border is the southernmost survey site, and is within close proximity to a major industrial complex (Table 1). At each site two scuba divers surveyed five 10 m line-transects at 8 m and 15 m depth. Transect lines followed the depth contours but otherwise went in a straight line with haphazardly chosen start points. Data was recorded continuously along each transect in the categories listed in Table 2. Total turf algae coverage was determined as the quotient of coral covered in turf algae (dense and sparse, in meters) divided by total reef (i.e. transect length minus length of sandy areas in meters). Dense turf algae coverage was the quotient. Surveys were conducted during winter, between 15 Nov 2008 and 6 Feb. 2009, which is the period of water column mixing in the GoA with high levels of available nutrients (Westhaus-Ekau, 2000). Water temperatures ranged from 24˚C in November to 21˚C in February.

RESULTS

Differences in Turf Algae Coverage between Sites

Turf Algae coverage varied between sites (Fig. 2). The Big Bay (BB) and Saudi Border (SB) sites had most turf algae at both depths, while at the Tourist Camp site (TC) least turf algae were found. Significant differences occur between the Tourist Camp and Saudi Border, as well as between the Tourist Camp and the Big Bay (ANOVA, $P<0.05$). The shallower transects consistently contained a higher percentage of turf algae than the deeper transects. The size of the algae was subjectively bigger at 8 m than at 15 m as well. The average turf algae percentage is consistently higher at 8 m than at 15 m.

Differences in Turf Algae on Massive versus Branching Corals

As shown in Fig.3 the average dense turf algae coverage was 20.2% less prevalent upon massive coral, and massive coral is 23.7% more algae-free. The difference of scarce turf algae coverage, however, was not significant at only 5.1% less coverage upon massive coral. The average proportional differences in turf algae coverage on massive vs. branching coral is shown in Fig.4. More dense turf algae were observed in branching corals compared to the massive. Massive coral also showed more algae free proportions compared to the branching coral.

Differences in Composition of Sites with Least and Most turf algae

Differences in the makeup of transects at the site with the least and the most turf algae coverage are shown in Fig. 5. Values are averaged from six of 10 m long-transects at 8 m depth at each site.

Table 1 Survey sites and brief descriptions

Name of Site	Description of Industrial and Recreational Activities
Clinker Port	○ Imports livestock such as sheep and grains such as rice and corn ○ Across two-lane street (towards mountains) is a factory that grinds sand for construction use ○ Releases clouds of dust ○ Fishing permitted
Marine Science Station I (MSS I)	○ Closed to the public for the past 30 years & diving is permitted for scientific purposes only. ○ Ferry Port >100m North (upwind) which produces large amounts of rubbish
MSS II	○ Same as MSS I, but 100m further South, and therefore, more remote and less influenced by Ferry Port
Tourist Camp	○ Public beach, but within Marine Park No-fishing Zone ○ Popular swimming, snorkeling, and SCUBA diving area
Shooting Club	○ Similar conditions as Tourist Camp, but a kilometer closer to the Tala Bay project
Big Bay (a.k.a. Tala Bay)	○ Major hotel construction area (thus, lots of sediment released offshore) ○ Area of especially poor mixing and circulation due to topography
Saudi Border	○ Major Industrial complex >100m North of survey site: ○ Ammonia (a Nitrogen-based compound) imported ○ Phosphorus products exported for fertilizer ○ Byproducts of such production (such as Aluminum fluoride) also exported for aluminum industry ○ Excess materials (i.e. metal products, tires, plastic etc.) dumped from the jetty in area ○ Heated water used in cooling system of phosphate plant pumped back into sea ○ Significant construction in the area

Table 2 Categories used for data collection along 10 m transects at both depths

Category	Description
S	Sand
LR	'Live Reef' – any living fauna on hard substrate
TDM	Dense Turf Algae on Massive Coral
TSM	Scarce Turf Algae on Massive Coral
TDB	Dense Turf Algae on Branching Coral
TSB	Scarce Turf Algae on Branching Coral
DMC	Dead Massive Coral (without epifauna/flora)
DBC	Dead Branching Coral (without epifauna/flora)

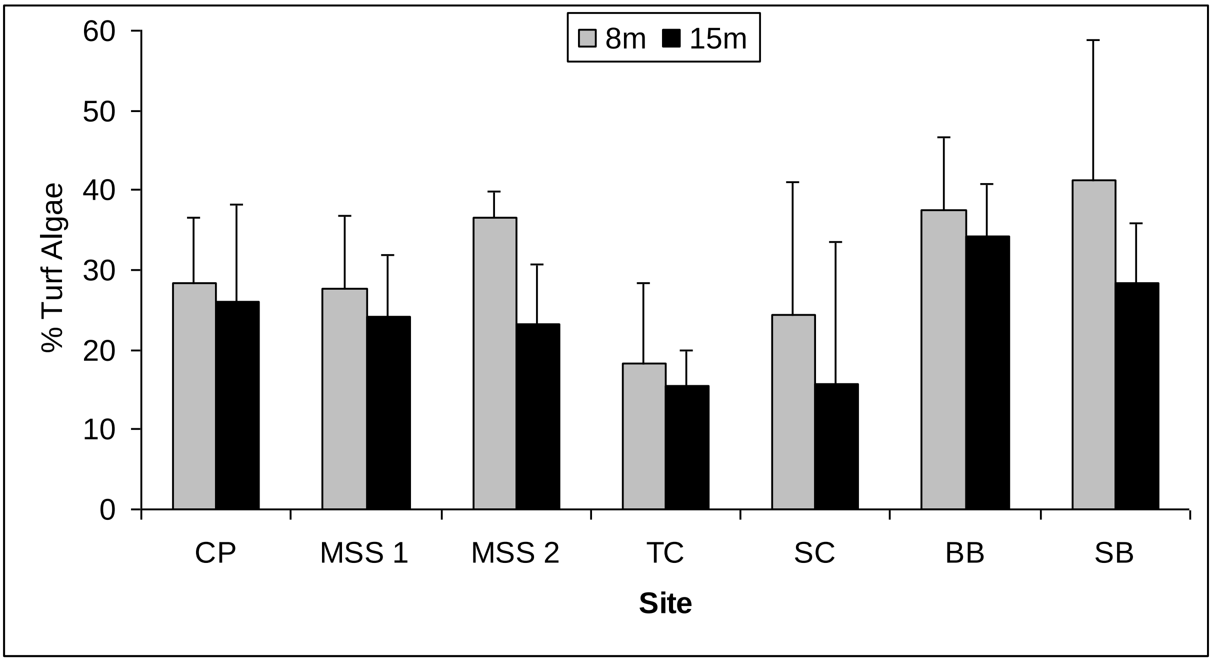

Fig. 2 Average Percentages of Total Turf Algae per transect at 8m and 15m. Error bars are standard deviations. As error bars overlap strongly between most of the sites, no significant differences were detected, except for between TC and SB, as well as TC and BB.

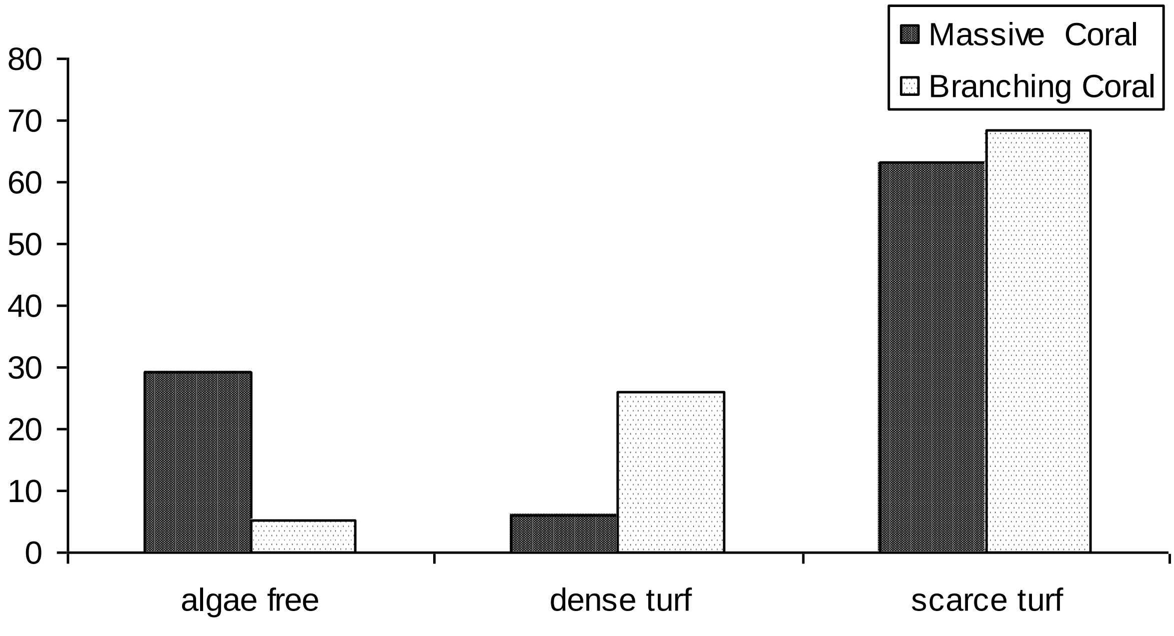

Fig. 3 Mean cover percent of turf algae on massive vs. branching corals

The average proportional differences in turf algae coverage on massive vs. branching coral is shown in Fig.4. More dense turf algae were observed in branching corals compared to the massive. Massive coral also showed more algae free proportions compared to the branching coral. *Differences in Composition of Sites with Least and Most turf algae* Differences in the makeup of transects at the site with the least and the most turf algae coverage are shown in Fig. 5. Values are averaged from six of 10 m long-transects at 8 m depth at each site. At the Saudi Border survey site the following results were obtained; 32% LR; 31% TA MC; 5% turf algae on branching coral (total of 36% turf algae on coral); 17% DMC; 0% DBC (total 17% *algae-free* dead coral). The obtained results at the Tourist Camp survey site were as the following; 54% LR; 4% TA MC; 11% TA BC (total of 15% turf algae on coral); 16% DMC; 4% DBC (total 20% algae-free dead coral).

The results revealed that the Tourist Camp survey site actually has 3% more algae-free dead coral, but 21% less turf algae on coral, and 22% more live reef. In summary, the overall turf Algae prevalence on Jordan's Coral Reefs showed the following pattern; 70% total turf algae to all dead coral reef, 28% total turf algae to total reef and 40% bare dead coral to total reef.

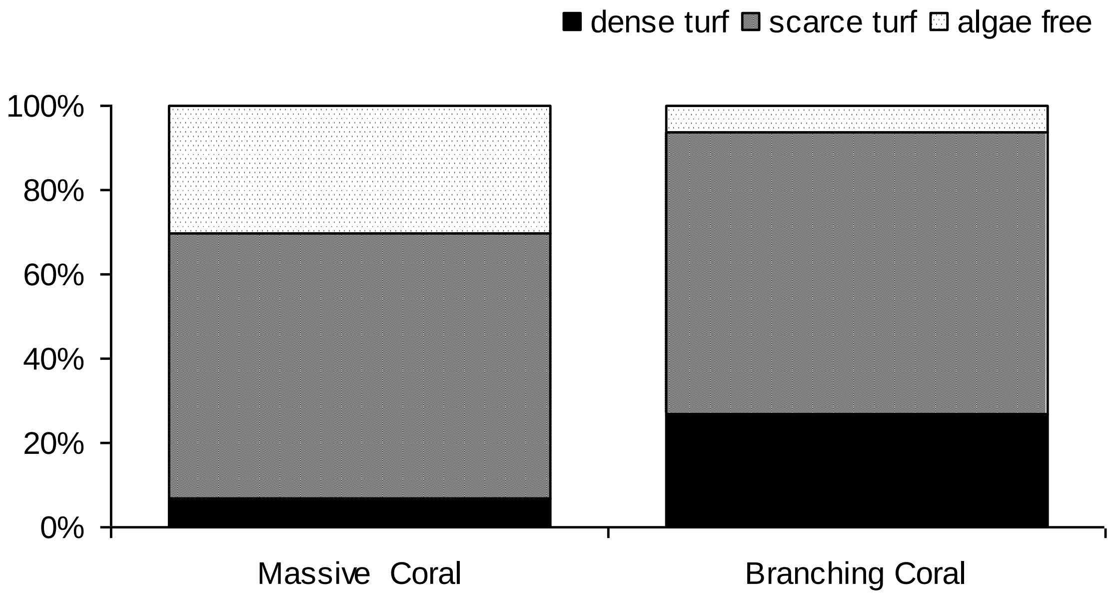

Fig. 4 The average proportional differences in turf algae coverage on massive vs. branching coral.

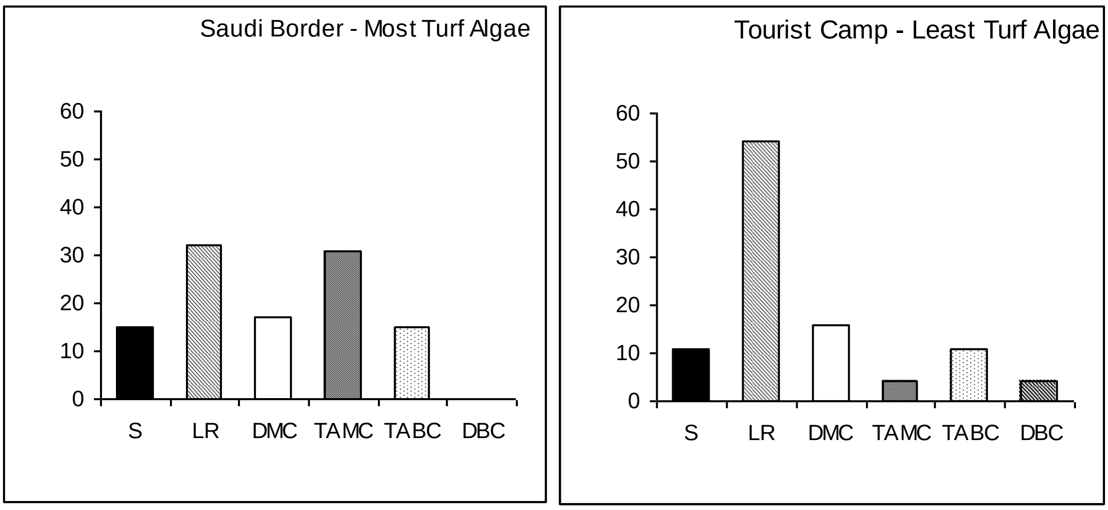

Fig. 5 Differences in the makeup of the transects at the site with the least and the most turf algae coverage (%). LR = Live Reef, DMC = Dead Massive Coral (algae-free), DBC = Dead Branching Coral (algae-free), TA MC = Turf Algae on Massive Coral, TA BC = Turf Algae on Branching Coral, S = Sand

DISCUSSION

Coral reefs are among the most complex systems in the marine environment. In many areas the loss of coral cover and diversity is coupled with an increase in algal biomass and shift in algal community structure (Szmant 2002; McManus and Polsenberg 2004). Typically, reef-building corals dominate the substrate on healthy accreting reefs, whereas non-coralline (i.e. fleshy and turf) algae are limited to the back reef and refuges from herbivores, and algal biomass is low. Coral–algal phase shifts are often, but not always, associated with a perturbation such as coral bleaching, outbreaks of a coral-eating species, or storm damage **(**McManus and Polsenberg 2004**)**. On degraded reefs, dead coral substrate and red coralline algae become overgrown by thick algal turfs that trap sediment. The turfs comprise a variety of fleshy foliose and corticated foliose macrophytes. This new high algal biomass state is generally associated with some combination of reduced grazing by herbivorous fish and invertebrates (as a result of disease and/or fishing) and nutrient enrichment. The relative importance of these factors is a matter of debate and varies between locations and even across individual reefs.

As shown in Fig. 2, two of the survey sites have significantly more overall turf algae coverage and more dense coverage of the algae, when divided by the total reef in our transects. One of these sites, Big Bay, lies just in front of a major hotel construction site, and the other site, the Saudi Arabian Border, is next to a fertilizer plant that produces phosphate products, and that has a cooling system which pumps hot water back into the sea just a few meters offshore. In contrast, the site with the least amount of algae and the most live reefs, the Tourist Camp, lies within a public beach area managed by the marine park. Interestingly, all three sites have similar human activities, including snorkeling, diving, swimming, tourist boats, (although fishing is permitted at the Saudi Border site). This indicates that industrial activity has a more detrimental effect to coral reefs than recreational activity. Evidence exists that the algae can exert direct negative effects on stony corals: the algae can contribute to bio-erosion, produce toxins and exploitative competition for space and resources. Indirect effects include retarding the settlement of coral larvae. However, it is extremely difficult to separate the individual processes influencing coral resilience and recovery post-perturbation. For instance, a reef may be subject to the effects of repetitious and diverse natural and anthropogenic perturbations.

Nevertheless, the observed decline in coral reefs might be as a direct result of the combined effect of other perturbations that generate the conditions necessary for algal establishment. Algal proliferation is likely to hamper coral reef resilience by inhibiting processes essential to the reef's vitality, notably stony coral recruitment and CA accretion (Birrell et al. 2005).

The Tourist Camp (TC) survey site surprisingly has 3% more algae-free dead coral than the Saudi Border (SB) site, yet 22% more live reef. The difference is that TC has 21% less turf algae on coral than SB, thus illustrating an inverse relationship between live reef and turf algae coverage and suggesting that the lower the amount of turf algae coverage in an area, the more potential the area has for live reef coverage.

Two concepts of how turf algae takes over coral are that it can out-compete coral for space on the reef, and also, it can serve as a vector of coral disease (Smith et al, 2006). Regardless of the mechanism, the role algae play on coral death has become immensely important, and the major concern is nutrient enhancement of coral reef waters (Tanner 1995). As the GoA is a semi-enclosed body of water, the circulation is low compared to open water bodies, and is especially sensitive to nutrient enrichment (Phosphorus and Nitrogen), and any type of water pollution (McCook, 1999). It could be concluded from the present study that the branching versus massive coral results illustrate another factor. Namely, the importance of grazers, such as herbivorous fish and urchins, which have more space and easier access to graze upon massive coral, which consistently had significantly less turf algae coverage (Figs. 2 and 3). Of all the dead coral surveyed, 70% of it was covered in turf algae (Table 3) and as algae kills more coral, more space is then created for algae on the dead reef, and thus a positive cooperation feedback loop is a potential situation. 70% is a high percentage, but with action, there is reason for the countries bordering the GoA to be optimistic about the state of their coral reefs, as well as their related tourist sectors.

RECOMMENDATIONS

- Develop tools aimed at slowing and/or preventing the takeover of reefs by turf algae, assigning priority to decreasing nutrient loading.
- Make information available about turf algae's detrimental relationship to the reefs for local decision-makers and stakeholders, so as to encourage beneficial procedures for controlling turf algae and facilitating the development of sound management policies for coral reefs in the GoA.
- Public awareness and education efforts are vital to enhance community interest about maintaining healthy coral reefs.
- Preservation of public beaches, which represent only 30% of Aqaba's shoreline—while limiting harmful activities such as fishing—is an important component of attaining community support.
- Collaboration of research and action between marine scientists surrounding the GoA, as the semi-enclosed water within the Gulf and that the reef along with its resources knows no political borders.

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