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RECOVERY PROBABILITIES OF CORAL REEF COMMUNITIES AFTER *ACANTHASTER PLANCI* INFESTATION: A CASE STUDY AT SHABROR UMM GAM'AR, HURGHADA, RED SEA, EGYPT

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ABSTRACT

Recovery patterns of coral reef benthic communities were estimated by linear extrapolation after *Acanthaster planci* outbreak of 1998 at Shabror Umm Gam'ar, Hurghada of the Egyptian Red Sea. The significance of using linear extrapolation was tested in a range of ten sites by comparison with the actual average yearly recovery rates. A total of 15 permanent transects, each is 10m long, were monitored at 10m and 12m depths in both Shabror Umm Gam'ar and the ten selected sites. The recovery rate estimated by linear extrapolation did not significantly differ from the recovery rate of stony corals in the ten selected sites. Moreover, an error of +7.69% to +17.5% increase in the extrapolated recovery rate exists and should be considered while handling the extrapolated recovery patterns of coral reef benthic communities. Stony corals were characterized by having an extrapolated slow recovery time of 64.9 years in spite of the fast recovery rate (0.67 % cover/year) and this is virtually due to the large cover required for restoration as a result of the large devastation by *Acanthaster planci*. In contrast, soft corals were characterized by having both fast recovery time (RT) and recovery rate (RR) as they are not preferred preys by the COTs. The correlation coefficient is negative between recovery time (RT) and recovery rate (RR), strong between RT and cover required for complete recovery CR, and weak between CR and RR. Diversity had an estimated fast recovery time (RT) of 4.3 years indicating that, the space cleared by *Acanthaster planci* improves the diversity faster than improving the percent cover.

INTRODUCTION

The Crown-of-thorns starfish (COTs) *Acanthaster planci* is a highly specialized coral predator found in the Red Sea (Ammar, 1998). A first step of recovery after coral mortality is recruitment (Brown and Suharsono, 1990; Glynn and De Weerdt, 1991). It is often stated that reef ecosystems are both more vulnerable to extinction and slower to recover, but rigorous analysis are surprisingly limited (Wood, 1999). Coral recovery after various environmental perturbations gained the attention of many scientists (Johannes, 1975; Endean, 1976; Pearson, 1981; Brown and Howard, 1985). Recovery time of reef coral communities was evaluated to be between 4-100 years (Coles, 1984). The available evidence suggests that coral communities may recover from major natural disturbance after several decades (Weiss and Goddard, 1977). Factors which can influence coral recolonization include the extent of damage and its location, the availability of coral larvae, the requirement for a "conditioning" period of the substratum before corals can settle, the availability and diversity of microhabitats for settlements and survival, the role of grazers, and competition with other organisms such as algae and soft corals (Pearson, 1981; Nezali *et al*., 1998). The reef of Shabror Umm Gam'ar of the Egyptian Red Sea has suffered, for the first time, from the outbreak of COTs during 1998

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and recovery rate is still a matter of debate. The question that is always asked by the decision makers is: how long will coral reefs need to recover after *Acanthaster planci* devastation ? The answer of that question, before complete recovery, could not be done except by linear extrapolation. Therefore, correction with actual average recovery rate is necessary. The purpose of this study is to estimate the recovery time (RT) and recovery rate (RR) as well as change in the community composition of coral reefs in terms of *Acanthaster planci* outbreak of 1998 at Shabror Umm Gam'ar in the Egyptian Red Sea. In addition, the degree of accuracy of the linear extrapolation method for estimating the recovery rate was tested in a range of ten other sites.

MATERIALS AND METHODS

Shabror Umm Gam'ar reef is an offshore site lying at 27°19\`97\`\`N, 33°55\`03\`\`E, about 12 km off Hurghada city. The seaward side of the reef, having high waves and currents, is at the north-eastern direction while the leeward side, which is considerably sheltered, lies at the southwestern side (Fig.1). The reef was monitored throughout the years 1997 (the year just before *Acanthaster planci* infestation), 1998 (the year of infestation) and 2005 (7 years after infestation), using a 10m long graded tape (loya, 1972) with replicates of 15 permanent transects monitored at each of 10m and 12 m depths respectively. percent cover of corals or other taxa were calculated as follows: Percent cover=intercepted length/transect length*100. Diversity was calculated by Shannon-Wiener formula (Shannon, 1948). The survey was conducted at mid-day, so nocturnal mobile taxa were not included.

Recovery rate (RR) of corals or other taxa expressed in % cover / year was estimated as follows:

RR (% cover / year) = (% cover during 2005 - % cover during1998) / 7

2005 is the year of last monitoring, 1998 is the year of infestation

The number 7 is the period (years) from 1998 to 2005

Cover required for restoration (CR) at the infestation year (1998) was calculated as follows:

CR=Cover just before the outbreak – cover during the outbreak

=Cover during 1997 – Cover during 1998

Recovery time (RT), which is the number of years required to reach the initial cover just before the infestation, was estimated as follows:

RT(years)=CR/RR

In a similar manner, recovery time (RT) of diversity was calculated as follows:RT=DR/RR

DR=diversity value required for restoration, RR=recovery rate of diversity (diversity index / year).

Recovery time for the number of molluscs and echinoderms was estimated in the same way

RT(years)=NR/RR

NR=number of individuals required for restoration, RR=recovery rate (individual / year)

Acanthaster planci was not included among the surveyed echinoderms as it was dealt with as a separate item.

The correlation coefficients between RT, RR and CR were calculated to show their association with each other. To test the significance and accuracy of the linear extrapolation method used to estimate the recovery rate and recovery time, a range of 10 sites (Table 4) which are monitored annually for the recovery rate after complete stopping of the severe anchor damage, were selected to conduct the test on stony corals only as soft corals were observed to recover within a short period. Both actual average recovery rate throughout nine years and its estimated value by linear extrapolation were calculated and compared for the significance of difference. Percent error of the recovery rate by linear extrapolation as compared to the actual average recovery rate for each of these 10 sites was calculated. The statistical significance of difference between the recovery rates estimated by linear extrapolation and those of actual average recovery rate for the ten selected sites was estimated by t-test using the computer program STATISTICA.

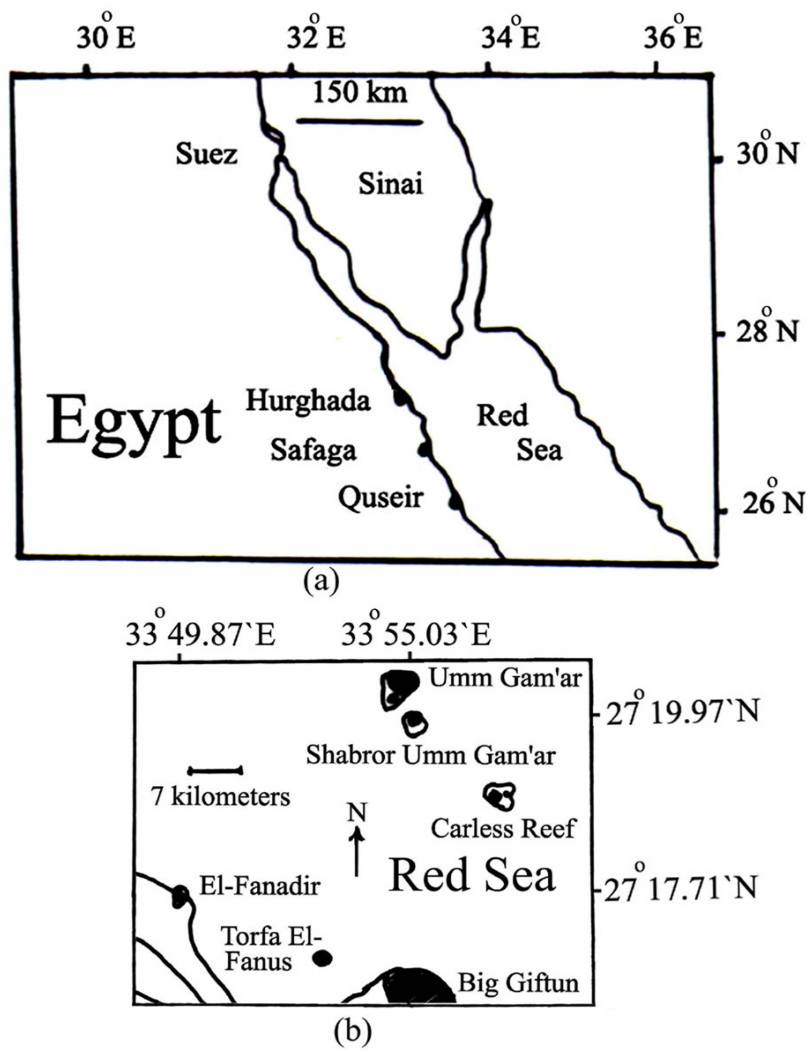

Fig.(1). a) Location map of Hurghada on the Red Sea coast
b) Location map of Shabror Umm Gam'ar in Hurghada area

RESULTS

The probability that the difference between recovery rates estimated by linear extrapolation and those of actual average recovery rate, for the ten selected sites of table (4) = 0.52 (t18=1.1). Moreover, percent error in the estimated recovery rate by linear extrapolation as compared to the actual average recovery rate in the ten selected sites ranges from +7.69% to +17.5% increase in the linear extrapolated estimation (Table 4). That error should be considered when dealing with recovery rate estimated by linear extrapolation. Stony corals have an estimated recovery time of 64.9 years with a recovery rate of 0.67 % cover / year after infestation (Table 1). *Acropora hyacinthus* has the fastest recovery rate (0.23%) although its recovery time (39.1 years) is considerably slow compared to most stony corals. Species like *Acropora humilis* and *Favia speciosa* are considered to have a long recovery time (400 years) as well as very slow recovery rate (0.03 and 0.01 % cover / year respectively).

In contrast to stony corals, soft corals have both fast recovery time (0.76 years) and recovery rate (1.31 %)(Table 2). *Xenia* sp. is the fastened recovering soft coral (RT=3.2 years, RR=0.31 %). The soft coral *Sarcophyton* sp. was not affected by the outbreak, it did not recover but in fact increased during and after the infestation. The hydrocoral *Millepora dichotoma* is characterized by having a recovery rate of zero value (Table 2) and did not recover. Patches of corals that were not preyed upon by *Acanthaster planci* during the year of infestation (1998) were not found during 2005 being covered mostly with algae. Coral diversity was estimated to restore initial level (before the infestation) after 4.3 years with the appearance of some new juveniles. Both algal turf and coralline algae increased during and after the infestation (Table 3). Dead corals and bare rocks which increased during the infestation were estimated to restore to the initial level after 12.6 and 7.14 years respectively (Table 3). In contrast to live taxa, the restoration of both dead corals and bare rocks were attained by a decrease in their level (negative RR value). Molluscs decreased during the infestation and did not recover, while echinoderms increased both during and after the infestation. Only one newly settling species of sponges (*Gelliodes* sp.) was recorded after infestation having a recovery rate of 0.04 % cover per year. The correlation coefficient was negative between RT and RR (r = - 0.09), strong between RT and CR (r = 0.64) and weak between CR and RR (r = 0.46).

DISCUSSION

The considerable probability of 0.52 that the difference is not significant between the recovery rate estimated by linear extrapolation and the actual recovery rate of stony corals, in the ten selected sites, validate the use of linear extrapolation estimation. Besides, the percent error of +7.69 - +17.5 increase in the extrapolated results, should be considered while handling the recovery patterns of coral reef benthic communities at Shabror Umm Gam'ar. Shabror Umm Gam'ar Reef is not included among the ten sites of testing the mentioned significance of difference because it has not been managed previously for annual monitoring. Accordingly, the data of yearly actual recovery rate is not available to answer the question of the decision makers concerning the recovery patterns in that site after the COTs devastation.

The slow recovery time of stony corals in spite of the considerable fast recovery rate is mostly due to the large cover required for restoration (CR) and this could be largely due to predation by *Acanthaster planci*. The appreciable negative correlation between RT and RR indicating that higher recovery rate will shorten the recovery time provided that the CR value is low. The strong correlation between RT and CR indicating the increase in cover required for restoration (i.e. increased extent of predation by *Acanthaster planci*) will prolong the recovery time. The weak correlation between CR and RR indicates that CR is not the only factor that affect the recovery rate (RR). Cowen (1988) observed a slow recovery of reef ecosystems after extinction events, Pearson (1981) and Dulvy *et al*. (1995) reported a period of 20-50 years for coral reefs to recover from severe damage. Among the stony corals, the tabular coral *Acropora hyacinthus* has the fastest recovery rate in spite of its slow recovery time, because of the large CR value since it was a preferred prey by *Acanthaster planci*. Hall (2001) indicated that, recovery of injuries of *Acropora hyacinthus* was influenced by the amount of algae that colonized the lesion and the zone of tissue available for restoration. The long recovery time of both *Acropora humilis* and *Favia speciosa* could be due to full predation by *Acanthaster planci* which led to large devastation, in turn a large cover is needed to restore the initial level (as indicated by higher CR). The new settlement of the stony coral *Stylophora pistillata* in areas of permanent transects agrees with the results of Loya (1972) who stated that *Stylophora pistillata* is an opportunistic species.The fast recovery time of soft corals (0.76 years), compared to that of stony corals, may be because soft corals could adapt fast and compete for space after *Acanthaster planci* infestation. Some evidences cleared that, soft corals replace stony corals and cause their death (Benayahu, 1985), it is also an important factor affecting coral recolonization (Pearson, 1981). The highest RR and fast RT of the soft coral *Xenia* sp. agrees with the statement of Atrigenio and Alino (1996) that, *Xenia* sp. is a potent competitor and plays an important role in determining succession and community structure. The increase in the % cover of the soft coral *Sarcophyton* sp. during the infestation helped to add to the total recovery time of soft corals. On the other hand, the non recovery of the hydrocoral *Millepora dichotoma*, could be mainly due to its full disappearance during 1998. The recovery of coral diversity after a short period (4.3 years) beside the appearance of some new small corals indicate that some of the available space cleared by *Acanthaster planci* was utilized for improving the coral diversity through coral recolonization and larval settlement. It was earlier reported that, the availability and diversity of microhabitats are important factors affecting recolonization and settlement of corals (Pearson, 1981). Molluscs have no estimated recovery time because their recovery rate is zero, while echinoderms have no estimated recovery time because they increased both during and after the infestation. In addition, sponges have no estimated recovery time because they are newly settling and were not found before the infestation. The observed increase in algal turf and coralline algae during and after the outbreak suggests that infestation by *Acanthaster planci* alters the community composition into algal domination rather than coral domination. The disappearance of the old preyed coral patches during 2005 could be mostly due to overtopping by algal domination. Porter and Meier (1992) also noticed rapid algal overgrowth on bleached and dying Flouridian corals population. Similarly, the increased levels of dead corals and bare rocks (being overtopped mostly by algal turf and coralline algae) were estimated to restore its initial level through a decrease in the RR value.

CONCLUSIONS

1-The probability that the difference is not significant between the recovery rate estimated by linear extrapolation and the actual recovery rate of stony corals in ten selected sites = 0.52. Besides, an error of +7.69% to +17.5% increase in the extrapolated recovery rates exist and should be considered while handling the recovery patterns of coral reef benthic communities.

2-Stony corals were reported to have a slow recovery time of 64.9 years in spite of the fast recovery rate and this is mostly due to the large cover required for restoration as a result of the large devastation by *Acanthaster planci*. In contrast, soft corals had both fast

recovery time and recovery rate as they are not preferred preys by the COTs.
3-The correlation coefficient is negative between RT and RR, strong between RT and CR, and weak between CR and RR.
4-Diversity had an estimated fast recovery time (4.3 years) indicating that the space cleared by *Acanthaster planci* improves the diversity faster than improving the percent cover.

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Table (1). Estimated recovery rate RR (% cover / year), cover required for restoration (CR) and recovery time RT (years) of stony corals after *Acanthaster planci* infestation of 1998 in the studied site.

Species name	RR	CR	RT
Stony corals			
Acropora hyacinthus	0.23	9	39.1
Acropora humilis	0.03	12	400
Pocillopora damicornis	0	0	0
Fungia klunzingeri	0	0	0
Herpolitha limax	0	0	0
Favites persi	0.03	1	33.3
Favites acuticollis	0	0	0
Favia pallida	0	0	0
Favia speciosa	0.01	4	400
Gardinoseris planulata	0.07	3.5	50
Porites echinulata	0.13	1.3	10
Montipora stilosa	0	4.2	X
Montipora ehrenbergi	0.07	1	14.3
Hydnophora microconos	0.01	1	100
New settling stony corals			
Acropora eurystoma	0.06	NS	NS
Goniastrea palauensis	0.03	NS	NS
Goniastraea retiformis	0.01	NS	NS
Stylophora pistillata	0.03	NS	NS
Porites columnaris	0.01	NS	NS
Favites flexusa	0.03	NS	NS
Favia laxa	0.01	NS	NS
Pocillopora verrucosa	0.03	NS	NS
Seriatopora hystrix	0.007	NS	NS
Tubastrea sp.	0.007	NS	NS
Total stony corals	**0.67**	**43.5**	**64.9**

NS = newly settled, X = no estimated recovery time because RR=0

Table (2). Recovery rate RR (% cover / year), cover required for restoration (CR) and recovery time RT (years) for hydrocorals, soft corals, sponges, mollusks and echinoderms after *Acanthaster planci* infestation of 1998 in the studied site.

Species name	RR	CR	RT
Hydrocorals			
Millepora dichotoma	0	1	X
New settling pseudoscleractinia			
Distichopora sp.	0.03	NS	NS
Soft corals			
Sinularia	0.04	1.5	37.5
Lobophyton	0	1	0
Xenia	0.31	1	3.2
Sarcophyton	Increased during infestation	Increased after infestation	Increased after infestation
New soft corals			
Scleronephthya sp.	0.15	NS	NS
Clavularia sp.	0.08	NS	Ns
Total soft corals	**1.31**	**1**	**0.76**
Sponges (new)			
Gelliodes sp.	0.04	NS	NS
Molluscs	0	2(NR)	X
Echinoderms	Increased during infestation	Increased after infestation	Increased after infestation

NS= newly settled, X = no estimated recovery time because RR=0, NR=number required for restoration

Table (3). Recovery rate RR (% cover / year), cover required for restoration (CR) and recovery time RT (years) for each of algal turf, coralline algae, dead corals, rocks and sediments after *Acanthaster planci* infestation of 1998 in the studied site.

Parameters	RR	CR	RT
Algal turf	+1.43	Increased during infestation	Increased after infestation
Coralline algae	+0.71	Increased during infestation	Increased after infestation
Dead corals	-3	-38	12.6
Rocks	-0.14	-1	7.14
Sediments	0	-2	-

Table (4). Percent error in the estimated recovery rate by linear extrapolation as compared to the actual average recovery rate in ten selected sites

Sites	Latitudes	Longitudes	% error
Abu Ramada	27°09.319`N	33°58.709`E	+9.6
Magawish	29°08.485`N	33°53.016`E	+12.90
Petra reef	27°08.991`N	33°53.636E	+17.5
Gaftun Kebir	27°11.063`N	33°57.843`E	+7.69
Carless reef	27°18.67`N	33°56.416`E	+13.6
El-Fanus	27°16.066`N	33°53.234`E	+11.8
El-Fanadir	27°17.708`N	33°49.806`E	+8.3
Sha'b Sabina	27°12.856`N	33°57.191`E	+15.6
Abu-Nugar	27°28.744`N	33°50.357`E	+16.7
Abu-Makhadeg	27°59.821`N	33°54.555`E	+12.12

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