ABSTRACT

Title of dissertation/Thesis: AN ENVIRONMENTAL ECONOMIC ASSESSMENT OF THE IMPACTS OF RECREATIONAL SCUBA DIVING ON CORAL REFF SYSTEMS IN HURGHADA, THE RED SEA, EGYPT.

Ramy Khaled Serour, Master of Science, 2004

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During visits to coral reef locations, divers support the economy by spending money on goods and services provided by local businesses. However, divers also impact the reef during their visits, causing stress. This study presents estimates of rates of damage to corals and assesses patterns of dive behavior on selected sites. I also present an economic analysis of diving activities in the region and propose an estimate of diver “carrying capacity”, using an emergy-based approach. While diving tourism generates revenues in the order \$5-8.3 million annually, divers inflict damage to the coral reef at a rate of ~1250 potentially damaging contacts a day at the most heavily used sites. As a result, I suggest that these sites should be subject to 13,000-14,000 dives per year. This study aims to

provide valuable information for the development of management plans to regulate diving operations and reduce reef degradation in the region.

AN ENVIRONMENTAL ECONOMIC ASSESSMENT OF THE IMPACTS OF RECREATIONAL SCUBA DIVING ON CORAL REEF SYSTEMS IN HURGHADA, THE RED SEA, EGYPT

By

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Thesis submitted to the Faculty of the Graduate School of the University of Maryland, College Park in partial fulfillment of the requirements for the degree of Master of Science
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Professor Kenneth Sebens
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DEDICATION

I dedicate this thesis/dissertation to my loving family, particularly my father, who inspired me, with his knowledge of the subject and his adventurous nature, to develop my passion for marine life.

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This work was supported by many people whom I wish to thank for their sincere contributions. I would like to express my appreciation and gratitude to Dr. Patrick Kangas, who deserves special recognition for his continuous spiritual support, motivation, and coordination. He helped me with a lot of ideas for the study and, most importantly, was my academic advisor throughout the duration of the Master's program. Drs. M. Reaka-Kudla and K. Sebens are thanked for their support as members of my committee and for their contribution in expanding my background in the field of ecology. I would also like to thank University of Maryland, especially the Marine, Estuarine, Environmental Science program for the outstanding academic experience I have had in the field of marine science.

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LIST OF ABBREVIATION

HEPCA : Hurghada Environmental Protection & Conservation Association.

GEF : Global Environmental Facility/World Bank.

GLM : General Linear Model.

MOT : Ministry Of Tourism.

PADI : Professional Association of Diving Instructors

UW : Under Water

CHAPTER 1: INTRODUCTION & OVERVIEW

1.1 General

Coral reefs are highly productive, diverse, and attractive ecosystems which, according to Spurgeon (1992), provide a wide range of benefits for mankind. Nevertheless, reefs worldwide are under siege, being damaged by over exploitation and indirect human impacts. Part of that problem stems from the fact that the overall economic value of the coral reef is rarely considered and appreciated (Costanza et al., 1997; Daily et al., 2000). It is believed that many coral reefs are negatively affected by the same economic activities they sustain (Wilkinson, 1992; Sebens, 1994; White et al., 2000).

Goods and services provided by coral reefs include fisheries and fish habitat functions, to which many communities depend on for their livelihoods. In fact, more than 350 million people worldwide depend on coral reef communities for food and survival. Coral reefs also provide a physical structure and function that helps to reduce coastal erosion and protect economically important constructions and land uses. Most importantly, they offer a rich medical resource, comprising raw materials for pharmaceutical industries. Such chemical compounds as antihistamines, antibiotics, and other medications for illnesses ranging form asthma to leukemia and heart disease, were found, extracted, and purified (Terence et al., 1996). Furthermore, one of the fastest growing uses of coral reefs is tourism and recreational activities, which may constitute a substantial part of tourism-dependant economies (Dixon et al., 1993; White et al., 2000; Zakai and Chadwick-Furman, 2002). For example, in Queensland, Australia, tourism associated with the Great Barrier Reef is the State's second largest industry sector and valued at around $1.5 billion per annum (Terence et al., 1996). Globally, recreation, as an ecosystem service offered by coral reefs, was valued at 3008 $ per hectare per year, constituting almost 50% of the total value of services offered per unit area (Costanza et al. 1997). The latter defines the quality of recreational services, such as SCUBA diving, that are offered by coral reefs around the world.

Recreational SCUBA diving is a rapidly growing division of the international tourist industry. As coral reefs have become more accessible and facilities for visitors improved, the number of people diving on this potentially fragile ecosystem has exponentially increased (Hawkins and Roberts, 1993). According to Harriot et al. (1997), PADI, the world's largest diver training agency, has seen an increase in international dive certifications from 10,000 for the year 1967 to more than 5 million by 1996. Until recently, diving tourism was thought of as an activity entirely compatible with the sustainable use of marine resources, as opposed to extractive activities, such as fishing, mining, and construction of tourist facilities. However, recent evidence has demonstrated that reefs may become degraded as a result of poorly planned or intensive tourist use (Jameson et al., 1999; Tratalos and Austin, 2001). With the increase in popularity of recreational SCUBA diving, inflicted physical damage by divers and boat anchoring has increased significantly. As a result, reef degradation attributed to diving pressure has become a widespread concern and risk that needs to be properly assessed, which in turn, will support effective management strategies.

SCUBA divers may unintentionally damage coral and other benthic reef organisms. Several previously described studies investigated how reef walking (Woodland and Hooper, 1997; Liddle and Kay, 1987; Hawkins and Roberts, 1993), snorkeling, and diving activities (Hawkins and Roberts, 1992) damage coral tissue by either breakage or abrasion. These studies provided a quantitative analysis of damage due to divers, thought to be the main cause of mortality in frequently visited dive sites, showing significant differences in coral cover between heavily used and the so called 'pristine' sites. Riegl and Velimirov (1991) showed that in heavily dived sites, there was more coral breakage, algal overgrowth, and tissue loss than in low frequency dive sites. Similarly, Hawkins and Roberts (1992; 1993), showed that there was a significantly high number of damaged colonies, loose fragments, and abraded coral colonies in heavily used dive sites. Furthermore, increased sediment loading on the reef due to diving activities may stress the corals and lead to mortality (Rogers, 1990).

1.1 Problem

The existing and proposed tourist facilities in Hurghada, Egypt, are huge and are posing a major threat to the marine natural resources in the region, particularly coral reef ecosystems. Activities such as land reclamation and beach filling are common, despite a setback requirement prohibiting development within 30 m of the high-tide line, and consequently, the fringing reef that stretched along the entire length of the coast has been completely degraded. Instead, soft sandy beaches are maintained to accommodate visitors that are interested in other activities (e.g. swimming and sun-bathing) and shore-based water sports. As a result, diving pressure was allocated to offshore sites (40 sites). Only seven out of those forty sites are located within bays or around offshore islands that protect them from northerly winds and wave exposure, becoming more accessible to daily diving operations. Seventy percent of diving activity is restricted to these seven sites. Considering the number of divers visiting Hurghada every year, the potential impact could be detrimental to the fragile coral reefs in the region.

1.2 Approach

According to Cesar et al.(1997), tourism is perceived as a sector with potential to provide the greatest revenues. It brings economic benefits to local communities and may help protect coral reefs by providing an incentive to conserve them. Many studies have shown, however, that tourism causes significant damage to coral systems (Hawkins and Roberts, 1992; 1993; Harriot et al., 1997; Medio et al., 1997; Rouphael and Inglis, 1997; Zakai and Chadwick-Furman, 2002). To ensure long-term viability, it is important that tourist use is kept below damaging levels. The study will thus provide information that is significant both from an economic and an ecological perspective.

In chapter 4, I provide, from direct observation, data on the rates of damage by recreational SCUBA divers to coral reefs. It was also intended to investigate the activity of photographers, which are thought to be the worst offenders to these fragile ecosystems, despite their training level. For management purposes, vulnerability of specific species to diver-related damage was assessed. Current levels of diver use at Hurghada are threatening its natural marine resources. Nevertheless, income generated by tourist expenditures on diving is remarkably high and was the reason for expansion of the industry, and hence, tourist facilities. Chapter 5 provides an analysis of economic activity due to diving tourism in the region. Considering positive and negative impacts divers have on the regions economy and environment, respectively, I propose in Chapter 6 an estimate of diver carrying capacity, using a different approach, that represents a balance between economic gain and environmental loss.

CHAPTER 2: STUDY OBJECTIVES

The present study has the following objectives:

1) To provide, from direct observation, data on the rates of damage by SCUBA divers to both hard and soft corals.

2) To provide a generalized summary of economic activity of diving tourism the region.

3) To model what levels of use by divers could be sustainable without harming Hurghada's diving tourism dependant economy.

4) Use assessment results to feed into an effective management plan that aims at regulating diving operations in the region, which in turn will decrease diving pressure, hence, damage inflicted by divers.

CHAPTER 3: STUDY SITE

Egypt lies at the northeast tip of Africa. The Mediterranean Sea borders Egypt from the north, separating it from Europe, while the Red Sea, marking its eastern border, separates it from Asia (Figure 1). Starting at its southern most tip, the straits of Bab El-Mandeb, literally known as "Gate of Lamentation", and ending by the Gulf of Suez and the Gulf of Aqaba to the north, The Red Sea has a length of more than 2250 km and a maximum depth of 3040 m, occupying a major zone of depression and faulting, known as The Great Rift Valley. From a historical standpoint, the earth's crust has been separating for the last 50 million years, making the Red Sea a representative of one of the rare examples today of an early stage in the development of an ocean (Beltagi, 1997). The entire water body covers a surface area of 580,000 km^2.

Extending between 13 degrees N and 30 degrees N, the Red Sea is characterized by warm water temperatures, ranging from 21° C - 30° C, for its most northerly latitudes (Hawkins and Roberts, 1994). The depth of the Red Sea offers a quality of clarity that is due to very low levels of sediment re-suspension and nutrient concentrations. Very low rainfall in the region and a lack of freshwater runoff are also responsible for low nutrient content, and hence, low planktonic activity. As coral reefs grow in warm, clear, and saline waters, the natural conditions of the Red Sea make it an optimal and unique ecosystem for coral recruitment. According to Hawkins and Roberts (1994), the combination of calm seas, clear waters, and rich marine life form the basis for the Red Sea's rising popularity as a tourist destination. It is believed that popularity of the Red Sea as a destination for international tourists is associated with the natural attractiveness and aesthetic value of coral reefs in the region.

Diving tourism started to boom in the 1980s and almost a decade later the region witnessed a veritable explosion of Red Sea tourism. With mainly water-based activities, Hurghada, on the Egyptian Red Sea coast (Figure 1), became a prime destination whose economy is thriving on the revenues generated by diving operations. It was one of the first tourist resorts on the Red Sea coast, along with Eilat, Israel. Hurghada started life as small fishing village. It was later founded by the British in 1909 to support the oil industry in the Gulf of Suez, attracting few tourists until the late 1970s, a period of regional un-stability that followed the 1967 war with Israel (Hawkins and Roberts, 1994). Now, it is one of Egypt's premiere resorts and is home to 35,000 residents. The town has undergone tremendous development attributed to tourism and the tourist villages now sprawl for almost the entire 60 km to the neighboring port of Safaga south of the resort. Over the last couple of decades Hurghada has completely transformed from a small fishing village into a tourist 'Riviera'.

The resort is located on a well defined series of bays that stretch 61 km to the south from the old town of Hurghada to Safaga. These bays are sheltered by an archipelago of islands several kilometers offshore. The region offers 35 diving sites characterized by patch reefs, ridge reefs (e.g Shaab El Erg, Shabrur Umm

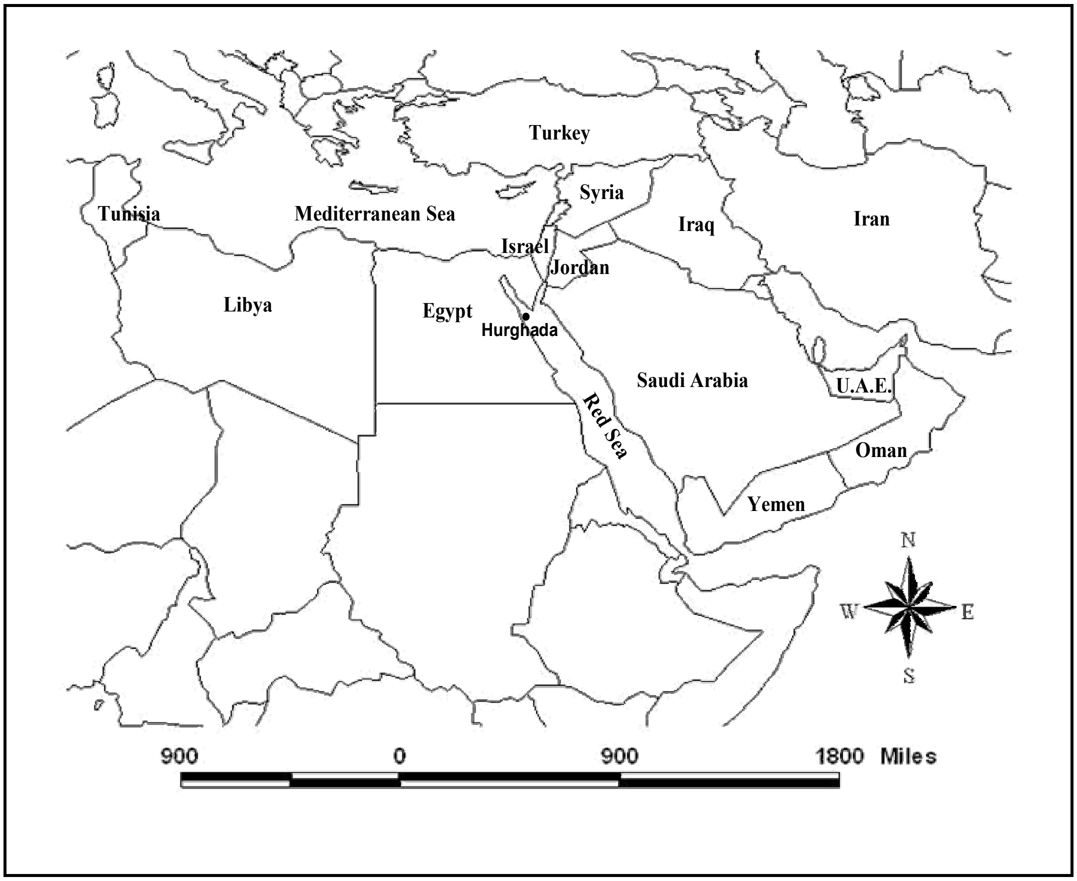


Figure 1 Geographical location of Hurghada, Red Sea, Egypt, with respect to the Middle East (Using ArcView 3.1).

Qammar), and island fringing reefs (e.g Small Giftun, Abu Ramada North and South, Sabeena gardens). About 19% of these locales are heavily used by recreational divers.

Hurghada was chosen as an appropriate site for this study for these reasons:

- Degradation of offshore reefs due to increased diving pressure and associated activities in the region is increasing at an alarming rate.
- The proposed tourist developments are huge and will pose a threat to the marine natural resources in the region.
- Lack of management plans to regulate diving operations, hence, decrease pressure on existing dive sites.

CHAPTER 4: ESTIMATION OF RATES OF DAMAGE TO CORALS BY SCUBA DIVERS

4.1 Introduction

Some of the most frequently visited coral reefs for recreational purposes are located at Hurghada, Egypt, in the northern Red Sea (Hawkins & Roberts, 1994; Jameson et al., 1999). Due to their proximity to Europe, extensive tourist facilities, and their diverse fauna, reefs in the region attract more than 150,000 dives per year, particularly those 7 locales that are most accessible to daily diving operations (GEF, 1998). During the past few decades, reefs at Hurghada have been undergoing continuous degradation as a result of a combination of intensive diving and other water-based recreational activities (Riegl & Velimirov, 1991; Jameson et al., 1999). According to Hawkins & Roberts (1994), their condition is critical; if management practices are not implemented, these reefs are predicted to collapse within 30-50 years.

Despite the economic importance of diving tourism in the region, few quantitative data are available concerning the relationship between diver behavior and damage rates to coral reefs at Hurghada. A comparison study of sites in Eilat, Israel and Hurghada, Egypt, exposed to intensive diving pressure, reported increased abundance of macroalgal cover on reefs in the former (Riegl & Velimirov, 1991). Another study conducted by Jameson et al.(1999) aimed at assessing the extent and severity of physical damage to corals in the region by screening several sites that are heavily used by SCUBA divers. Rates of damage were not quantified in either of these two studies. Medio et al.(1997) noted that in order to model what levels of diver use may be sustainable at what levels of coral cover, information is required about the actual rates of damage to corals.

The present study assesses frequencies of diver behavior that damage corals in relation to dive use levels at seven reef sites in Hurghada. From direct observation, rates of damage by SCUBA divers to corals are reported. It was also intended to compare rates of contact by divers using under water cameras and/or videos with those that are not. Based on findings, I then recommend options for reef management that may reduce diver-related stress to levels that are ecologically sustainable.

4.2 Methods

The study was undertaken in the northern Red Sea at seven dive sites within the boundaries of the Hurghada bay, Egypt (Refer to Appendix A for geographical location). The sites are relatively sheltered within the archipelago of islands opposite to the bay, providing accessibility for daily diving operations and providing optimum conditions for inexperienced divers under training.

Observations were made over 4 weeks during high season (summer 2002) and 3 weeks (winter 2002/2003) during low season on groups of divers from a dive center in a hotel catering mainly to Italian, German, Russian, and

Polish tourists. Most were ‘Open Water’ and ‘Advanced Open Water’divers, but a few were ‘Dive Masters’ or ‘Instructors’. Each day, six divers (three ‘buddy’ pairs) were selected at random from a boat party of 8-20 divers, depending on the diving season. Each pair was then observed for 10 minutes per dive and the number of contacts made with the substrate was recorded (after Rouphael & Inglis, 1997). Contacts were recorded as counts affecting hard coral, soft coral, hydrocoral, and bare substratum. Where contact was with a living coral, whether hard or soft, it was noted if the coral was obviously broken. Furthermore, diving activity of under water photographers was also observed and recorded. Divers were followed at a distance of 2-3 m. The group, to be observed, was not aware of the nature of the study to ensure natural behavior, as I appeared to be an enthusiast recording information for personal interest.

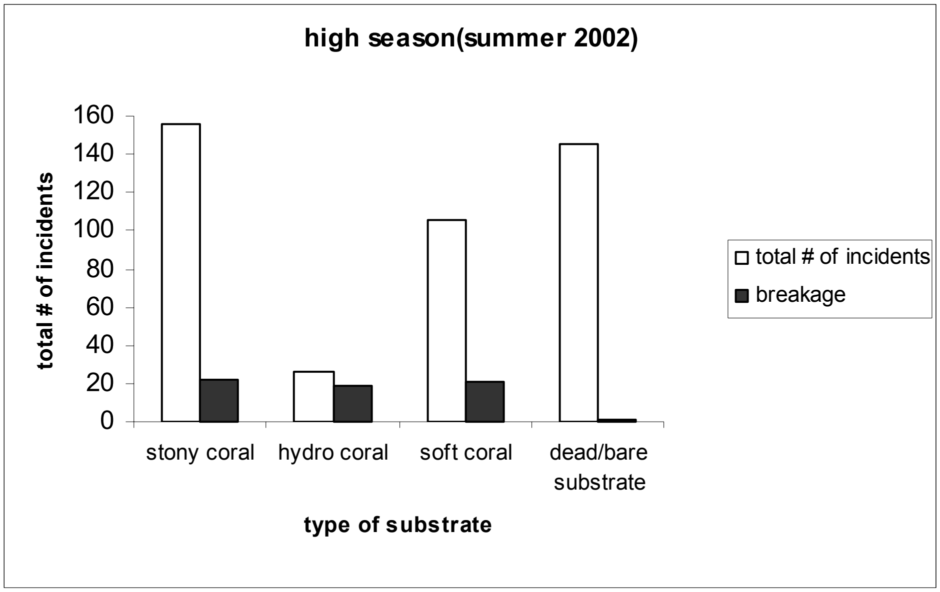
Statistical analysis of the data was performed using the SAS program. For comparisons of medians, variances, and hypothesis testing, non-parametric methods of analysis were applied to data sets, having first been tested for normality and homogeneity of variances (major ANOVA assumptions) using the Shapirro-Willes W test and the Levene’s GLM test, respectively. Unless otherwise indicated, data are represented as medians and ranges.

4.3 Results

Observations of the divers showed high frequencies of behaviors that potentially damage the coral reef in use. Divers were observed to contact the reef voluntarily and involuntarily with their hands, fins, and equipment. Some were observed breaking corals. Others, particularly divers under training, had contact with the sea bed raising sediment clouds that were observed actually dispersing and settling on nearby colonies.

Data analysis yielded an average of 1.29 incidents per diver per10 minutes including 0.86 potentially damaging incidents with live coral per diver per 10 minutes over a period of 4 weeks during high season (n = 336 divers). Assuming a typical dive lasts for 45 minutes and that each diver has two dives per day, then the typical number of potentially damaging incidents per diver per day would be 7.74. Similarly, over a period of 3 weeks during low season, analysis yielded a mean rate of 1.46 contacts per diver per 10 minutes that include a rate of 0.875 potentially damaging incidents with live coral per diver per 10 minutes (n = 232). The latter would extrapolate to 7.9 contacts per diver per day.

Some of the divers' contacts with the reef damaged corals (hard, soft, and *Millipora* species), through breakage, abrasion, or crushing (Figure 2 & 3). However, points of contact exhibiting some sort of damage, particularly abrasion, could not be distinguished from those that did not, and therefore, all contacts with live coral were considered. Observations of divers inflicting damage to different types of substrate revealed 36% to stony corals, 6% to *Millipora* corals, 24.5% to soft corals, and 33.5% to dead/bare substratum during high season and 38.6%, a)



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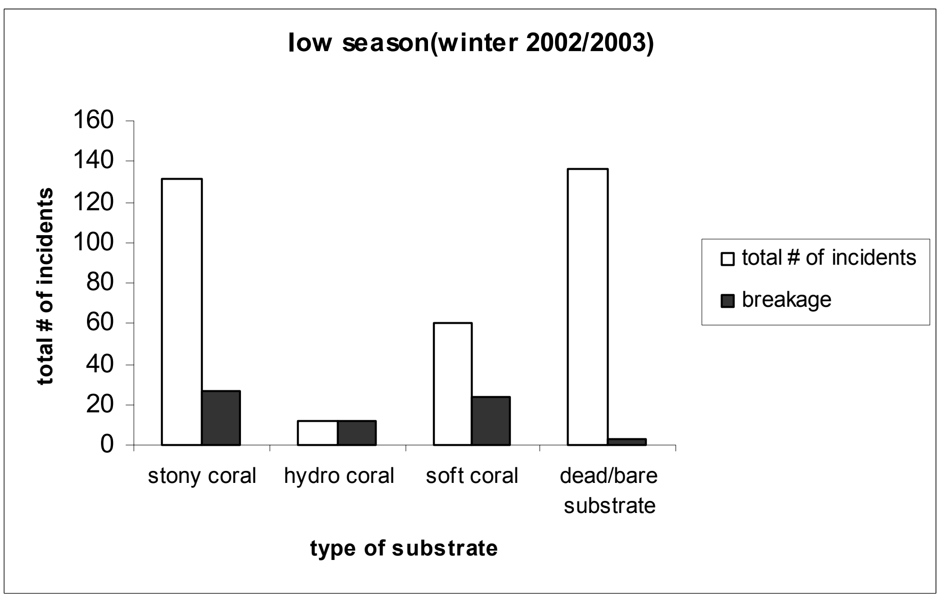
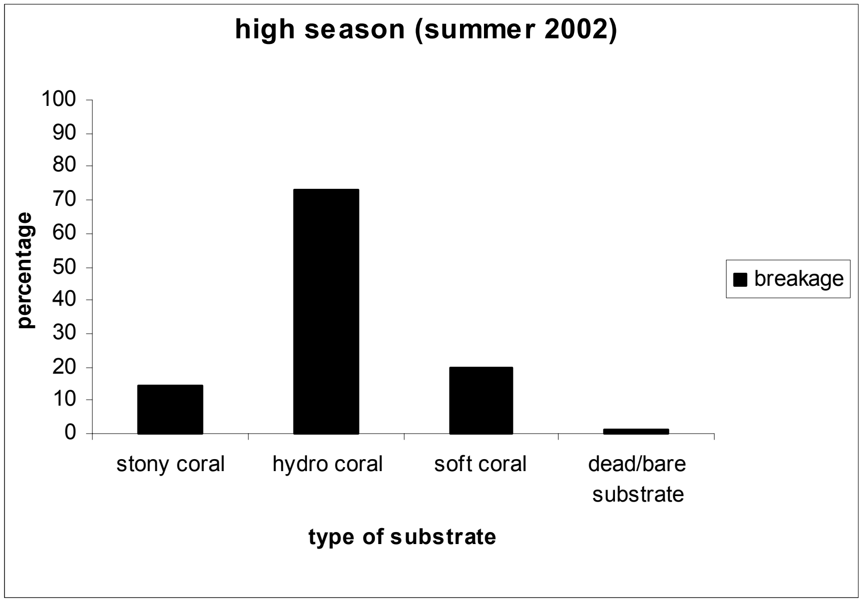


Figure 2. Behavior of recreational SCUBA divers on coral reefs at Hurghada, Egypt, Red Sea. Total number of potentially damaging incidents over a period of **a)** 4 weeks during high season and (n = 168 buddy pairs) **b)** 3 weeks during low season (n = 116 buddy pairs). Each buddy pair was observed for 10 minutes in the coral reef environment.

a)



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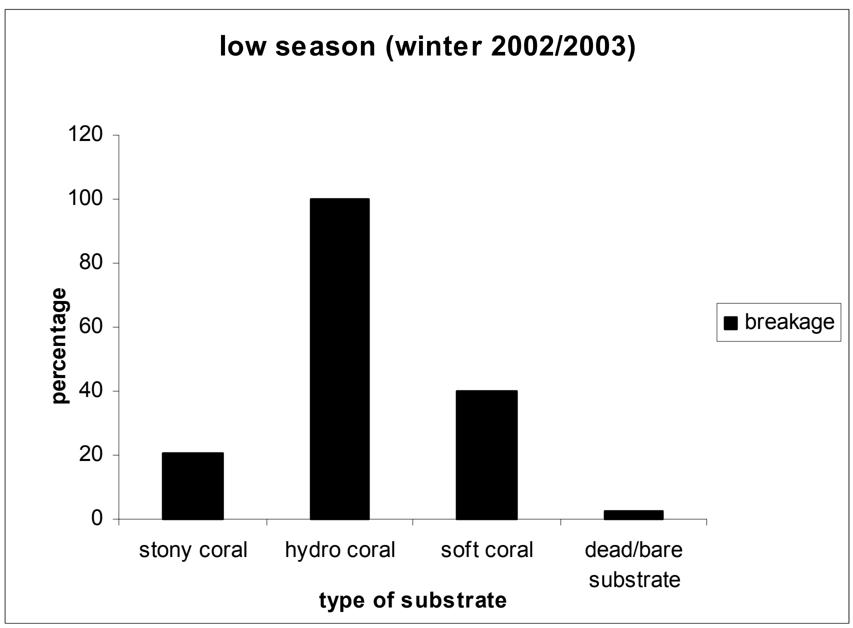


Figure 3. Percentage of incidents observed causing obvious breakage to four different forms of substrate over a period of **a)** 4 weeks during high season and **b)** 3 weeks during low season (n = 433 incidents; 339 incidents, respectively).

3.5%, 17.7%, and 40.1%, during low season, respectively (Figure 2). The mean rate of contacts was highly significant among the different types of substrate (Kruskal-Wallis test, $\chi^2 = 87.4$, $P < 0.001$). Observations of incidents causing actual breakage of colonies in relation to the four different classes of substrate revealed rates of 0.14 incidents/ buddy pair/ 10 minutes to stony corals (n = 156 incidents), 0.80 incidents to *Millipora* (n = 26 incidents), 0.20 incidents to soft corals (n = 106 incidents), and 0.01 incidents to dead/bare substratum (n = 145 incidents). Similarly, the second data set representing low season, revealed rates of 0.21 contacts to stony corals (n = 131 incidents), 1 to *Millpora* (n = 12 incidents), 0.48 incidents to soft corals (n = 60 incidents), and 0.03 incidents to dead/bare substratum (n = 136 incidents). Rates involving each class of substratum were compared to those of *Millipora* species, using 2 sample Wilcoxon Rank test, to assess vulnerability of species described. Comparisons yielded very highly significant differences between each class and *Millipora* species in both time periods (Table 1 and 2).

Salm (1985, 1986) and Dixon et al. (1993) pointed out that underwater photographers could be the worst offenders of reef diving. The present data during both seasons support this view. Divers using underwater cameras and videos were observed, at many instances, negatively buoyant, using the reef as support, to minimize any movement during the shooting process. Photographers accounted for 7.15% of the high season sample and 17.2% of the low season

Table 1. Comparison of rates of contact causing breakage in relation to four different classes of substratum: stony corals, *Millipora*, soft corals, and dead substratum (high season sample; summer 2002).

Type of substrate	Median number of Incidents/buddy pair /10 minutes	Z^a	p
stony corals	0.14	-8.27	< 0.0001
Millipora species	0.80	__	__
Soft corals	0.20	-5.67	< 0.001
Dead/bare substratum	0.01	8.79	< 0.0001

[a] Wilcoxon 2 sample test (normal approximation)

Table 2. Comparison of rates of contact causing breakage in relation to four different classes of substratum: stony corals, *Millipora*, soft corals, and dead substratum (low season sample; winter 2002/2003).

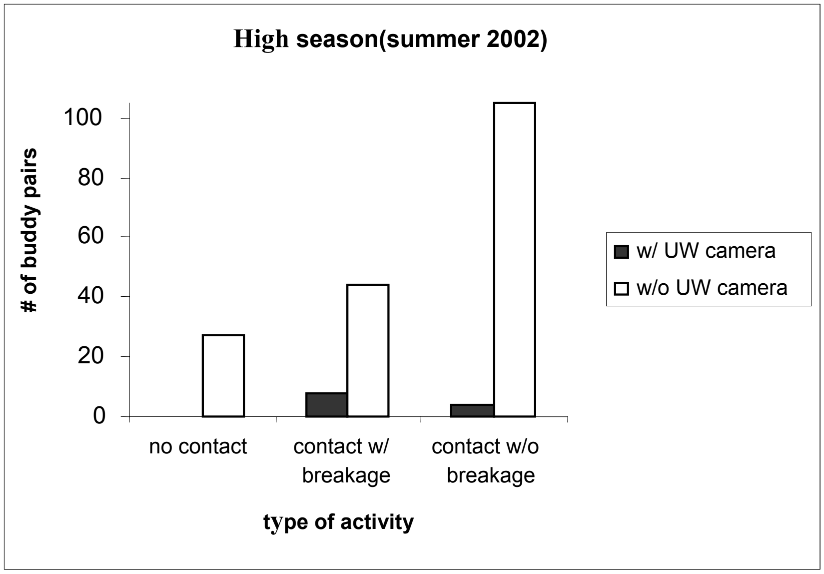
Type of substrate	Median number of Incidents/buddy pair /10 minutes	Z^a	p
stony corals	0.21	-7.65	< 0.0001
Millipora species	1.0	__	__
Soft corals	0.48	-4.28	<0.001
Dead/bare substratum	0.03	6.72	< 0.0001

[a] Wilcoxon 2 sample test (normal approximation)

sample and yet, 66.6% of photographers versus 25% non-photographers during high season and 80% versus 36.4% non-photographers during low season, were responsible for incidents causing complete breakage of coral colonies (Figure 4). Furthermore, the mean rate of contacts with live coral inflicted by photographers and non-photographers per 10 minutes were compared using non-parametric methods of analysis. Median rates of contact by divers using UW cameras were 4.5 (range=2-7) incidents per buddy pair per 10 minutes (n = 12 buddy pairs, whereas, non-photographers inflicted damage to the reef at a rate of 1 (range=0-6) (n = 156 buddy pairs) incident per pair per 10 minutes (high season sample; 2 sample Wilcoxon Rank test, $p < 0.001$). Similarly, divers using UW cameras had a median rate of potentially damaging contacts of 3 (range=0-4) (n = 20 buddy pairs) versus 1 (range=0-5) (n = 96 buddy pairs) potentially damaging incident per buddy pair per 10 minutes inflicted by divers that are not using photographic instruments (low season sample; 2 sample Wilcoxon Rank test, $p<0.01$)

4.4 Discussion

Levels of natural and anthropogenic disturbance to coral reef systems vary widely over both temporal and spatial scales. Reefs in regions with high turbulence or frequent storms may experience naturally high levels of coral breakage and abrasion (Schleyer and Tomalin, 2000). To date, one study of diver induced damage has quantified the relative importance of diver-related versus a)



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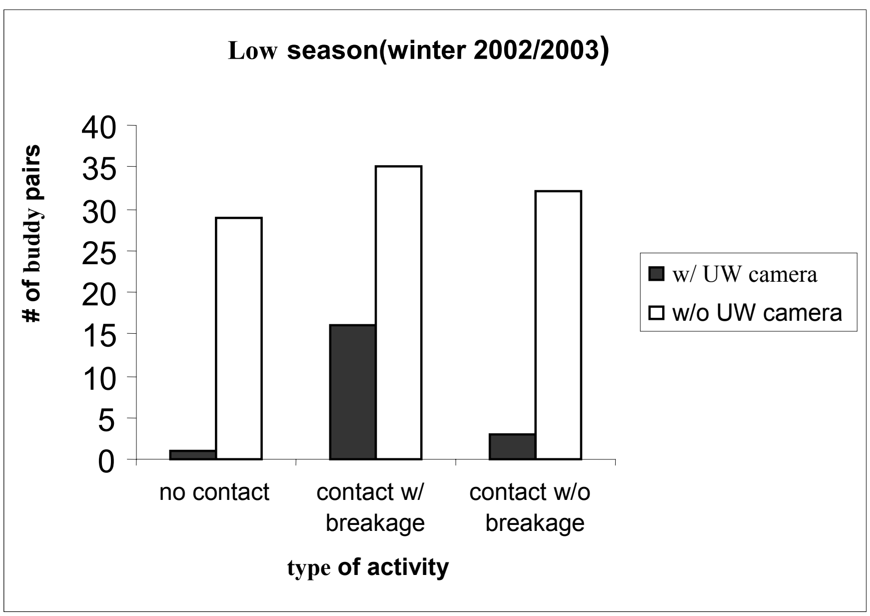


Figure 4. The activity of divers using UW cameras compared to that of non-photographers. 66.6% of photographers were observed breaking colonies (n = 12 pairs) during **(a)** high season and 80 % (n = 20) during **(b)** low season. Each buddy pair was observed for 10 minutes during the dive.

natural damage to corals. Schleyer and Tomalin (2000) showed that, due to turbulent waters on coral reefs in South Africa, 15-100% of all damage was attributed to natural causes, whereas, 0-40% was related to activities of recreational divers at each site studied. In contrast, however, the northern Red Sea, is an enclosed body of water with low levels of water motion and very rare tropical storms (Hawkins and Roberts, 1992). According to Jameson et al. (1999), pristine reefs in the region show low frequencies of coral damage from natural causes (0-2% of colonies affected). Thus, levels of diver-related damage reported in this study, likely represent a major impact to coral reefs in these relatively quiet waters.

To date, there have been few previously described studies in the literature of rates at which tourist SCUBA divers damage corals. The present study, not only provides an estimate of the rate at which divers damage live coral through direct physical contact, but assesses vulnerability of some species to such damage and impact of divers using photographic instruments.

Rates of coral damaging behavior by divers at Hurghada at different reef sites were similar to those observed for divers in Sharm -El-Sheikh, Egypt (at 1.2 incidents/diver/10 minutes; Medio et al., 1997). Reef topography was not accounted for as a variable during analysis, since, other studies showed that rates of damage do not depend on the structure of the reef framework (Rouphael and Inglis, 1997; Zakai and Chadwick-Furman, 2002). The mean rate of potentially damaging contacts to living corals was estimated at 7.74 (high season) and 7.9

incidents per diver per day (low season). Based on this estimate, an indication may be derived of the overall rate of damage at each site. Assuming a dive boat will accommodate an average of 15-16 divers (high season) and 7 divers (low season), and that 11 boats (high season) and 6 boats (low season), on average visit dive sites daily, then the typical number of potentially damaging incidents per site per day would be 1319.7 and 331.8 during high and low season, respectively. Furthermore, if the area of reef swum by divers at each side typically amounts to 20m x 50m section of that reef, then the estimated rate would correspond to 1.32 incidents per m^2 per day (high season, 186 days) and 0.33 incidents per m^2 per day (low season, 116 days). Combining rates during both seasons will yield a rate of 283.3 incidents per m^2 per year. The described estimate was found to be ~ 2x the rates estimated for Sharm-El- Sheikh sites by Medio et al. (1997). The reason these estimates are very different at these two popular destinations is related to the levels of use at each site. According to Hawkins and Roberts (1994), unlike Sharm-El-Sheikh, there are, as yet, no management plans to regulate diving around Hurghadas' waters.

The present study shows that, in all cases of damage, stony corals (mainly *Acropora* and *Pocillopora* species) were the most frequently affected genera. This may in part be caused by the fact that these species are very common and proportionally more often affected by damaging behavior. *Millopora,* however, were the most affected species, particularly through breakage, emphasizing the species' fragility. Unfortunately, it was not possible, within the confines of experimental logistics, to quantify the actual extent of damage. These findings support Loya's (1972) claim that the coral species suffering the highest amount of damage relative to their numerical presence are *Acropora, Millipora,* and *Stylophora*. According to Zakai et al. (2000), coral breakage affects processes such as growth and sexual reproduction, which may serve as indicators of coral condition for sustainable reef management. Hawkins and Roberts (1992) noted that broken and abraded tissue is likely to be more susceptible to invasion by pathogens, possibly increasing mortality. Therefore, human induced breakage on frequently visited reefs may have detrimental effects on coral communities. This may not be the case for Highsmith (1982) and Meesters et al. (1994). They argue that these branching forms, previously mentioned, are relatively fast growing and hence to a certain extent can tolerate repeated breakage, implying that high diver-related stress will not necessarily have adverse effects on communities consisting primarily of these species. Even so, from an aesthetic standpoint, heavily dived parts of the reef, with a large number of broken colonies and loose fragments, compared to 'pristine' sites, may be less appealing to divers.

Surprisingly, divers using photographic instruments, although mostly experienced, were found to be the most 'destructive' to the coral reef environment. Nearly all contacts by UW photographers in both seasons involved obvious breakage of coral colonies. Also, they were observed to contact the reef more often compared to other divers that are not using photographic instruments.

Contacts were mostly voluntary to achieve optimum buoyancy and stability while shooting. The proportion of photographers during low season was considerably higher than that in high season. The latter could be attributed to avoiding large crowds of divers at popular sites, which is in favor of the nature of their activity. Yet, they were found to be the worst offenders among groups of divers.

In brief, this study aims at advancing knowledge concerning diver impacts on coral reefs, by: (1) documenting exceptionally high frequencies of SCUBA diving on these reefs, (2) revealing and estimating consequently high rates of coral damage, (3) documenting vulnerability of some species of coral to diver induced breakage, and (4) revealing high levels of damage caused by photographers. For management purposes, I recommend the following criteria in reef management to reduce levels of coral damage caused by divers and regulate diving operations at Hurghada: (1) limit the total number of divers per site, (2) transfer divers under training and introductory dives away form fragile reef dominated systems to more robust sandy areas, (3) require that all dives be preceded by an environmentally educational briefing emphasizing importance of coral reefs and sensitivity of such systems to any kind of stress, particularly physical contact (after Medio et al., 1997) or distribute handouts to divers describing the problem; such a project could be supported by the government and the EEAA, and (4) incorporating mandatory sessions on how to behave in the coral reef environment during certification training courses. The application of a management plan incorporating these elements at Hurghada may result in substantial reduction in diver-related stress at this heavily used and economically important tourist destination.

CHAPTER 5: AN ECONOMIC ANALYSIS OF DIVING ACTIVITIES IN HURGHADA

5.1 Introduction

The popularity of the Red Sea as a destination for international tourists is associated with natural attractiveness of its coral reefs. It is estimated that around 600,000 dives per year take place in the Hurghada area (GEF, 1998). Given that diving tourism is a lucrative industry and with the 'explosion' in numbers of tourists visiting the area, hence, demand for the sport, Hurghada's economy has undergone a complete transformation from a fisheries based to a diving tourism dependant economy. Most major tourist villages and hotels have fully operational dive centers and water sports centers that offer daily excursions to the popular sites around Hurghada. In response to the growth of the industry, the number of dive operators in the Hurghada area has tripled between 1993 and 1998. There are between 99 and 125 diving operators in the region, but, standards and quality varies markedly (GEF, 1998). As a result, competition in the market has increased. With the increase in demand, more diving vessels and resorts were built to accommodate incoming visitors; and revenues generated from the newly introduced sport 'rocketed' at an incredible rate (Hawkins and Roberts, 1994) (refer to appendix C). According to Mr. Ayman Gomaa, Chief Ranger in HEPCA, Hurghada Environmental Protection and Conservation Association (pers. Comm.), The Egyptian Ministry of Tourism sees this area "as a new gold coast".

In this chapter, I present an economic analysis of diving activity in Hurghada. Using estimated average spending subsidies of tourists, the analysis estimates gross and net receipts generated by diving tourism, on both a seasonal and an annual basis.

5.1 Methods

Table 3 represents a summary of diving activity in the region. Data were collected in the field at dive sites visited over 4 weeks during high season and 3 weeks during low season. On a daily basis, numbers of daily diving vessels and divers on each vessel at each dive site were recorded. The daily average spending subsidy of tourists on the sport of SCUBA diving, during their stay, was surveyed as an average value of prices offered by different dive shops. An estimate of overall average daily expenditures including diving, lodging, food, and other expenses were provided by Mr. Ayman Gomaa, during an interview. Total revenues generated by diving tourism were estimated for both high and low season (year 2002/2003); and accordingly, an annual estimate is presented. It is important to take into account that estimated figures for diving revenue is based on gross receipts and that some of this income will be dissipated outside Egypt, going to tour operators and to service the international diving industry. According to Dixon et al. (1993), net receipts are one third to one half of gross receipts.

Table 3. Seasonal & daily numbers of boats and divers utilizing Hurghada's offshore sites. (70% of activity is restricted to 7 sites), based on data collected over 4 weeks during high season and 3 weeks during low season.

	High season 186 d/300 d season (May-Oct.)	Low season 114 d/300d season (Nov.-Apr.)
Mean # of boats /day*	77	42
Mean # of boats /season*	14,322	4,788
Mean # of divers / day*	1,155	294
Mean # of divers/ season*	214,830	33,516

*data collected in the field

Taking a similar approach, the net value of diving tourism in Hurghada is presented.

5.3 Results

a) Seasonal activity

High season (May-October)

214,830 divers will make up a total of 429,660 dives assuming each diver makes 2 dives a day. According to GEF (1998), the average charge for one day of diving is $30 a day (varying between $15-$50 depending on the quality of dive operators). Some UK tour operators are securing dive packages for their clients at much lower rates, around $15 a day (2 dives). Average daily expenditures including diving, lodging, and food would sum up to 50$. With 214,830 divers using these reefs, the total revenue to operations at average daily expenditures would round up to $10.7 million per high season (gross). 50%-70% of gross receipts goes to worldwide tour operators that service the diving industry, mainly Europe (Dixon et al., 1993). Thus, net receipts of diving related tourism in Hurghada is in the region of $3.2-5.4 million per high season.

Low season (November-March)

Using the same approach, 33,516 divers gives a total of ~ 67,000 dives during the low season. The total revenue to diving tourism at $50 a day would yield $1.7 million /low season.Using gross income estimated above, net receipts would round up to $500,000 - $838,000/low season.

b) Annual activity:

To determine annual estimates, I combined field estimates of both high and low season data sets. For practicality, these values are modified to fit the general trend of operations (considering the 7 most heavily dived sites where 70% of activities occur). Annual estimates would give a total number of 248,346 ~ 250,000 divers/year**,** totaling 496,500 dives per year. According to a personal interview with Mr. Hilal, Chairman of the Red Sea Association for Diving & Watersports , during the year 2001, 410,000 divers visited the region to explore the offshore sites it had to offer, totaling 820,000 dives that year. To fit the general model, 70% of activity is restricted to 7 sites. Therefore, an estimate of 574,000 dives and 287,000 divers, assuming each diver makes 2 dives, for the year 2001 would be the case. Another estimate from a project funded by GEF (Global Environment Facility)/World Bank yielded 657,000 divers and 1.32 million dives a year**.** 70% of 1.32 million would give 919,800 dives per year and 459,900 divers a year**.** To be more general, a mean of the 3 above estimates of numbers of divers a year visiting the area would give 331,750~332,300 divers a year. A charge of $30 a day for two single tank dives, + $20 on average for lodging and food, would yield a total of $16.6 million a year (gross). Net income will be in the order of $5-8.3 million a year.

5.4 Discussion

Tourism, especially diving, plays a central role in Hurghada's economy. In the early 1980s, diving pressure was very low with only two or three dive vessels, each carrying about ten divers**.** By the middle of the decade, this had increased to 20 boats (Hawkins and Roberts, 1994). Activity has since increased, providing an impetus for further tourist development. To foster this rapid growth, the Egyptian government stipulates that construction must begin within 2-3 years of land purchase. Unfortunately, this has led to poorly conceived plans and uncoordinated development (Gomaa, per. comm.).

Net revenues generated by diving activities in the Hurghada region totaled $ 3-5 million a year. Hawkins and Roberts (1994) estimated net income from dive shops at $ 9-15 million for Sharm El Sheikh. Estimates would be 30% higher if all 40 dive sites in the Hurghada area were considered. On top of that, the EEAA in 1998, started collecting fees for use of certain offshore sites: $5 for a non-Egyptian diver, and 5 Egyptian pounds (L.E.) for Egyptians. In 2000, the total income from such fees at Hurghada was $480,000- 500,000 (Red Sea Protectorates annual report, 2000). Maintenance of mooring buoys at dive sites are covered by these fees. It costs $200 a year to maintain each buoy for a total maintenance cost of $ 13,800, less than 2.6% of annual fees income (Gomaa, per. comm.). Also, according to Hegazy (2002), 63% of divers spend between $100-500 on recreational diving alone during their stay.

The latter is enough evidence to support the value of such an activity to the local and national economy. The question is, considering the flow of income, why are there no conservation programs to regulate diving activity in the region? MOT officials describe marketing Red Sea SCUBA diving internationally as ‘ecotourism’. According to Kangas et al. (1995), an important feature of ecotourism is that income generated by the tourists’ visits is used to improve the natural resource base that originally attracted the tourist. However, in developing countries such as Egypt, revenues generated from diving tourism may not be effectively used for conservation as government officials and investors are overseeing the impact the sport has on the environment. A similar situation has been described for coral reefs of Indonesia (Cesar et al. 1997) and Sri Lanka (Berg et al. 1998). Economic aspects of SCUBA diving require further study in an effort to identify tradeoffs between environmental damage and economic benefits.

CHAPTER 6: DIVING "CAPACITY" AND THE VALUATION OF REEF DAMAGE USING AN EMERGY-BASED APPROACH.

6.1 Introduction

As aforementioned, hotel/resort development along the Egyptian Red Sea coast is proceeding rapidly, and consequently, is threatening valuable coral reef ecosystems. According to Jameson et al. (1999), Egypt's coastal zone management program is still in the process of development and in some regions (e.g., Hurghada), tourist development on the coast has proceeded without an active marine management system in place. As a result, more than 150-200 full time operating vessels and 120 dive centers in the Hurghada area have had free rein to operate unsupervised between offshore dive sites. Hawkins and Roberts (1994) expressed concern over the future rapid expansion of divers using reefs off Hurghada and predicted that such levels would be unsustainable and cause serious reef degradation. Diving activity in the region represents a typical example of a "tragedy of the commons" case, as dive operators are trying to compete in the local market and collectively with the Sharm-El Sheikh market, another popular diving destination on the Red Sea coast. Reeve et al. (1998) pointed out that effective coral reef management programs are critical to sustainable tourism strategies for the Red Sea. For management purposes, this study proposes an emergy-based approach to investigate and estimate diver "carrying capacity" on coral reef systems.

Diver carrying capacity is usually expressed as a maximum number of dives per site per year, and is measure of the number of dives a particular site can sustainably support without becoming degraded. Reef degradation due to diving activity has been quantified in terms of decreased live stony coral (Hawkins et al., 1998) or increased damage to corals (Schleyer and Tomalin, 2000). Chadwick-Furman (1997) stated that when diving rate is below these carrying capacities for a given reef site, coral damage is minimal, but, above the carrying capacity, coral damage may increase greatly. The carrying capacity of reef systems for SCUBA divers appears to depend on a combination of factors that vary between sites, namely, presence of vulnerable types of organisms, training level of divers, and the presence of other anthropogenic stressors (Hawkins and Roberts, 1997; Rouphael and Inglis, 1997; Schleyer and Tomalin, 2000). In contrast, Rouphael and Inglis (1997) show that some factors that vary between sites, such as reef topography, could be un-related to diver carrying capacity. Despite the difficulty of accurately assessing reef capacities for recreational diving, the concept remains an important and useful tool for coral reef management. Estimates of diver carrying capacity may aid efforts to limit use to sustainable levels for long-term management (Davis and Tisdell, 1995).

From an energetic standpoint, systems of nature and humanity are part of a universal energy hierarchy, which is a network of energy transformation processes that join small scales to large scales. Available energy at one level is used up in each transformation process to generate a smaller amount at the next larger scale. According to Odum (1971; 1996), calories of energy of different kinds are not equivalent in their contribution of useful work. Directly and indirectly, it takes 1000 kilocalories of sunlight to make a kilocalorie of spatially dispersed organic matter, about 40,000 to make a kilocalorie of coal, and 10 million or more to support a typical kilocalorie of human service. The larger the scale, the higher the quality, but the less there is of it. The available energy, of one kind from the previous heirarchial level, that is used to make a quantity of energy into the next level, is referred to as emergy (suggested by H. Odum and David Scienceman in 1983) , spelled with an "m". To keep from confusing energy that is in a product with that which has been used up to make it, emergy units are called emcalories (or emjoules). Since people don't think in emergy units, the economic equivalent , called the emdollar, is obtained by dividing emergy calculated for a particular process by the ratio of emergy to money in the economy (refer to appendix B). Emergy accounting techniques were used to valuate the damage, in the form of reduction in metabolic energy caused by SCUBA diver-related stress, to estimate diver carrying capacity.

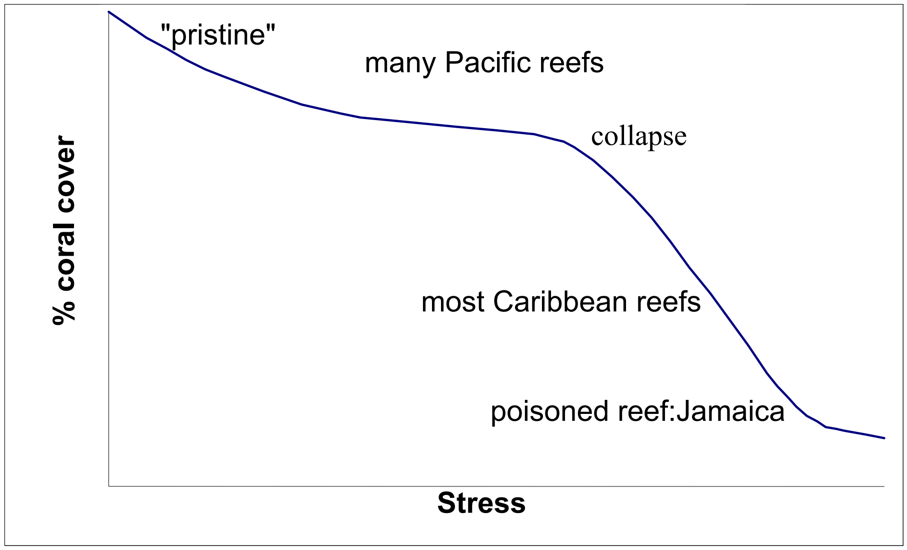
The model predicts the optimal number of divers that can visit a particular site based on the balance between dollar value of their spending subsidy vs. the em-dollar equivalents of the metabolic stress they cause. The metabolic stress is calculated from graphical relationships and converted to em-dollars via an emergy calculation. The spending subsidy is calculated using average daily expenditures of diver tourists. The study's primary objective is to model what levels of use by divers could be sustainable without harming Hurghada's diving tourism dependant economy. Furthermore, it is hoped that the assessment results can be used feed into management plans that aim at regulating dive operations and decreasing diving pressure in the region.

6.2 Methods

a)Dose-Response Analysis:

Dose-response relationships can be used to estimate the level of damage caused by a particular stressor. Due to the lack of information regarding direct relationships between SCUBA diving and coral health, a previously described general model illustrating the relationship between reef stress and coral cover was used in this study (Figure 5). The model aggregates data from different locales in the Caribbean and the Pacific equatorial belt quantifying the effects of different natural and anthropogenic disturbances on coral reefs systems. Using that general analysis, Knowlton (1992) shows that the relationship between reef stress and its cover is typically non-linear and a small increase in stress level can result in a large decline in reef health over certain portions of the stress gradient. For the purpose of our proposed model, it was assumed that the cause of stress on Hurghada's offshore reefs is related to diving activities. Since these offshore sites are less likely to be influenced by land-based pollution and are subject to favorable sea and weather conditions all year round, the assumption that SCUBA diving impact is the prime stressor seems to be justified. The x-axis in Figure 5 quantified diver use (# of dives/year) and was calibrated using aggregated data from South Africa and the Northern Red Sea (Table 4). The y-axis represented

a)



b)

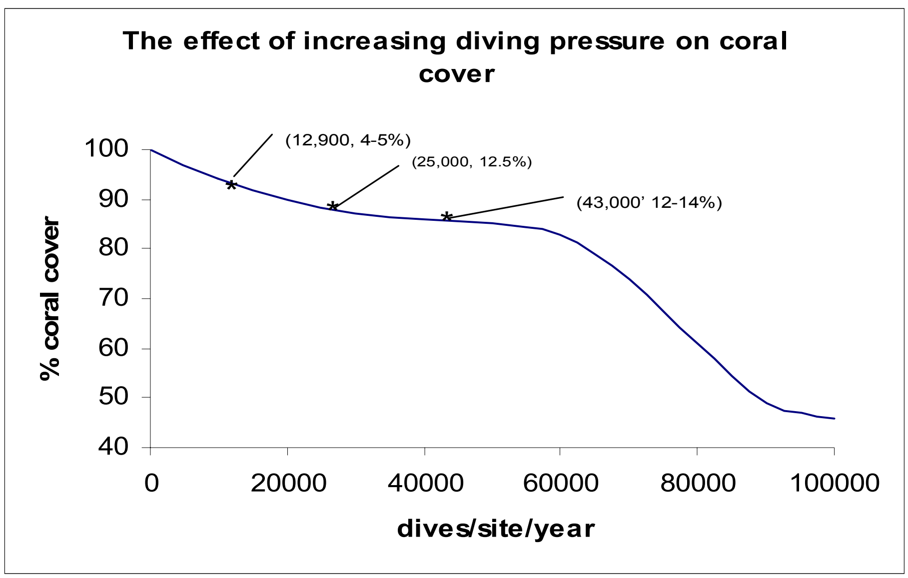


Figure 5. A relationship between reef use and coral cover. The effect is typically nonlinear; **a)** a general model depicting the relationship between stress and coral cover (from Knowlton, 1992). **b)** same model was used to define variables of interest; for axis calibration, values pertaining to dive use and damage were adopted from previously described studies. (The model applies to sites that could potentially have 100%coral coverage).

Table 4 Quantitative studies on effects of diver-related stress on coral reef systems.

Dose	Response	Location	Reference
25000 dives/year	0-25% coral damage	South Africa	Schleyer&Tomalin 2000
43,000 dives/year	12-14% coral damage	Red Sea	Jameson et al. 1999.
12,900 dives/year	4-5% coral damage	Red Sea	Jameson et al. 1999.

percentage coral cover and was calibrated using percentage values assuming thatthere is 100% coverage at zero dives/year (‘pristine’ conditions) and 0% coverage at a maximum number of dives/year (maximum stress conditions). The pattern of the dose-response curve was then overlain on these axes to estimate the damage caused by a particular level of diving.

The other relationship investigated for our proposed approach was between coral cover and reef metabolism. Again, due to the lack of information in the literature, a data set developed by Kinsey (1991), was implemented to construct a graphical model. Kinsey presents a table for metabolic performance, in terms of productivity, of three main types of benthic substratum: “continuous coral”, algal pavement, and sand/rubble (Table 5). We constructed a graph, with this data set relating primary productivity (kg C/m^2/yr.) versus coral cover, by using linear regression (Figure 6). Coral cover was presented in percentage values and the axis was calibrated using the three types of substratum, aforementioned, assuming that “continuous coral” is 100% coverage and “algal” is 50% coverage, whereas, sand and rubble represents 0% coverage. The points on the graph represent reef metabolism attributed to a particular level of coral

Table 5. Standards for metabolic performance for three main types of benthic substratum. Source: Kinsey 1991.

Substratum type	Photosynthesis (g Cm^{-2} day^{-1})
"C ontinous coral"	20
Algal pavement	5
Sand/rubble	1

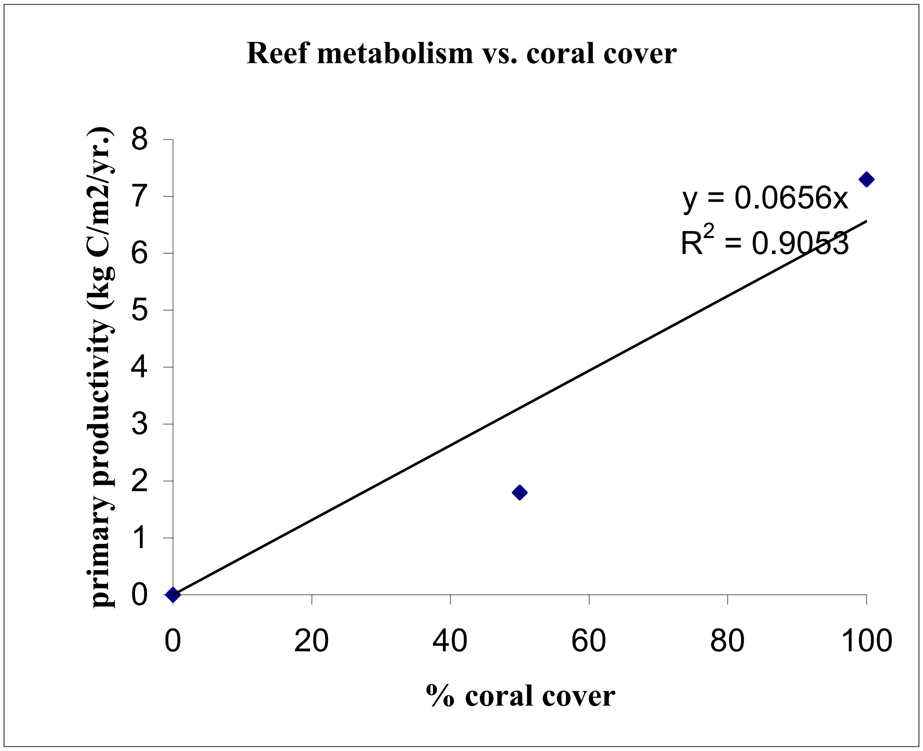


Figure 6 Coral cover vs. metabolic performance (using data from table 5).

coverage. We related diver use and metabolic stress using these two different relationships (i.e. diver use vs. coral cover and coral cover vs. metabolism), previously described. Different levels of diver use were selected for determining the percent coral cover, using the first graphical representation (coral cover vs. diver use). These percentages were then plugged into the second graphical representation (coral cover vs. metabolism) and the primary productivity generated from the first curve was estimated. Thus, reduction in reef metabolism due to diver related stress could be quantified. This procedure was repeated several times at different stress levels (diver use) to generate an independent data set of reef metabolism loss at different levels of diving. The reef metabolism values were then converted into em-dollars using emergy-based calculations.

b)Emergy Calculations:

To simulate reduction in metabolism, we had to first determine reef metabolism at 100% coral cover and convert that into em-dollar equivalents, as a starting or reference point. The calculation was done as follows:

From the coral cover vs. metabolism graphical relationship (figure 7), 100% coral cover yielded 5.4 Kg.C/m2/yr. To proceed with the emergy calculation, the metabolic value was converted into Kcal./m2/yr. and ultimately Joules/m^2/yr. using 10Kcal/g.C and 4184 J/Kcal.(Odum 1971), respectively. The rate of flow of the input (i.e., metabolic activity) was then multiplied by a solar transformity for estuarine gross production (4.7 E3 sej/j; Odum 1996) to determine empower. Accordingly, annual em-dollar flow was calculated using 1.1 E12 sej/$ as the global emergy/money ratio (Brown and Ulgiati 1999). Finally, the em-dollar/m^2/year index was applied to a typical dive site, assuming that area swum by divers 50m x 20m (Medio et al. 1997).

(5.4 Kg.C/m^2/yr.)(10Kcal./gC)(4184J/Kcal.)(4.7 E3 sej/j)(1.1 E12 sej/$)(1000 m^2/site). = **$965.36**

The emergy calculation procedure was repeated at different levels of diver use. The em-dollar values of coral reef metabolism at different stress levels was represented as a graphical relationship (shown in figure 7) relating revenues generated and numbers of dives/site/year.

6.3 Results

The diver carrying capacity investigated in this study is a threshold point, which provides a balance between metabolic loss describing ecological impact and economic gain attributed to revenues generated by diving tourism in the region. Metabolic loss from an emergetic standpoint was previously described. The spending subsidy of divers visiting Hurghada was graphically presented on the same axis, assuming, on average, a diver spends $50 a day (expenses include dive trip, lodging, and other daily expenditures; field data). The point where the metabolic input curve and the spending subsidy curve intersect represents a balance between these two factors defining the diver carrying capacity under study (Figure 7). Quantitatively, the "carrying capacity" derived from the graphical representation exhibited a range of 13,000 –14,000 divers/site/year. Theoretically, any level of use lower than the threshold point determined represents more economic gain than metabolic loss. However, beyond that range, the system will suffer more ecological impact than economic gain.

6.4 Discussion

Population biologists and ecologists generally define the term 'carrying capacity' or 'k' as the number of individuals of a given species that could be sustained indefinitely in a given area (Miller Jr., 1996). In ecological terms, the size of a population in a given place and time is determined by the interplay between its biotic potential and the habitat's resistance. Because humans vary so widely in their impact on life-supporting processes, social scientists added a second dimension, humans and intensity of use to the concept of carrying capacity (Odum 1997). Using this paradigm, Salm (1986) introduced a new definition for the term 'carrying capacity', which he called 'tourist or diver carrying capacity'. The latter represents the number of tourists or divers, which a

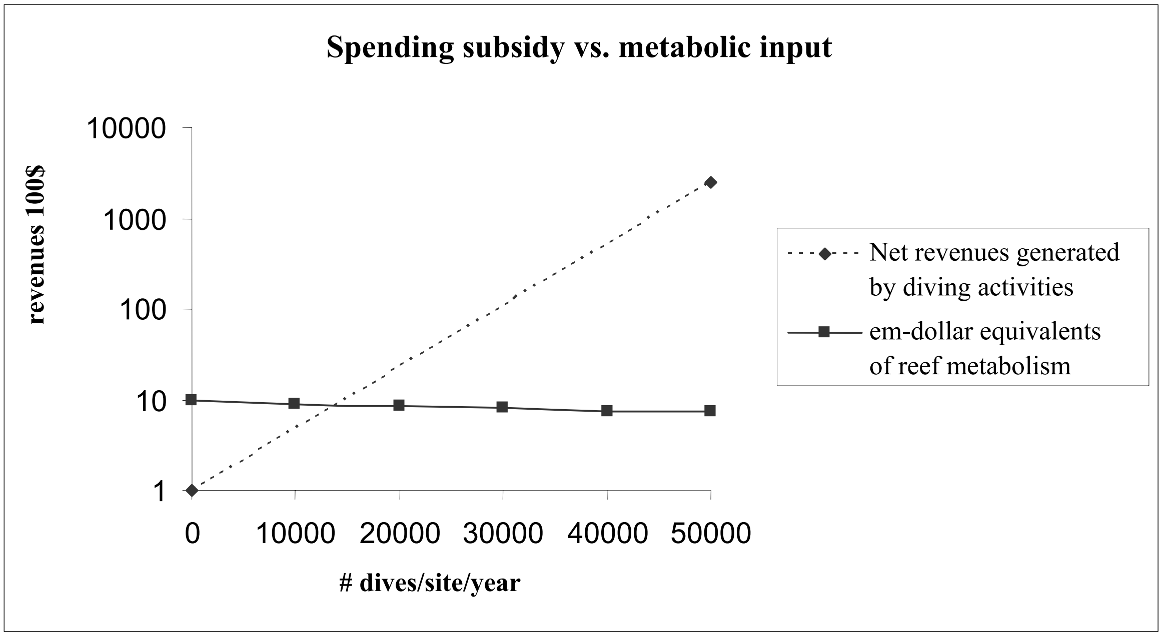


Figure 7 A graphical representation of economic gain vs. ecological impacts caused by intensive diving. The point where the lines intersect represents the equitable point between economic gain and environmental cost. (13,000-14,000 dives/site/year).

reef can tolerate without being significantly degraded accounting for ecological sustainability. For the purpose of our study, a different perspective was added to the definition Salm introduced. Taking the region's economy into account, we defined the term diver carrying capacity as the regional balance between the economic benefits the divers contribute and their ecological impact. However, it is important to note that reef use below or within the threshold range does not imply economic sustainability.

To account for sustainability, an alternative approach to interpreting the model's output is considered. From an emergetic standpoint, where the two curves intersect, defines the point where the emergy investment ratio is equal to one. According to Tilley and Swank (2003), when the emergy investment ratio approaches the value of 1, the system is both economically and ecologically sustainable. In other words, when the investment into the economy (F) balances the emergetic output of the free environment (I), in this case reef metabolism, the system will be sustainable (Refer to Appendix B). The same principle could apply to the model's output. At the point of intersection, divers investment as a spending subsidy balances the emergetic contribution of reef productivity. An F/I ratio less than one, representing that area to the left of the point of intersection, means that F is "small" in value and the diving market would likely be economically unsustainable. On the other hand, a ratio "larger" than one, illustrated by the area to the right of the point of intersection, means that as more divers visit the region, further investing into the economy, the reef metabolic output is decreasing. At some point the system, although economically sustainable, would more likely be ecologically unsustainable. Theoretically, as sites continue to be degraded, less tourists will be attracted to the region and the system will go back to being economically unsustainable. According to the model's output, the reason the region continues to attract that many divers is that rate of metabolic loss due to diver-related stress is significantly low as level of use increases. Therefore, more diving tourists could potentially visit the region as long as the metabolic input "curve" doesn't crash. However, considering these exceptionally high rates of damage previously documented, the reefs systems may not sustain such intense activity.

The diver carrying capacity value (13,000-14,000) estimated by the emergy-based approach lies within the range of values described in literature. Dixon et al. (1994) analyzed coral cover in the Bonaire Marine park and estimated that the diver carrying capacity threshold for the Bonaire Park is 4,000-6,000 dives/site/year. Similarly, Hawkins and Roberts (1994) surveyed percent of damaged coral colonies in the Red Sea Ras Mohammed National park and suggest 10,000-15,000 dives/site/year as a "good rule of thumb". Sampling a variety of hard, soft, and hydro-corals, Chadwick-Furman (1997) found the threshold for reef use in the US virgin Islands to be 500 dives/site/year and attributed the significantly low estimate to the fragility of the community in the study area. Given the information above, and considering Hurghada's current levels of dive site use which is close to 75,000 dives/site/year, it is reasonable to say that the capacity of Hurghadas' reefs to sustain diving activities has been exceeded and the consequences could be detrimental.

These reef carrying capacities can be used to effectively design and plan proposed tourist development so it is in balance with potential diving generated economic revenues. However, these indices are rarely considered by planners and developers, and coral reef managers have to fight "uphill" battles to convince authorities involved to limit the volume of diving tourism. Since the volume of diving tourism directly impacts local and regional economies, reef diver carrying capacities are usually very sensitive political and economic subjects (Jameson et al. 1999). Understanding of this subject by scientists, managers, and politicians is still very limited. Further region specific assessments are encouraged for sustainable development.

In conclusion, a new emergy based measure of diver carrying capacity on coral reefs is presented. The measure evaluates the balance between the positive and negative aspects of diver use in a regional context. This approach can be used for policy development and management planning of coral reef systems.

CHAPTER 7: SUMMARY AND CONCLUSIONS

7.1 Summary Of Studies

Coral reefs provide a major impetus for tourist development throughout the tropics. The increased popularity of the natural resource has led to extremely rapid growth of many coastal towns. Using Hurghada as a case study, I examined both the positive and negative influences that diving tourism has had on the local economy and the coral reefs, respectively. Overall, the present effects of diving tourism on coral reefs around Hurghada are worrying rather than alarming. In general, tourism tends to hold back industrial development and should provide a powerful economic reason to preserve reefs. With careful planning, diving tourism should bring prosperity to the region rather than threaten its most valuable natural resource.

Overcrowding at dive sites may lead to excessive degradation of those sites. Congestion may have two interrelated impacts. First, it may reduce the aesthetic value of the reef and second, a high level of use may reduce the ecological functions at particular dive sites. Although the industry generates $5-9 million of net revenues, current levels of use and levels of diver-related stress, have pushed these reefs beyond their tolerance. At all dive sites in Hurghada, diver carrying capacities, estimated to be 13,000-14,000 dives per site per year, have been exceeded. The consequences of such intense diving activity would likely cause significant degradation at the most heavily used sites. Furthermore, space limitation below and above the surface of the water would likely prevent divers from enjoying the experience. Consequently, there is a need to design and implement management strategies which will ensure sustainable use and regulate activity in the region.

7.2 Management Recommendations

Since diver volume directly impacts local tourist economies, beneficiaries, particularly dive operators, discourage the application of such carrying capacities that will limit economic growth. To increase capacity of Hurghada's reefs to more divers at ecologically sustainable levels, I propose the following: There are two alternative solutions to limiting levels of use; either spread diver use equitably across reefs, in accordance with their diver carrying capacities and increase the number of dive sites, which could be achieved by using more liveaboard vessels, or, to avoid degrading more sites, do not allow dive operators to use some sites or certain parts of the same site to facilitate "supplyside" regeneration that would sustain recovery . According to Davis and Tisdell (1995) assessing the demand for use of recreational dive sites requires a focus on two questions: 1) why do people participate in recreational SCUBA diving? ; and 2) what factors are important in the choice of a dive site? Since the first issue is in relation to the second question, it is important to take into consideration, when defining new sites, the reasons people participate in the sport, which include the following:

i) a desire for a ‘wilderness experience’
ii) a general interest in marine ecology.
iii) An interest in particular underwater features (e.g. geological formations, shipwrecks) and marine life (sharks, individual fish species, corals).
iv) Pursuit of hobbies such as underwater photography

If such procedures are followed, diving pressure on these heavily used sites will be dissipated amongst a larger number of sites, and that may reduce diver-related degradation and attain ecological sustainability.

Another approach that would help decrease diving pressure at heavily used sites is allocate a limited number of permits to dive operators to use particular sites, with the number of divers allowable is specified in the permit conditions. Application of such policy should be enforced rigorously. No other commercial operator could then utilize those sites. Other recommendations include: i) presenting comprehensive briefings, which were found to reduce diver inflicted damage (Medio et al., 1997), prior to each dive, emphasizing the importance, value, and vulnerability of fragile coral reef ecosystems; ii) transferring training grounds to shallow lagoons, away from coral dominated sites, until buoyancy skills are mastered and divers are more confident in open waters; iii) Discourage divers, particularly photographers, to contact the reef at any instance or situation.

7.3 Future Research

To reduce the conflict between recreation and conservation, economic aspects of SCUBA diving require further study. The difficult task of estimating demand curves for diver consumers will be an important aspect of such work. Also, a notion of feed back should be added to the model so that divers attracted to the region would be responsive to changes in coral cover caused by diver-related stress and another feed back loop that considers the coral reef's ability to recover through regeneration. It would be interesting to examine the responsiveness of the measure of diver carrying capacity to such dynamics. On the other hand, carrying capacity needs must be addressed in relation to site-specific factors and management objectives. Further research is needed to define clearly the roles and relative importance of various factors at each site in determining the diver carrying capacity of coral reefs. Furthermore, research should focus on alternative sources of tourist attraction that have potential value towards the local economy. Integrating all approaches aforementioned, ecological and economic sustainability leading to sustainable development could be achieved.

Appendix A

Table 6 . Geographical location of dive sites investigated

Site Name(s)	**Latitude**	**Longitude**	**Dive Use**
Shaab Petra, Erog Magawish	27° 5' 25.1"	33° 55' 0.0"	Heavy
Shaab Sabina	27° 12' 49.7"	33° 57' 12"	Heavy
Little Giftun Island	27° 11' 9"	33° 58' 53.4"	Heavy
Abu Ramada Island, South	27° 9' 43.3"	33° 58' 35.3”	Heavy
Gota Abu Ramada (West)	27° 8' 21.6"	33° 57' 11.8"	Heavy
Gota Abu Ramada (East)	27° 8' 0.0"	33° 57' 0.0"	Heavy

Appendix B

Emergy Definitions in equation form

The definitions and concepts in equation form are quoted from Odum (2000).

Emergy, a measure of real wealth, is defined as sum of the available enrgy of one kind previously required directly and indirectly through input pathways to make a product or service (unit: emjoules). In most recent papers, solar emergy (E_{ms}) is used with the unit solar emjoule (abbreviation: sej).

Empower (J_{ems}) is the emergy flow per unit time (units: solar emjoules per year, sej/yr.)

Solar Emergy Flow = $J_{ems} = \sum(T_{rs1}*J_{e1} + T_{rs2}*J_{e2}\ldots\ldots T_{rsi}*J_{ei})$

where T_{rs} = solar transformity and J_e is a flow of available energy.

Transformity, is the emergy per unit available energy (emergy per unit exergy). It is the intensive unit of emergy and measures the quality of energy.

$T_{rs} = J_{ems} / J_e$

Emergy per money ratio(Ems/$) is a measure of the real wealth buying power money of money calculated for a state or nation for a given year. It is useful where data on human services are in money units.

$E_{ms}/\$ = J_{ems}/J_{\$}$

Emdollars (Em$) are the dollars of gross economic product based on a contribution of emergy.

$E_{m\$} = E_{ms}/(E_{ms}/\$)$

Emergy Investment Ratio (EIR) is the ratio of inputs purchased and fed back from the economy (F_{em}) divided by the free environment emergy input (I_{em}). It is a measure of economic viability.

$EIR = F_{em}/ I_{em}$

APPENDIX C

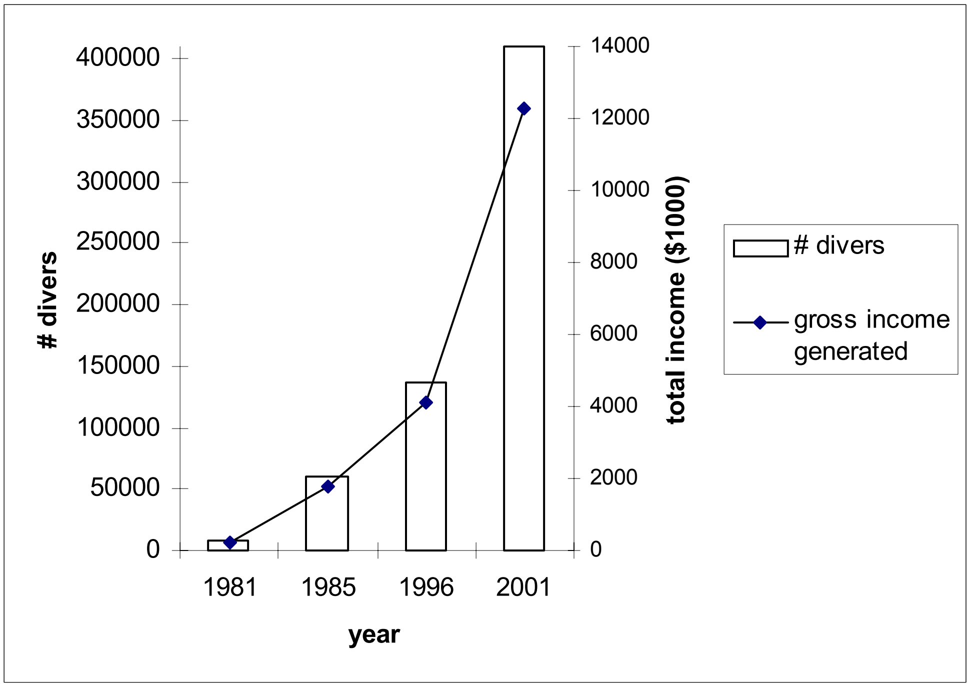


Figure 8. The growth of the diving industry and the economy dependant on it. The illustration shows an exponential increase in numbers of divers visiting Hurghada, and hence, the revenues generated by such activity.

REFERENCES

Beltagi, A. (1997). Report on the oceanographic conditions in the coastal area of the Egyptian Red Sea. GEF, Red Sea, Egypt.

Berg, H., Ohman, M., Troeng, S. and Olof Linden (1998). Environmental economics of coral reef destruction in Sri Lanka. *Ambio* 27:627-634.

Brown,M. and S. Ulgiati (1999). Emergy evaluation of the bioshere and natural capital. *Ambio* 28: 468-493

Cesar, H., Lundin, C.G., Bettencourt, S. and J. Dixon (1997). Indonesian coral reefs- an economic analysis of a precious but threatened resource. *Ambio* 26: 345-350.

Chadwick-Furman, N. (1997). Effects of SCUBA diving on coral reef invertebrates in the US Virgin Islands: implications for the management of diving tourism. *Proc. 6th Int. Coelen*. *Biol*. pp.91-100.

Costanza,R., d'Arge, R., Groot,R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R., Paruelo, J., Raskin, R., Sutton, P. and M. van den Belt (1997). The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.

Daily, G., Soderqvist,T., Aniyar, S., Arrow, K., Dasgupta, P., Ehrlich, P., Folke, C., Jannson, A., Jannson, B., Kautsky, N., Levin, S., Lubchenko, J., Maler, K., Simpson, D., Starrett, D., Tilman, D. and B. Walker. (2000). The value of nature and the nature of value. *Science* 289:395-396.

Davis, D. and C. Tisdell (1995). Recreational SCUBA diving and carrying capacity in Marine Protected Areas. *Ocean & Coastal Management* 26:19-40.

Dixon, J., Fallon Scura, L. and T. Van't Hof (1993). Meeting ecological and economic goals: marine parks in the Caribbean. *Ambio* 22: 117-125.

Dixon, J., Fallon Scura, L. and T. Van't Hof. (1994). Ecology and micro-economics as "joint Products": The Bonaire Marine Park in the Caribbean.

In: C. Perrings et al. (eds) *Biodiversity Conservation: problems and politics.* Kluwer Academic Press, Dordrecht.

Fishelson, L. (1973a). Ecological and biological phenomena influencing coral species composition on the reef tables at Eilat (Gulf of Aqaba, Red Sea). *Marine Biology* 19: 183-196.

Fishelson, L. (1973b). Ecology of coral reefs in the Gulf of Aqaba (Red Sea) influenced by pollution. *Oecologia* 12:55-67.

GEF, Report No. 4 (1998). Reef recreation management action plan for the Egyptian Red sea coast (Hurghada-Safaga). GEF, Red Sea, Egypt.

Gomaa, A. Chief Ranger in HEPCA (personal communication)

Harriott, V., Davis, D. and S. Banks. (1997). Recreational diving and its impact in Marine Protected Areas of Eastern Australia. *Ambio* 26:173-179.

Hawkins, J. and C. Roberts (1992). Effects of recreational SCUBA diving on fore-reef Slope communities of coral reefs. *Biological Conservation.* 62: 171-178.

Hawkins, J. and C. Roberts (1993). Effects of recreational SCUBA diving on coral Reefs: trampling of reef flat communities. *Journal of Applied Ecology* 30:25-30.

Hawkins, J. and C. Roberts (1994a). Can Egypt's coral reefs support ambitious plans for diving tourism. *Proc. 7th Intl. Coral Reef. Symp.* pp.1007-1013.

Hawkins, J. and C. Roberts (1994b). The growth of coastal tourism in the Red Sea: present and future effects on coral reefs. *Ambio* 23: 503-508.

Hawkins, J. and C. Roberts (1997). Estimating the carrying capacity of coral reefs for SCUBA diving. *Proc.8th Int. Coral Reef Symp*. 2:1923-1926.

Hawkins, J., Roberts, C., Hof, T., Meyer, K., Tratalos, J. and C. Aldam (1998). Effects of recreational SCUBA diving on Caribbean coral and fish communities. *Conservation Biology* 13: 888-897.

Hegazy, I. (2002). A survey of Red Sea tourists' and tourism operators' willingness to pay for coral reef conservation. A report prepared for the Egyptian Environmental Policy Program. Red Sea, Egypt. pp15-17.

Highsmith, R.C., (1982). Reproduction by fragmentation in corals. *Mar.Ecol.Prog.Ser* 7: 207-226.

Hilal, K. Chairman of The Red Sea Association for Diving & Watersports (personal communication).

Jameson, S., Ammar,M., Saadalla,E., Mostafa,H. and B. Riegl (1999). A coral damage index and its application to dive sites in the Egyptian Red Sea. *Coral Reefs* 18:333-33

Kanagas, P., Shave, M. and Paul Shave. (1995). Economics of an ecotourism operation in Belize. *Environmental Management* 19: 669-673.

Kinsey D. (1991). The coral reef: an owner-built, high density, fully serviced, self sufficient, housing estate in the desert: Or is it? *Symbiosis* 10:1-22.

Knowlton, N. (1997) Hard decisions and hard science: research needs for coral reef management In: Coral Reefs: Chalenges And Opportunities For Sustainable Management. *Proc. 5th Annual World Bank Conferenceon Environmentally and Socially Sustainable Management.* Pp. 183-187.

Liddle, M. (1975). A selective review of the ecological effects of human trampling on natural ecosystems. *Biological Conservation* 7: 17-36.

Liddle, M. and A. Kay (1987). Resistance, survival, and recovery of trampled corals on The Great Barrier Reef. *Biological Conservation* 42:1-18.

Loya, Y. (1972). Community structure & species diversity of hermatypic corals at Eilat, Red Sea. *Marine Biology*. 13:100-123.

May,R. (1977). "Thresholds and breakponts in ecosystems with a multiplicity of stable States." *Nature* 269:471-477. In: Knowlton, N. 1997. Coral reefs: challenges and opportunities for sustainable management. *Proc. 5th Ann. World Bank Conf.*183-187

McClanahan, T., Sheppard, C. and D. Obura (2000). Coral Reefs of the Indian Ocean: Their Ecology and Conservation. Oxford University Press, pp 50-52.

Medio D., Ormond,R. and M. Pearson (1997). Effect of briefings on rates of damage to corals by SCUBA divers. *Biological Conservation* 79: 91-95.

Meesters, E., Noordeloos, M. and R. Bak (1994). Damage and regeneration: links to growth in the reef-building coral *Montastrea annularis*. *Mar.Ecol.Prog.Ser.*112: 119-128.

Miller, Jr., T. (1996). *Living In The Environment*. Wadsworth Publishing Company, New York. 727 pp.

Odum, E. P. (1971). *Fundamentals Of Ecology*, 3rd ed. W.B. Saunders Co., Philadelphia, PA.

Odum, E.P. (1997) *Ecology: A Bridge Between Science and Society*. Sinauer Associates, Inc., Sunderland, Massachussetts. 330pp

Odum, H.T. (1996). *Environmental Accounting, Emergy, and Decision making*. J.Wiley and Sons. New York.370 pp..

Odum H.T.(2000). Emergy evaluation of an OTEC electrical power system. *Energy* 25: 389-393.

Red Sea protectorates, Annual Report (2000) Submitted to Nature Conservation Sector, Egyptian Environmental Affairs Agency, Cairo, Egypt.

Reeve, S.M., Jameson, S.C., Abdel Fattah, R.S., Riegl, B., Hassan, R. and A.P. Newman (1998). Best practices for tourism center development along the Red Sea coast. Tourism Development Authority, Cairo 107pp.

Riegl, B. and B. Velimirov (1991). How many damaged corals in Red Sea reef systems? A quantitative survey. *Hydrobiologia* 216/217:249-256.

Reigl, B. and B. Velimirov (1994). The structure of coral communities at Hurghada in the Northern Red Sea. *P.S.Z.N.I: Marine Ecology* 15: 213-231.

Roberts, C. and R. Ormond (1987). Habitat complexity and coral reef fish diversity and abundance on Red Sea fringing reefs. *Mar.Ecol.Prog.Ser.* 41:1-8.

Rogers, C. S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Mar.Ecol. Prog. Ser.* 62:185-202.

Rouphael, A.B. and G. Inglis (1997). Impacts of recreational SCUBA diving at sites with different reef topographies. *Biological Conservation*. 82: 329-336.

Salm, R.V. (1985). Integrating marine conservation and tourism. *Intl. J .Env. Stud.* 25:229-238

Salm,R.V. (1986). Coral reefs and tourist carrying capacities: the Indian Ocean Experience.*UNEP Ind. Environ*.9:11-14

Schleyer, M. and B.Tomalin (2000) Damage on South African coral reefs and an assessment of their sustainable diving capacity using a fisheries approach**.** *Bull.Mar.Sci.* 67:1025-1042.

Sebens, K. (1994). Biodiversity of coral reefs: what are we losing and why? *Am. Zool.* 34: 115-133.

Spurgeon, J.P. (1992). The economic valuation of coral reefs. *Mar. Poll. Bull.* 24: 529- 536.

Terence, J., Ogden ,J., Weibe W. and B. Rosen. (1996). *Functional roles of. biodiversity: a global perspective*. (eds.) Mooney,H., Cushman, J., Medina,E., Salsa, O. and E.-D.Schulze. John Wiley & Sons Ltd., pp. 395-428.

Tilley, D. and W. Swank (2003). EMERGY-based environmental systems assessment of a multi-purpose temperate mixed-forest watershed of the southern Appalachian Mountains, USA. *Journal of Environmental Management* 69: 213-227.

Tratalos, J.A. and T.J. Austin (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation* 102: 67-75.

Weilgus, J., Chadwick-Furman, N., Dubinsky, Z., Shechter, M. and Naomi Zeitouni. (2002). Dose-response modeling of recreationally important coral reef attributes: a review and potential application to the economic valuation of damage. *Coral Reefs* 4: 1-15.

White, A.T., Vogt, H.P. and T. Arin (2000). Philippine coral reefs under threat: the economic losses caused by reef destruction. *Mar. Poll. Bull.* 40: 598-605.

Wilkinson, C.R. (1992). Coral reefs of the world are facing widespread devastation: can we prevent this through sustainable management practices. *Proc. 7th Intl. Coral Reef Symp.* 1: 11-21.

Woodland, D. and N. Hooper (1977). The effect of human trampling on coral reefs. *Biological Conservation* 11: 1-4.

Zakai,D., Levy,O., and N. Chadwick-Furman (2000). Experimental fragmentation reduces sexual reproductive output by the reef building coral *Pocillopora damicornis*. *Coral Reefs*.19: 185-188.

Zakai, D. and N. Chadwick-Furman (2002). Impacts of intensive recreational diving on reef corals at Eilat, Northern Red Sea. *Biological Conservation* 105:179-187.