Universidade do Algarve

Faculdade de Ciências do Mar e do Ambiente

Can reef conservation programmes help reduce SCUBA diving damage to coral reefs? A case study in Thailand

Dissertação apresentada por

Bruno Miguel Silvestre Mendes

Para a obtenção do grau de

Mestre em Biologia Marinha, na especialidade de Ecologia e Conservação Marinha

Faro, 2008

Universidade do Algarve

Faculdade de Ciências do Mar e do Ambiente

Can reef conservation programmes help reducing SCUBA diving damage to coral reefs? A case study in Thailand

Dissertação apresentada por

Bruno Miguel Silvestre Mendes

Para a obtenção do grau de

Mestre em Biologia Marinha, na especialidade de Ecologia e Conservação Marinha

Dissertação orientada por:

Dr. Karim Erzini

(UALG – Faculdade de Ciências do Mar e do Ambiente)

Dr. Niphon Phongsuwan

(PMBC – Phuket Marine Biological Center)

Faro, 2008

"Most people are familiar with terrestrial habitats and can relate to a walk in the woods. Few, however, have experienced the wonders of a coral reef except for occasionally viewing a Jacques Cousteau special. Whilst it is easy to capture images of rain forests being cut down and to collect data to quantify the magnitude of habitat destruction on land , it is more difficult to study and document coral reef processes and degradation"

(Richmond 1994)

Acknowledgments

I would like to give all my gratitude to my mother for having the biggest importance for the accomplishment of this work and for always believing in me. To all my family, for all their support, help and incentives.

I also would like to express my sincere thanks to the following individuals and institutions for their major and invaluable inputs:

Dr. Karim Erzini for accepting to be my supervisor and helping me through the hard process of writing the dissertation.
Dr. Niphon Phongsuwan from the Phuket Marine Biological Centre, for accepting to be my co-supervisor, extremely helpful and for having received me with open arms in the Greenfins-Thailand programme.
The Phuket Marine Biological Centre, Greenfins Thailand and all the Staff for providing the background for the study and the best support.
André Glória for helping me out during the field work, as a Greenfins volunteer and as the best friend ever.
Meyung for her amazing energy and help during the field work as a Greenfins volunteer
Bex Tyrer for being the most "everything" in my life, the most amazing partner and for the specific support and help with the writings.
Justine and Aey for their partnership in the Greenfins project and for their supply of materials for the thesis.
Guy Corsellis (Asia Divers, Koh Tao) and Mark Soworka (Buddha View, Koh Tao) for their friendship, role-modeling, availability and contribution for this thesis
All the dive operators' members of Greenfins that were available and authorized the study during their dive operations.
Ninja, for his amazing friendship, love and life. Away but in the heart.

A last but not least big thanks to my friends from Portugal and from all around the world that somehow supported me and accompanied me during this process.

Abstract

Coral reefs are under threat all over the world. Coastal human activities are not always sustainable in this vulnerable ecosystem and may produce continual and cumulative damage. At the present, Thailand is a main tourist destination for SCUBA divers from all around the world and this industry is having a big expansion in recent years. However this growth is revealing problems at the conservation level, since Thailand has difficulties implementing and enforcing environmental laws and regulations to manage its coral reefs. Therefore, reef conservation programmes appear as a non-regulatory form to attempt to reduce the damage produced by SCUBA divers to the corals. The reef conservation programme Greenfins was funded in 2004 with the mission statement "to protect and conserve coral reefs by establishing and implementing environmentally friendly guidelines to promote a sustainable diving tourism industry".

This study attempts to quantify the amount of damage that SCUBA divers produce in Thailand and compare the damage produced by guided SCUBA divers form Greenfins dive operators and non-Greenfins members. Also, some diver personal characteristics, diver history, diver environmental characteristics and dive characteristics were examined and tested against the influence in the number of divers that damaged the reef and the damage rate. The mean average of damaging contacts was 1.97 per 30 minutes of the dive and the median damage was one contact per 30 minutes of the dive. Most damage occurred in the first 10 minutes of the dive, involuntarily and caused by the diver's fins. Comparatively, these results are relatively lower than those of other studies with non-Greenfins operators. In Thailand, reef topography was the only factor that influenced the damage to the corals, with diving in vertical topographies showing a lower damage. However in the Andaman Sea, divers with high level of environmental awareness and divers with knowledge of Greenfins were less damaging to the corals, suggesting a better involvement of the members with the aims of the programme.

This study suggests that dive operators should promote the environmental education of their staff and customers in order to reduce damage on the coral reefs. Some measures that can be implemented are for example: choice of the dive sites according to reef topography, with preference given to vertical topographies; provide documentation and information on coral reefs marine life and conservation; improve the pre-dive briefings,

vulnerability of corals, buoyancy control and fins awareness.

To a certain extent it can be concluded that the implementation of reef conservation programmes such as Greenfins, may be already improving the education of the SCUBA divers and reducing the damage on the corals of Thailand.

Keywords: tourism, SCUBA diving, coral reefs, Greenfins, Thailand, damage

Resumo

Os recifes de coral estão sob ameaça ecológica por todo o mundo. As actividades humanas neste vulnerável ecossistema nem sempre são sustentáveis e podem provocar danos contínuos e cumulativos. A Tailândia é um país com grande procura turística devido aos seus recursos naturais, clima, baixo custo de vida e oferta de actividades recreativas. A sua indústria de mergulho encontra-se em grande expansão e apesar dos inúmeros beneficios económicos, é actualmente uma preocupação ao nível da conservação da natureza. A Tailândia, como muitos outros paises do Sudeste Asiático revela problemas na implementação das suas políticas de conservação da natureza e na gestão dos seus recursos naturais. A fiscalização e gestão destas actividades ao nível prático são escassas e dificilmente conseguidas ao nível governamental.

Como forma não-regulatória de reduzir o impacte da indústria de mergulho recreativo com escafândro autónomo (i.e. SCUBA diving) nos recifes de coral da Tailândia, foi criado em 2004 o programa de conservação dos recifes de coral, denominado Greenfins, com o intuito de " proteger e conservar os recifes de coral, através do estabelecimento e implementação de directivas amigas do ambiente para promover uma indústria turistica de mergulho sustentável".

De facto, existe agora um interesse em monitorizar, compreender e gerir o comportamentos dos mergulhadores de forma a puder contribuir para a gestão dos recifes de coral. Este estudo teve como objectivo quantificar o impacte dos mergulhadores recreativos com escafândro autónomo na Tailândia. Isto foi possível através da análise dos contactos provocados pelos mergulhadores com os corais e da comparação entre os mergulhadores usuários de centros de mergulho membros do programa Greenfins e os mergulhadores sem particular afiliação a qualquer programa de conservação de recifes de coral.

Os mergulhadores foram observados em 27 locais de mergulho distintos, a profundidades entre zero e trinta metros, localizados no Mar de Andamão e no Golfo da Tailândia. No total foram observados 155 mergulhadores aleatoriamente, durante 30 minutos dos seus mergulhos e anotados todos os contactos com o recife de forma a calcular a taxa de contactos e a proporção de mergulhadores que provocaram danos no recife. De acordo com estudos anteriores, os contactos prejudiciais para os corais foram

distinguidos em toque, quebra ou re-suspensão de sedimento sobre os corais. Globalmente, foram registados 430 contactos com o substrato, sendo considerados 306 dos contactos como prejudiciais para os corais. A média de contactos prejudiciais com os corais foi de 1.97 por cada 30 minutos de mergulho e a mediana foi de um contacto por cada 30 minutos de mergulho.

Para testar o efeito de certas características na quantidade de mergulhadores que danificam os corais e na taxa de contactos prejudiciais, foram testadas 11 variáveis, incluindo características pessoais do mergulhador (i.e. sexo, idade e fotógrafia subaquática), histórico do mergulhador (número de mergulhos registados (experiência) e certificação de mergulho), características ambientais do mergulhador (nível de consciência ambiental, conhecimento do programa Greenfins e ocorrência de briefing ambiental) e características do mergulho (i.e. topografia do recife, corrente subaquática e tamanho do grupo de mergulho).

A quantidade de mergulhadores que danificaram os corais e a taxa de contactos deste estudo foram inferiores a outros estudos semelhantes. Isto sugere que actualmente, o programa Greenfins já exerce um efeito benéfico em relação ao prejuízo nos corais causado pelos mergulhadores. Relativamente à análise das 11 variáveis enunciadas, na amostra global da Tailândia, o único resultado que apresentou significância estatística foi a topografia do recife. As topografias verticais em forma de pináculo e de parede apresentaram o menor número de mergulhadores a danificarem o recife e uma menor taxa de contactos. Foi possivel prever a probabilidade de provocar danos aos corais quando se mergulha em pináculos como 0.30 inferior a quando se mergulha noutras topografias e a probabilidade de danificar os corais é superior 2.24 vezes.

A maior parte dos danos aos corais ocorreu nos primeiros 10 minutos do mergulho e a maior percentagem de contactos ocorreu involuntariamente, e produzida por contactos com as barbatanas. Também a maior parte dos danos foram causados a corais moles, seguido dos corais duros, no entanto a maioria dos contactos com o substrato ocorreram com substrato inerte.

Não foram encontradas diferenças na média de danos provocados nos corais, entre o Mar de Andamão e o Golfo da Tailândia. No entanto, quando analisadas separadamente essas duas amostras, algumas variáveis tiveram influência nos danos causados aos corais. No Mar de Andamão, o nível de consciência ambiental e o prévio conhecimento

do programa Greenfins mostraram uma relação com a ocorrência de danos aos corais. O nível de consciência ambiental também influenciou a taxa de contactos. Um maior nível de consciência ambiental produz uma redução no número de mergulhadores que causaram danos nos recifes, assim como ter conhecimento do programa Greenfins mostrou uma redução no número de mergulhadores que causaram danos. Também um maior nível de consciência ambiental mostrou um menor número de contactos por 30 minutos de mergulho. Outra importante descoberta foi que o número de contactos voluntários com os corais diminuiu com o facto do mergulhador ter conhecimento do programa Greenfins.

Quando analisadas separadamente as amostras de mergulhadores com e sem conhecimento do programa Greenfins, a variável sexo mostrou influência nos danos causados aos corais. Um maior número de indíviduos do sexo feminino provocam danos nos corais durante o mergulho, mas pelo contrário os mergulhadores masculinos provocam mais danos durante 30 minutos.

Este estudo sugere que os centros de mergulho devem promover a educação ambiental dos seus guias de mergulho e dos seus clientes de forma a reduzir os impactes nos recifes. Algumas medidas podem ser tomadas são por exemplo: a escolha do sitio de mergulho, consoante a topografia, preferindo as topografias verticais e tendo em conta a experiência dos mergulhadores; expôr e facilitar documentação sobre a vida marinha e conservação; melhorar os briefings introdutórios ao mergulho, com particular referência á vulnerabilidade dos corais e ao controlo de flutuabilidade e barbatanas.

De certa forma pode-se concluir que a implementação de programas de conservação dos recifes de coral, como o Greenfins, já demonstram uma melhoria na educação dos mergulhadores e uma redução nos danos produzidos nos corais da Tailândia.

Palavras-chave: turismo, recife de coral, mergulho recreativo com escafândro autónomo, Greenfins, Tailândia, impacte

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Aim of the Study

The purpose of this study is to quantify diver damage in Thailand and compare the damage by contact from recreational guided SCUBA divers from Greenfins dive operators and non-Greenfins members. Another aim is to examine the relationship between those characteristics of the divers and of the dives with the contacts and damage to the coral reefs. In order to achieve this, the independent variables were divided into diver personal characteristics (i.e. gender, age and photographer), diver history (i.e. number of logged dives (experience) and certification), diver environmental characteristics (i.e. environmental awareness level, knowledge of Greenfins programme and environmental briefing occurrence) and dive characteristics (i.e. reef topography, current and dive group size). The examination of these independent variables was important to the study because it was hoped that this would allow for the identification of characteristics and factors contributing to significant differences in contacts and damage to the reefs from recreational SCUBA divers. It was felt that such knowledge, in Thailand, was limited and it was hoped that an increase in information would be of practical help to both the dive operators and the policy makers and ultimately, improve coral reef conservation.

1.2 The Coral Reefs

Coral reef ecosystems are unique and among the most complex and biodiverse ecosystems on earth. Renowned for their beauty, they draw millions of tourists from around the world each year (Burke et al., 2002). Coral reefs are highly productive ecosystems that provide a variety of valuable goods and services to local and international communities. According to Cesar (2000), these goods and services include recreational opportunities for diving, snorkelling, and viewing (direct use values);

coastal protection and habitat/nursery functions for commercial and recreational fisheries (indirect use values); and the welfare associated with the existence of diverse natural ecosystems (preservation values). Coral reefs also possess a high actual and potential value as biochemical material for pharmaceutical and other products. They also possess a high ecological value, promoting the growth of mangroves and seagrasses, both of which provide essential sheltering habitat to many marine species, and help to protect coastal areas from erosion (Burke et al., 2002).

According to many authors (Burke et al., 2002; Brander et al. 2007; Tratalos & Austin, 2001) and despite the provision of their multiple valuable services, including their immensurable natural heritage value, coral reefs face a number of anthropogenic threats, including pollution, over-fishing and sedimentation resulting from land-use practices. Further evidence (Jameson et al., 1999; Tratalos & Austin, 2001) has demonstrated that reefs may become degraded as a result of poorly planned or intensive tourism use.

In particular, as will be shown below, recreational SCUBA diving not only *directly increases* the risk of physical damage to the reef via contact from the divers, but it also *indirectly increases* the risk of reef degradation. Scuba diving brings increased risks to the reefs from the anchoring of (and pollution from) dive boats, a potential disturbance to the reef ecology through the changing of marine behaviour and a possible decrease in water quality due to the inadequate development of coastal areas of tourism (Yeemin, 2004). Although these indirect impacts from recreational SCUBA diving are not the focus of this study their potential for reducing the carrying capacity of the reef are important and will be elaborated on below.

1.3 SCUBA Diving and its Impacts

Scuba diving is probably the most popular adventure sport in the world and large numbers of scuba divers visit coral reefs every year. Diving tourism is spread around 91 countries and territories (Spalding et al., 2001). The magnitude of this industry can be understood from the analysis of recent data on diver training. The world's largest scuba diving training organisation, the Professional Association of Dive Instructors (PADI), accounts for around 75% of all SCUBA diving certifications world-wide. Worldwide, from its beginning of operations in 1964 to 2006, PADI has issued more than 15 million

certifications. In 2006, PADI issued a total of 924.270 certifications, from which 535.657 were new divers. PADI Asia Pacific (which includes the area of focus for this study) issued a total of 127.493 certifications at the entry-level. The island of Koh Tao alone, which is a central recreational dive hotspot in Thailand, and one of the research bases for this study reached a record total of 27.000 PADI certifications in 2007 (PADI, 2008). This small island is one of the most important locations in terms of certifications for PADI in all of Southeast Asia.

Figure 1 – Diver holding to bare substrate to regain control during a wall dive.

Researchers such as Worachananant, (2007) argue that the current sensitivity of the worlds coral reefs to pollution and other major disturbances, decreases their resistance to what may appear to be relatively small impacts from recreational SCUBA divers or snorkelers, resulting in what can be referred to as the 'cumulative impact' reef damage. As a result, in cases where the reefs are simultaneously affected directly by other forms of degrading perturbations, these recreational impacts may slow or prevent the recovery of the reef (Hawkins et al. 1999; Plathong et al., 2000). In Thailand, this theory has particular relevance due to the devastation to the coral reefs caused by the December 2004 Tsunami. The long term impact of the Tsunami on Thailand's coral reefs varied greatly. In the two areas of this study, the Gulf of Thailand remained unaffected while the Andaman Sea witnessed the highest number of human causalities and the greatest geographic and natural resources impact within the entire country (Yeemin, 2005). This study was conducted three years after the event and visible signs of the damage to the reefs were still evident. It cannot be discounted that the Tsunami appears to have

further reduced the carrying capacity of the reefs to external factors and specifically to the impact of SCUBA divers, or that vice versa, SCUBA divers are reducing the recovery rate of Thailand's affected reefs (Phongsuwan, 2006).

Damage to corals by visitors and SCUBA divers in particular are becoming increasingly significant as an environmental impact affecting coral reefs. Several studies have analyzed how snorkelling and SCUBA diving (Rogers et al., 1988; Hawkins & Roberts, 1992; Talge, 1992; Zakai & Chadwick-Furman, 2002; Barker & Roberts 2004) can impact the reefs by breaking, bumping or re-suspending sediment on corals.

In the case of bumping, in general no visible damage occurs, but part of the protective mucus layer may be damaged or removed, providing a higher susceptibility to diseases or to other overgrowing organisms (Talge, 1990 and 1991; Hawkins et al., 1999).

Breaking coral produces visible damage such as fractured hard skeleton and kills the polyps directly involved. Evidence, though, shows that larger broken fragments from some corals (e.g. branching corals) may likely use fragmentation for reproduction and growth, but diver's breakage usually is resumed to small tips of the corals which have low survival (Talge, 1991; Zakai & Chadwick-Furman, 2002).

Sedimentation is also considered in this study, since it can damage corals by preventing the symbiotic *zooxanthellae* from photosynthesizing and maintaining the corals healthy. Heavy sedimentation has been for long associated with fewer coral species, less live coral, lower coral growth rates and greater abundance of branching forms (Rogers, 1990).

The effects of diver damage on the coral reefs is complex, but in general it can result in a reduction of the percentage cover of live coral and an increase in the amount of dead coral and coral rubble (Hawkins & Roberts, 1993; Tratalos & Austin, 2001; Hawkins et al., 1999; Zakai & Chadwick-Furman, 2002). Diving may also affect species diversity, although lower levels of coral survival in areas subject to a high disturbance can be offset to some degree by the colonization opportunities made available by diver damage. This may explain why the effect of diving on species numbers appears weaker than it does for hard coral cover (Tratalos & Austin, 2001).

During SCUBA diving, contact with the substrate can manifest in different ways:

- It may be voluntary, usually to gain control, to move closer to objects of interest, to take photographs, or in a current;

- Involuntary, generally as a result of inexperience, carelessness and a lack of buoyancy control.

(Talge, 1990)

The possible impacts of SCUBA diving are of particular concern in countries like Thailand, where coral reefs are a highly prized part of the natural heritage and the dive industry is an important part of the economy (TAT, 2008). Despite the economic importance of the local dive industry based on coral reefs, there is only a limited amount of quantitative data available concerning the relation between frequencies of SCUBA dives, diver behaviour and damage rates to coral reefs in Thailand. As explained above, this lack of extensive studies regarding impacts made by different SCUBA divers at different dive sites is a gap this study aims to reduce.

1.4 The Coral Reefs of Southeast Asia and Thailand

Southeast Asia supports significant richness in marine biodiversity. It is home to around 34 percent of the world's total area of corals (COBSEA, 2005). Thailand alone has a total coastline of more than 2,600 km and 300 islands, along which stretch approximately 153 km^2 of coral reefs (Phongsuwan, 2006). Thailand's coastal waters are located between 6º N and 13º N, offering good environmental conditions for coral reef development (Sudara, 1981; Yeemin, 2005). Its coastlines are spread along the east and the west coasts of the Gulf of Thailand and along the Andaman Sea (see Fig. 4). Thailand is ranked in 26th place out of a total of 80 countries around the world that possess reef corals in their waters and its reef corals account for 0.75 percent of the coral reefs worldwide (Spalding et al., 2001). The coastline of the Andaman Sea and the west coast of the Gulf of Thailand are considered as two different oceanographic groups in Thailand, with distinct coral patterns and abundances. Within these groups there are three different types of reefs: coral communities with no true reef structure, developing fringing reefs and early formation fringing reefs. (Yeemin et al., 2001)

Thailand has more than 250 species of hard corals and more than 30 species of soft corals (Yeemin, 2005). These two general types of corals were used in this study:

- Hard corals (e.g. *Porites sp., Acropora sp., Echinopora sp., Montipora sp., Millepora*

sp., *Favites sp.*, etc);

- Soft corals (e.g. *Gorgonacea, Dendronephthya sp., Lobophytum sp., Capnella sp.*, etc).

Hard (scleractinian) corals, which create the substratum and structural complexity of coral reefs, are vulnerable to damage resulting from human recreational activities. This is due to their slow growing carbonate substructure, which is relatively brittle and their polyps which are easily crushed. Also some of the most contacted hard coral species by divers have massive morphologies which usually have a low capacity for recovery from damage (Hall, 1997). In contrast, when studying the diver impact on soft corals it appears that these flexible, fast growing corals are able to withstand disturbance better than hard corals (Tratalos and Austin, 2001). Due to their morphology, branching corals have higher susceptibility to diver contacts and break more frequently than other types of hard corals (Rouphael & Inglis, 1997).

In terms of coral reef status, Thailand represents a mixed pattern from 1994 to 2004 (see Fig. 2), with improvements in the health of some reefs and the deterioration of many others within the Gulf of Thailand, while the status of the Andaman Sea reefs remains relatively unchanged (Yeemin, 2005). Worachananant (2007) reported that recently there has been a rapid and steady growth in tourism and recreational activities, such as SCUBA diving, which leads to obvious increases in coral reef-related tourism activities and its associated problems, in the Gulf and the Andaman Sea.

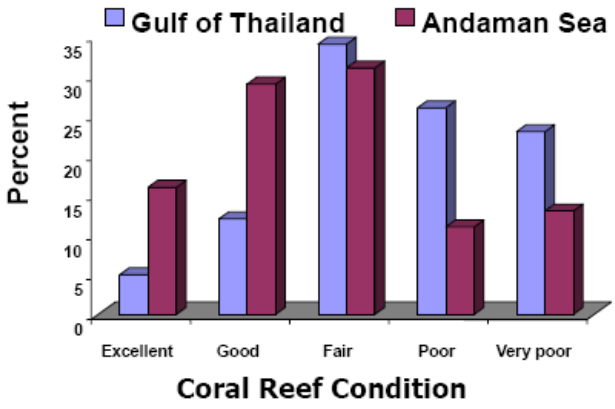


Figure 2 – Coral Reef Condition in Thailand (2002 – 2004). Source: Status of Coral Reefs in East Asian Seas Region 2004

According to Phongsuwan & Chansang (1992), in the Andaman Sea, the factors that affect the reefs may differ depending upon the location and in some places it may be a combination of effects. Outbreaks of *Acanthaster planci*, damage from sedimentation, tourism activity resulting in boat anchoring and eutrophication, along with an intense period of dynamite blasting, can be identified as the possible causes for the deterioration of those particular reefs. The impact of the 2004 tsunami, for example, was assessed in 174 sites covering the six affected provinces and resulted in 13% of the sites showing severe impact, 47% showing low to moderate impact and 40% had no visible impact. Apparently this damage is less significant than that resulting from major threats such as the ones produced by humans (Phongsuwan et al., 2006). A localized assessment of a National Park in the west coast (Mu Koh Surin) indicated that areas of high tsunami-related coral damage, correlated with areas that did not have substantial live hard coral cover prior to the tsunami and that the overall loss in coral cover as a result of the tsunami averaged at about 8% (Yeemin, 2005). Therefore, most of the coral reefs did not suffer serious damage and it is estimated that they will naturally recover within the 5 to 10 years, if effective management is implemented to reduce damage from human activities (Phongsuwan et al., 2006).

In the Gulf of Thailand, where part of the observations took place, according to the CPAD Newsletter (CPAD, 2006), the island of Koh Tao has experienced accelerating levels of development in its relatively short history of tourism. Observation from locals suggests that as recently as 10-15 years ago, this island had a much broader and richer biodiversity than at present. Yeemin et al. (2005) reported that Koh Tao had seen live coral coverage declining by 17% within a period of five years, mostly due to boat and anchor damage. In Koh Tao degradation of coral communities was caused by both natural and human factors, such as typhoons and the bleaching event of 1998 which resulted in high mortality rates for several coral species. As well as these natural disasters there have also been a variety of human impacts, such as land development, waste water discharges, trampling by tourists, divers and anchoring. A future challenge for Koh Tao is the implementation of integrated coastal management plans and effective tourism management, which requires more studies on carrying capacity and particularly on diver damage quantification.

1.5 Reef Tourism

Worldwide, 10% of world GDP is created by travel and tourism industry. In Thailand, according to the World Travel and Tourism Council (WTTC), the contribution of travel and tourism to the GDP is expected to rise from 14.1% (1,280.5 bn THB or 38.3 bn US$) in 2008 to 15.4% (THB 2,974.7 bn or US$ 78.7 bn) by 2018 (WTTC, 2008). Reef tourism is a major global industry in expansion and it is the major foreign exchange earner for the country. The relative increase in expendable capital from developed countries combined with the gradual increase in leisure time, the expansion of global tourism and the reduction of long haul flights from Europe and other countries, to tourist hubs such as Thailand have fuelled both the dive and snorkelling industries (TAT, 2005). Paradoxically, technical advances in equipment paired with an increased trend in environmental issues, nature conversation and outdoor pursuits have, according to Barker and Roberts (2004), resulted in an increase in the popularity of coral reef recreation and in particular in SCUBA diving. More than 12 million visitors from around the world, travel to Thailand´s 26 marine parks (which cover 50% of its reefs, Main and Dearden, 2007) each year (TAT, 2006). One of the main reasons for this influx of visitors to Thailand specifically is the diversity of its marine life, including a rich abundance of soft and hard corals and reef and pelagic fish. Dive tourism in Thailand has rapidly increased by more than twenty times from 25,000 divers in 1985 (TAT, 2008). Thailand now welcomes over 550,000 dive tourists each year and is home to over 80,000 certified divers of its own. The island of Phuket for example is a main center for the diving industry in Thailand and in 2000 there were over 85 dive companies operating through the Andaman Sea (Bennett, 2002).

Thailand was the country of selection for this study due to its high popularity among worldwide SCUBA divers, the increasing growth of marine recreational tourism (Worachananant, 2007) and the recent availability and implementation of a pioneer environmental programme named Greenfins. Therefore, if tourism is well planned, and is appropriate to local circumstances, it can do much for the sustainable development of coastal areas in Thailand. Tourists are attracted to pristine seas, so there is a strong incentive to manage the environment properly (GESAMP, 2001).

1.6 The Environmental Programme "Greenfins"

According to IYOR 2008, there is an urgent global need to increase the awareness and understanding of coral reefs, and to further conserve and manage these valuable environment and related ecosystems.

In response to the increased threats to coral reefs, in 2004, the reef conservation programme Greenfins was implemented in three countries: Thailand, Indonesia and the Philippines. Greenfins is an initiative of the United Nations Environmental Programme (UNEP) and the Coordinating Body on the Seas of East Asia (COBSEA). In Thailand it was implemented by the Phuket Marine Biological Center (PMBC) and the Department of Marine and Coastal Resources (DMCR).

The main objective of the Greenfins programme is to protect and conserve the coral reefs. It aims to promote public awareness through the creation of a network of environmental friendly dive operators that adopt sustainable tourism practices in coral reef areas, while simultaneously promoting the monitoring of coral reefs (Greenfins, 2007). The programme was officially launched in Phuket, during the Workshop of 30th May 2007. At the present time the Greenfins programme is running well in two of the initial three countries and in both Thailand and Philippines, it is now well established. Greenfins still needs to be fully implemented in Indonesia. In 2007, Greenfins had registered 77 member dive operators (mostly foreign) and more than 200 individual members (mostly locals) distributed in Thailand.

The Greenfins programme provides certificates to dive operators according to a set of environmentally friendly guidelines. Initially the dive operators (represented by the managers and staff) are introduced to the programme with a formal presentation and supplied with a full package of materials from the programme, including a Code of Conduct (see Appendix) to which they agree to obey. At the dive operator's discretion a full training in ReefWatch, a reef survey technique adopted by the programme is usually provided. Other trainings are also provided upon request or recommendation, such as presentations on the biology of the reef and environmental education, the construction of mooring buoys and dive site and beach clean ups.

To assure that the affiliated dive operators promote and follow the Greenfins Code of Conduct, network leader assessments are made in each shop, vessels and dive

operations every year. The procedure assesses some of the issues previously mentioned. For example, whether or not the dive operator promotes a no-touch policy to every diver, amongst other environmental recommendations. Those who promote the practices and have good results retain their membership and can even achieve a certificate of excellence. This has the additional benefit of providing reassurance to potential environmentally aware customers. The results of the assessments are reported yearly to the UNEP and released for public consultation.

Anecdotal evidence suggests that Greenfins certified dive operators have a different attitude towards their customers and employees regarding their responsibility towards teaching diving and guiding recreational divers. Amongst others, normal procedures for certified dive operators includes promoting environmental awareness, emphasising the importance of good buoyancy control, a no touch policy and general training on the biology of coral reefs to their staff. These procedures appear to influence the way the dive staff interact with the clients, raising their awareness for the environment and increasing their respect for the sea. It cannot be discounted that an environmental friendly centre (namely a Greenfins member) may attract a particular kind of public who is already more aware, concerned of environmental issues and motivated to reduce their impacts on the reef. For some of the Greenfins members, when registering for the dive trip, either inside the dive centre or via the internet, many clients are asked to fill out a questionnaire which includes questions about the client's dive history and a Greenfins code of conduct for review. Environmental and reef ecology posters are displayed around the dive centre and other materials are very accessible to the customers.

1.7 Carrying Capacity and Future Perspectives

Internationally the carrying capacity of coral reefs has been determined to be around 5000 per site per year (Harriot, 2002). In 2002, following an experiment in the Red Sea, Zakai and Chadwick-Furman proposed a carrying capacity of 5000-6000 dives per site per year, confirming the findings of Harriot et al. (1997) in Australia, Hawkins and Roberts (1997) in Egypt, Hawkins et al. (1999) in the Caribbean and Schleyer and Tomalin (2000) in South Africa. Carrying capacity is dependent on the amount of

environmental damage inflicted by divers, the capacity of the biological systems to recover from the damage and the acceptability to divers of crowded diving conditions (Salm, 1986).

According to Hawkins and Roberts (1997) educating divers on how to minimize the damage they cause underwater considerably reduces impacts, therefore raising the carrying capacity of an area. Recent studies have shown that carrying capacity as a means to quantify damage in coral reefs is more complex than it appeared. This is because it is based on the assumption that the effects of individuals are relatively similar and can be averaged over large homogeneous groupings, however, individual divers may vary greatly in their behaviour and in the amount of damage that they cause (Talge, 1990; Roberts and Harriot, 1995; Rouphael and Inglis, 1995; Harriot et al., 1997; Medio et al., 1997; Hawkins & Roberts, 1997).

Carrying capacity also varies according to site characteristics and wise management will incorporate monitoring of damage levels to keep site use within sustainable intensities. Therefore the conservation of these sensitive environments may be more effectively facilitated, if dive operators and dive guides are able to identify potential situations and provide divers with cautionary pre-dive briefings (Medio et al., 1997), targeting and emphasising environmental friendly diving practices such as those recommended by the Greenfins´ Code of Conduct. Such non-regulatory measures may provide a rewarding positive result in the global management of the coral reefs. Therefore, scientists, managers, policy-makers and stakeholders must work together effectively if the seas and coasts are to be protected and developed, and if their resources are to be used sustainably (GESAMP, 2001).

1.8 Literature Review on Diver's Influencing Characteristics

Some studies (Rouphael and Inglis, 2001; Liew, 2001; Uyarra & Côté, 2007) analysed the differences in damage produced by males and females. Some of those studies showed that males cause more damage than females and that may be because male divers are more likely to ignore pre-dive instructions on safety and environmentally benign behaviour than female divers (Vredenburgh and Cohen, 1993). However, recently in Thailand, Worachananant (2007) reported exactly the contrary, having

females producing more contacts with the corals and causing more damage than males.

Photographers are considered by many authors (Rouphael & Inglis, 2001; Worachananant, 2007; Barker & Roberts 2004; Medio et al. 1997) as some of the worst offenders to the coral reefs, damaging more corals due to the manipulation of photography equipment, the proximal activity to the reef and the deliberate contact with the marine organisms when taking a picture.

One of the most influencing characteristics in damage behaviours is diving experience, based on the number of logged dives, since it is generally recognized that divers with more dives usually have more buoyancy control, hence less interactions with the corals. Some authors (Worachananant, 2007; Barker & Roberts, 2004) studied the effect of this diving experience on the damage produced on the reef and in general concluded that less experienced divers produce more contacts with the coral reef. In general, regarding the diver's certification, it appears that there is no important relation with damage inflicted to the corals (Harriot et al. 1997; Barker & Roberts, 2004).

Current effect was studied by Barker and Roberts (2004) and Thompson (2004), but both studies had no significant results, and it appears that current may have no effect on the diver damage. Nevertheless, the presence of different levels of current produces higher stress on the dives and may influence the damage behaviour.

Barker and Roberts (2004) results appear to indicate that dive companies need to ensure that dive guides brief divers accordingly and with an environmental approach, but most importantly that the guides actually intervene when they see divers damaging the reef. Barker & Roberts also recommend that dive groups should be small enough to ensure that dive guides can supervise all members of the group effectively. Although the study provided no ideal number, interviews with dive leaders and personal experience could define a 'small group' as three or less divers.

A study by Medio et al (1997) in Egypt, illustrated how educational tools such as the environmental briefings may be used to reduce rates of damage to living corals, and they concluded that diver behaviour may be influenced by those tools. Studies from Davis and Tisdell (1995), Plathong et al. (2000) and Medio et al. (1997) exploring the effects of environmental education concluded that increased diver education on reef damage resulted in a lower incidence of physical damage to the reef during diving or snorkelling. Other researchers (Barker & Roberts, 2004; Kenchington, 1993; Salm

1986; Tilmant, 1987; Worachananant, 2007) emphasised the importance of public awareness and active participation (such as the training of dive staff) in environmental programmes, especially for those involved in the tourism industry. However in 1996, according to a study by Medio, in which 100 questionnaires were sent to marine parks and reserves world-wide, less than 25% had implemented diver environmental awareness programmes. In recent years, according to PADI (2008) the affiliation and participation in environmental programmes such as Project AWARE continues to increase worldwide.

Many previous studies (Barker & Roberts, 2004; Rouphael & Inglis, 1997; Hawkins et al., 1999; Zakai & Chadwick-Furman, 2001; Medio et al., 1997; Uyarra and Côté, 2007; Liew et al., 2001; Harriot et al, 1997; Walters & Samways, 2001; Worachananant, 2007) have examined the effects of SCUBA diving and have explored the relationship of some of the mentioned variables to coral damage among organized dive operations run by random dive centres. However, such studies did not include a reference to particular affiliations with reef conservation programmes or a specific environmental mandate. In fact, there is a lack of data regarding the relationship between SCUBA divers and coral damage when diving with trips organised by environmental friendly dive centres.

In order to rectify this lack of data, the following study proposes to observe divers from environmental friendly dive operators in the Andaman Sea and the Gulf of Thailand, and where possible, compare findings with other previously mentioned studies. The observations were made on dive operators affiliated and certified with the Greenfins programme.

1.9 Research Questions

This study investigates the following:

- If SCUBA divers from dive operators affiliated with Greenfins cause on average, less damage than non-Greenfins SCUBA divers.
- If the factors: gender, age, underwater photography, number of logged dives (experience level), diver certification, environmental awareness level, knowledge of Greenfins and pre-dive environmental briefing, reef topography, current and dive group size are influencing factors on the divers behaviours.
- Whether these variables influence the contact rate and the number of divers contacting with the total substrate or who damaged the corals.
- Whether some combination of these variables could be used in order to model the amount of potential damage which certain diver characteristics could cause to the coral reefs.
- Checking for any differences in the average number of contacts between three time periods of the dive.
- Comparing the two sample sets, the Gulf of Thailand and the Andaman Sea in terms of average diver damage rates.
- Identify any relationship or differences in damaging contacts and contact rates by the independent variables *within* the two sample sets, the Gulf of Thailand and the Andaman Sea.

2 Methodology

2.1 Study Site

Using the reef conservation programme Greenfins as background, permission was obtained from 22 dive operators members (see Appendix), based on Koh Phuket, Koh Lanta, Koh Tao and Kao Lak (Similan), Thailand (see Fig. 3), to accompany divers on their daily dive trips as an observer.

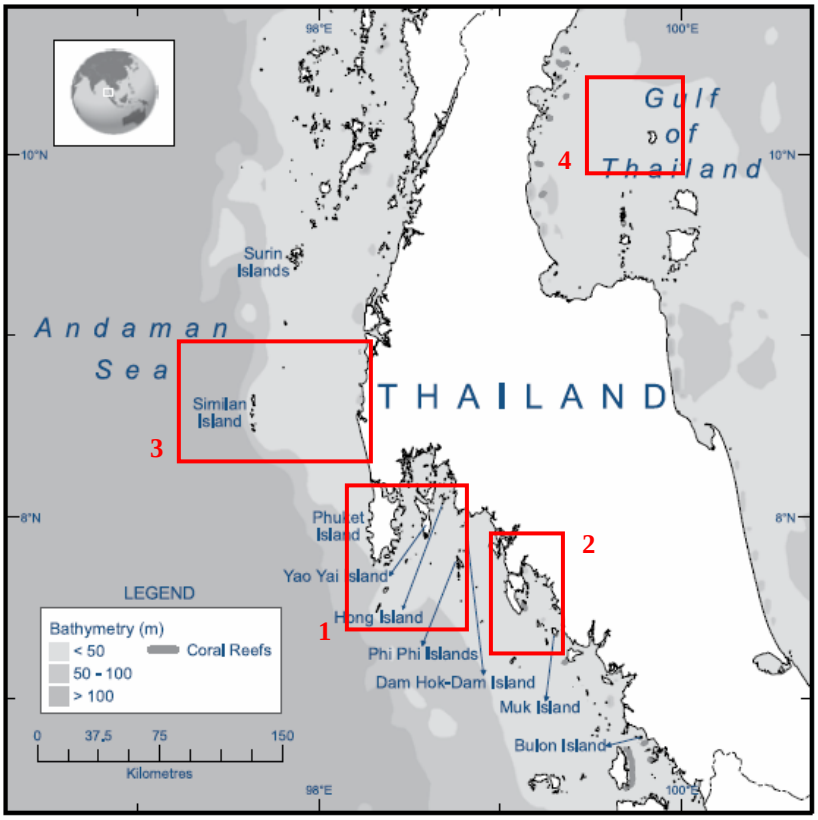


Figure 3 – Map of Thailand showing both Andaman Sea and Gulf of Thailand. Red Boxes are the areas where the observations took place: 1- Phuket and Koh Phi-Phi Group; 2- Koh Lanta Group; 3- Khao Lak (Similan) Group; 4- Koh Tao Group. Adapted from Status of Coral Reefs in Tsunami affected countries: 2005

The dive sites used for this study were as follows:

Table 1 **– Study Dive Site Names and Geographical Coordinates**

Andaman Sea	Phuket and Koh Phi-Phi	Koh Doc Mai	N07º47' E98º31'
		Koh Bida Nok	N07º39' E98º45'
		Koh Bida Nai	N07º39' E98º46'
		Koh Racha Noi (South Tip)	N07º29' E98º19'
		Koh Racha Noi (Maritta Rock)	N07º29' E98º19'
		Koh Racha Yai	N07º36' E98º21'
		Shark Point	N07º47' E98º38'
		Anemone Reef	N07º48' E98º38'
	Koh Lanta	Koh Ha (Lagoon)	N07º25' E98º53'
		Koh Ha (Cave)	N07º25' E98º53'
		Koh Ha 5 (Secret Garden)	N07º25' E98º53'
		Koh Ha 1	N07º25' E98º53'
		Koh Ha Yai	N07º25' E98º53'
	Similan	Anita's Reef	N08º34' E97º38'
		East Eden	N08º35' E97º38'
		Stonehenge	N08º34' E97º37'
		Elephant's Head	N08º37' E97º38'
Gulf of Thailand	Koh Tao	Twins	N10°07' E99°48'
		White Rock	N10º06' E99º48'
		Ao Leuk	N10º04' E99º50'
		Chumpon Pinnacle	N10º10' E99º46'
		Southwest Pinnacle	N09°59' E99°46'
		Shark Island	N10º03' E99º50'
		Japanese Gardens	N10°07' E99°48'
		Red Rock	N10°07' E99°48'
		Mango Bay	N10º07' E99º50'
		Green Rock	N10º07' E99º48'

2.2 Data Gathering

Data was collected on scuba divers and dive operations during 11 months spread over two major periods. The first period was from January 2007 to July 2007 and the second period from October 2007 to November 2007. Both periods were considered high season for the diving industry at each particular area of study. Nevertheless, dates were imposed by a matter of logistics and availability of the dive operators. During this period, the behaviour of 155 guided divers (n=155) was studied during 30 minute observations per diver. The divers were observed over 27 dive sites, at 0–30 m depth, located on the Andaman Sea and the Gulf of Thailand (Fig. 3).

The total number of divers on the boats varied from one to forty, but the divers were grouped in smaller groups of one to nine divers and assigned with a dive leader (i.e. Divemaster or Instructor). Stratified random selection was used to decide which groups and which divers were to be observed before they entered the water, aiming for a representative sample of chosen sub-groups. Some of those included visible detectable characteristics such as gender, age and whether the diver was an underwater photographer or not. On each sample dive used for the study, between one and three divers were discretely observed from a distance of 3–5 m underwater, depending upon visibility conditions. To keep the anonymity of the observer and prevent any change in behaviour by the divers, the dive staff were asked to treat the observer as a normal guest. If divers asked about the observer's work, they were informed that the observer was collecting general data on the reef's health.

Behavioural observations started from the time divers had descended and began adjusting their buoyancy or in the case of observations on student divers, the observations started as soon as they finished their skills practice and began adjusting their buoyancy for the dive. All of the observations lasted for the duration of 30 minutes. The observation times were divided in three 10 minute periods since the start of the dive. Each contact was then recorded in a pre-prepared slate, according to the time of observation during the dive (i.e. first, second or third 10 minute period of the dive). This adopted approach allowed the analysis of the differences in number of contacts, depending on the time of the dive, since it appears that more contacts may occur during the first period of the dive, when divers drop down over the reef and adjust

their buoyancy. Profiles of the dive at each site varied according to the reef topography. All divers concluded their dives sometime after the end of the 30 minute period.

In terms of contact with the reef the distinctions between diver behaviours were defined as: source of contact (i.e. body contact, fin contact or equipment contact); the effect of contact (i.e. breakage, bump or raising of sediments). The type of benthic substrata contacted was also recorded as one of four categories: hard corals, soft corals, bare substratum (e.g. rock, sand, dead coral) and other living substrata. This last category included other invertebrates such as sea anemones, sea cucumbers, giant clams and certain living organisms that could not be included in the other categories. When the contact was with sandy substrate and if sediment was kicked up increasing the risk of sedimentation landing on nearby corals, this would be considered as a contact with sand resulting in sediment re-suspension.

For further elaboration, either contacts with the living corals or re-suspension of sediment over them were considered as the variable: contacts with damage. Those contacts plus any contacts with bare substratum and other non-coral living benthos were considered as the variable: total contacts with substrate. The type of contact and damage observed was also classified as voluntary if the contact was seen as an intentional act of the diver or as involuntary if it was an unintentional act. Prior to entering the water at each dive site, the dive leader gave a briefing containing a general description of the dive site, information about the planned dive profile and safety rules. In some of the cases recorded, the dive leader had an environmental friendly approach, explaining briefly about the biodiversity and fragility of the coral reef system, and reminded the divers not to touch the substrate, not to remove or collect anything underwater and to remember to control their buoyancies and fins. Immediately after the end of each observation dive, each diver was requested to answer a questionnaire relating to their diving certification, experience and other personal information (see Appendix). Right after delivering back the questionnaires, the divers were interviewed personally to confirm the answers. Also, three questions were used to provide quantification for the variable environmental awareness level. The divers were asked whether or not they were affiliated with an environmental organization, whether they had any preference for environmental diving centres over non-environmental ones and if they read any marine life magazines. Any diver who answered with more than one positive response to these three questions was considered as possessing a high level of environmental awareness.

Any diver who only answered with one or no positive answers was considered as having a low level of environmental awareness.

According to the number of previously logged dives, divers were categorized into three different groups: a novice diver as having less than 50 dives; an intermediate diver as having between 51 to 100 dives; and an experienced diver as someone with more than 100 dives. The certification levels were classified according to the international dive standards: a student diver (i.e. any diver in training or non-certified diver with an instructor); basic level diver (open water or equivalent certification); an advanced level diver (i.e. at least rescue diver or equivalent certification); and instructor diver (i.e. any diver with instructor certification, but not the leader of the dive).

Additionally at each dive site, data on patterns of diver activity and usage (e.g. number of dive boats over each dive site) were also collected, to attempt to estimate roughly the number of divers and understand the magnitude of the problem.

2.3 Biological Characteristics of the Sites

All the dive sites were characterized according to dive site conditions: temperature, current, visibility and reef topography. General physical conditions present during the dives were measured qualitatively and quantitatively underwater by the observer. The measured variables were: visibility and current, (which were measured using an estimate based on observer's experience), the temperature, maximum depth, average depth and total dive time (all of which were measured using a dive computer ®Suunto Mosquito). The variable current was measured as weak, moderate, strong or none.

The description of the topography of the dive sites took into account the categorization as defined by Rouphael and Inglis (1997), but ultimately it was adapted from Reefwatch (Greenfins) in order to achieve a better relation with the morphology of Thai reefs, as shown below and in Fig. 4:

Slope – fringing reef sloping gently;

Garden – sandy bottom with spread patches of rock boulders and corals;

Pinnacle – submerged pillar or pillars standing alone and rising from a sandy bottom or coral garden with more than 100 m of open water between the pillars and the reef;

Wall – vertical or near vertical drop-off extending from the surface of water to the bottom of the dive site with no discernible slope;

Varied – for some combination of the other topographies.

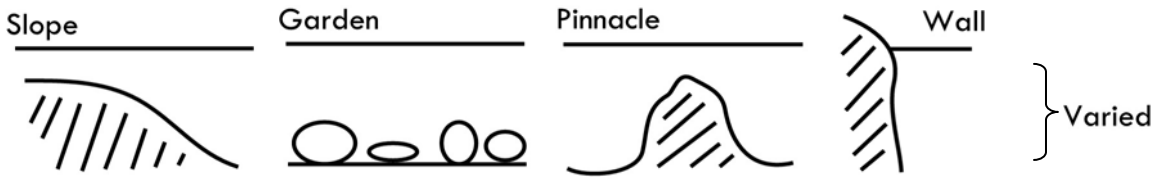


Figure 4 – Schematic interpretation of the reef topographies used in this study (modified from Greenfins, 2007)

2.4 Statistical Analysis

Statistical analysis of the data was performed using the SPSS program, version 16.0. An alpha level of 0.05 was used for all statistical tests performed on the sample.

Several descriptive statistics were performed on all variables to synthesize and report the sample. Due to the high non-normality of the variable distributions and the categorical nature of most variables, non-parametric statistical tests were performed to test the significance of the results. Mann-Whitney tests and Kruskal-Wallis tests were performed to identify differences in the average contact rate with the substrate and with damage between the independent variables. Chi-square tests (χ^2) were used to find relationships between the categorical independent variables and the occurrence of damage contact, determining if the number of divers who damaged the reef varied among the groups of the categorical independent variables and in which way. Whenever the asymptotic method for significance was not adequate due to violation of the assumptions of the Chi-square (i.e. more than 20% of the categories not having a minimum expected frequency of 5), exact tests such as the Fisher's exact test were used. Any correlation between age, number of logged dives and the number of divers in the group with the contact rate of damage was obtained using Spearman's rank correlation

coefficient. Friedman's test was used to check for differences in the average of contact rate in the three distinct 10 minutes periods of the dive.

Logistic regression modelling was used to predict the binary outcome of damage (damage or no damage) to the coral reef according to possible combinations of eleven independent variables. The independent variables which were tested were: gender, age, photographer, number of logged dives, diving certification, current level, reef topography, number of divers in the group, environmental awareness level, previous knowledge of Greenfins and whether an environmental briefing was given or not. The variables: age, number of logged dives and number of divers in the group were the non-categorical variables, and all the other variables were categorical. Categorical variables were coded using a deviation contrast (i.e. to examine how influential each category of each variable was to the average of all categories) and a forward stepwise method was used with a significant level of α=0.05. Likelihood ratio is associated with that method and it re-runs the model excluding the non-significant variable combinations.

3 Results

During the study period, 66 dives were made at 27 dive sites in the Andaman Sea and the Gulf of Thailand. 155 divers were observed underwater throughout their dives and a total of 430 contacts with the substrate were recorded. 306 of the contacts were considered as damaging to the reef and were made against living reef corals (i.e. hard and soft corals) or re-suspended sediment over them, while the remaining 124 contacts were produced with other benthic organisms, rock substrate or dead coral.

From the total 155 observed divers, 88 (56.8%) contacted the substrate at least one time during the dive, with a mean contact rate of 2.77±0.64 (mean±95%CI) and a median of one contact per 30 minutes of the dive. Of those divers, 78 (88.6%) made contact with some forms of live coral or re-suspended sediment over the corals. For this study, both of these behaviours, contacts (i.e. bumps or breaks) with living corals and the re-suspension of sediment over them, were considered as damaging contacts and were what was mostly analysed. Fig. 5 shows both distributions, the one from all contacts with the substrate and the other from the contacts that were considered as damaging.

Distributions were highly non-normal (skewed to the right) with a minimum value of zero. The substrate contact distribution presented a maximum of 18 contacts. 67 (43.2%) divers did not contact the substrate at all. For the distribution of the damaging contacts the maximum was also 18 contacts, while 77 divers (49.7% of the sample) made no damaging contacts with the reef. The mean was 1.97±0.49 (95% CI) damaging contacts per 30 minutes of the dive and the median was one contact.

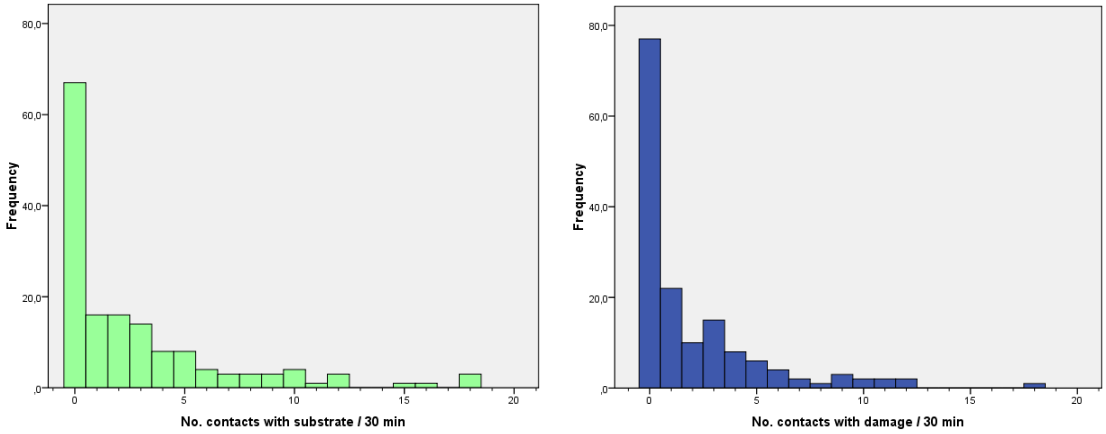


Figure 5 – Frequencies of divers (n=155) observed according to: number of contacts with the total substrate (green) and number of contacts considered as damaging (blue), during 30 minutes of their dives.

3.1 Contacts with Damage

3.1.1 Diver Personal Characteristics

Gender

In the total sample, 105 divers (67.7%) were males and 50 divers (32.3%) were females. A similar proportion of male divers and female divers contacted the reef with damage at least once during the 30 minute observation period of the dive. 53 (50.5%) of the male divers and 25 (50.0%) of the female divers contacted the reef with damage one or more times. When a Chi-square test was performed, it was found that gender and the occurrence or not of damage were not related (χ^2= 0.003, d.f.=1, p= 0.956).

Table 2 – Summary of effects for the total number of divers and diver/reef interactions recorded over the whole study period by diver personal characteristic variables: gender, age, class and photography.

		Contact with substrate		Contact with damage	
		No. Divers	%	No. Divers	%
Gender	M (n=105)	62	59.05	53	50.48
	F (n=50)	26	52.00	25	50.00
Age class	[<21] (n= 10)	7	70.00	6	49.52
	[21 - 50] (n= 128)	70	54.69	63	49.05
	[>50] (n= 17)	11	64.71	9	48.57
Photographer	No (n=130)	74	56.92	66	50.77
	Yes (n=25)	14	56.00	12	48.00

The number of contacts with damage per 30 minutes was not influenced by gender. Even though slight differences in the average number of contacts among female and male divers were visible in the sample (see Fig. 6), those differences were not great enough to exclude the possibility of random sampling variability. Therefore no significant difference was found between the number of contacts with damage / 30 minutes made by male divers in comparison to female divers (Mann-Whitney U test, p=0.734).

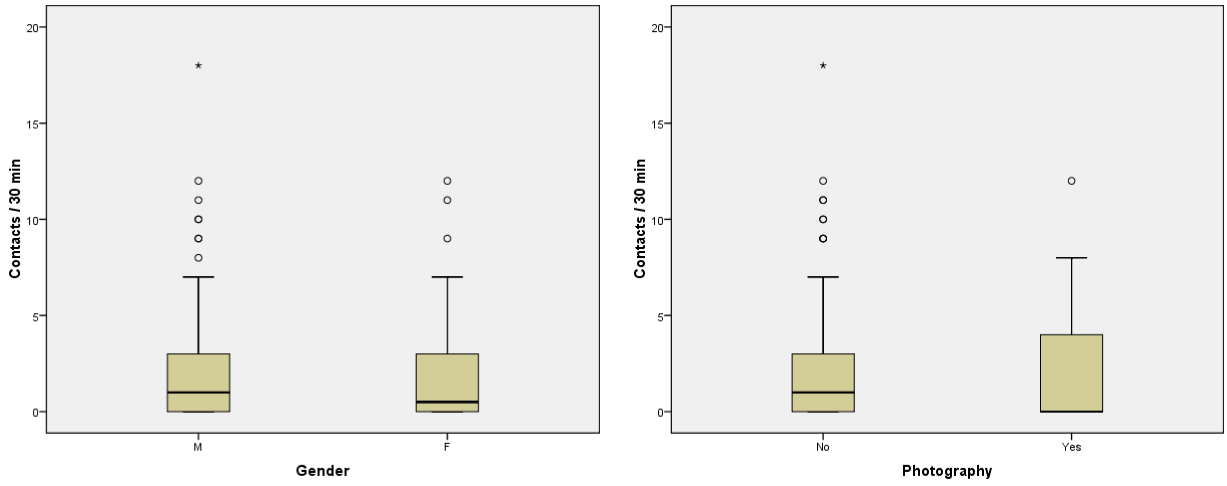


Figure 6 – Box-plot graphs of the diver characteristics variables: gender and photography, against number of contacts with damage to the reef per 30 minutes of the dive. Open circles represent outliers and asterisks represent extreme values.

Table 3 – Rates of damage per 30 minutes of the dive by the diver characteristics variables: gender, age class and photographer

		No. contacts with damage / 30 min					
		Total	Mean	S.E. of Mean	Minimum	Maximum	Median
Gender	M (n=105)	216	2.06	0.31	0	18	1.00
	F (n=50)	90	1.80	0.41	0	12	0.50
Age class	[<21] (n=10)	24	2.40	1.00	0	10	1.50
	[21 - 50] (n=128)	246	1.92	0.27	0	18	0.00
	[>50] (n=17)	36	2.12	0.76	0	11	1.00
Photographer	No (n=130)	248	1.91	0.27	0	18	1.00
	Yes (n=25)	58	2.32	0.64	0	12	0.00

Age

Age ranged from 15 to 76 years old, with a mean of 32.65±1.85 (95%CI) and a median of 30 years old. To test the relationship between age and the occurrence or not of damage contact, age was classified as those divers under the age of 21, divers aged between 21 and 50 and divers over the age of 50. Within the first classification of divers aged less than 21, six of those divers (60.0%) did some damage to the reef. The second classification had 63 divers (49.2%) producing damage contact and the third classification had nine divers (52.9%). This result did not show significance for a relationship between these two variables (Fisher's exact test χ^2=0.525, d.f.=2, p=0.858).

When the number of contacts with damage per 30 minutes was analysed against age (Fig. 7), no correlation was found (Spearman's rank correlation, r= -0.039, p=.629, n=155).

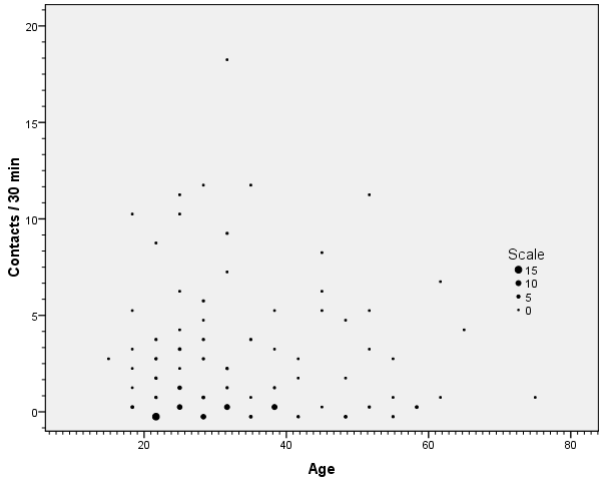


Figure 7 – Scatter plot of the diver characteristics variable: age, against number of contacts with damage per 30 minutes of the dive.

Photography

Twenty five (16.1%) divers were photographers using non-professional photography equipment (i.e. regular digital cameras with underwater housing), and this category included both male and female individuals. It is important to mention that no specialist photographers were amongst the sample, meaning that no divers would be using bulky and difficult to handle photography equipment.

Twelve divers (48.0%) engaged in photography activities produced damage to the reef, contrasting with 66 divers (50.8%) of the non-photographers who caused damage to the reef. This difference was not statistically significant (χ^2=0.064, d.f.=1, p=0.800).

Nevertheless, photographers had a higher mean of contacts [2.32±1.33 (95%CI)], but a lower median of zero than non-photographers, who had a mean of 1.91±0.53 (95%CI) contacts and a median of one contact. One explanation for this difference might be because some small group of individual photographers had a higher number of contacts, increasing the overall average mean of the group. But this difference between the rate of contact with damage made by non-photographer and photographer divers was not significant (Mann-Whitney U test, p=.692).

3.1.2 Diver History

Certification level

Basic level divers were the most surveyed group with a total of 113 divers (72.9%), 33 (21.3%) had advanced certification, 5 (3.2%) were student divers and 4 (2.6%) were instructors.

Table 4 - Summary of effects for the total number of divers and diver/reef interactions recorded over the whole study period by diver history variables: certification level and experience level.

		Contact with substrate		Contact with damage	
		No. Divers	%	No. Divers	%
Certification level	Student (n=5)	3	60.00	3	60.00
	Basic (n=113)	63	55.75	56	49.56
	Advanced (n=33)	19	57.58	17	51.52
	Instructor (n=4)	3	75.00	2	50.00
Experience level	Novice (n=101)	55	54.46	50	49.50
	Intermediate (n=21)	11	52.38	9	42.86
	Experienced (n=33)	22	66.67	19	57.58

56 (49.6%) of basic level divers damaged the reef. In contrast, 17 divers (51.5%) from the advanced level contacted the reef with damage. Three student divers (60.0%) and two instructors (50.0%) made damage contact with the reef at least once (see Table 4). A non-significant exact test resulted from these small differences (Fisher's Exact Test χ^2= 0.437, d.f.=3, p=1.00), indicating no relationship between the two variables.

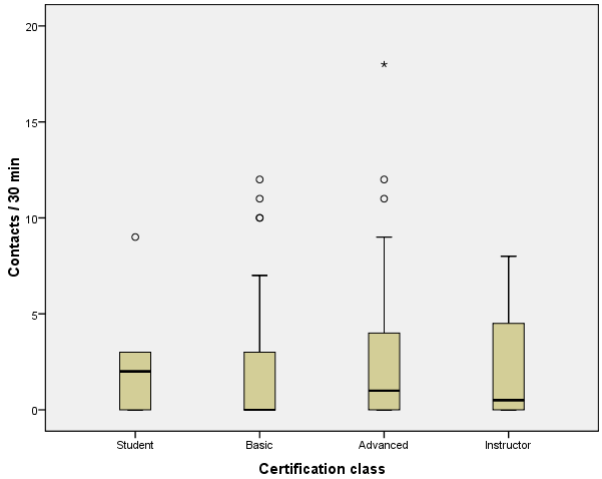


Figure 8 - Box-plots for diver history variable: certification class against number of contacts with damage per 30 minutes of the dive.

There was no difference between the number of contacts with damage in the four analysed certification levels (Kruskal-Wallis H, χ^2= 0.767, p=.858) (Fig. 8).

Table 5 – Rates of damage per 30 minutes of the dive by the diver history variables: Certification level and experience level

		Contacts with damage / 30 min					
		Total	Mean	S.E. of Mean	Minimum	Maximum	Median
Certification level	Student (n=5)	14	2.80	1.66	0	9	2.00
	Basic (n=113)	192	1.70	0.24	0	12	0.00
	Advanced (n=33)	91	2.76	0.77	0	18	1.00
	Instructor (n=4)	9	2.25	1.93	0	8	0.50
Experience level	Novice (n=101)	180	1.78	0.28	0	12	0.00
	Intermediate (n=21)	35	1.67	0.63	0	11	0.00
	Experienced (n=33)	91	2.76	0.68	0	18	1.00

Experience level (number of logged dives)

The SCUBA divers who were observed varied widely in experience. The number of dives completed until the time of observation varied from 2 to >1500, with a mean of 87.07±31.44 (95%CI), a median of 32 dives and a mode of 6 dives. Experience level was defined as the number of previous logged dives resulting in three categories:

Novice (less than 50 dives), Intermediate (50 to 99 dives) and Experienced (more than 100 dives). Most divers in the sample were novice divers (see Table 5) and from those 55 (54.5%) contacted the reef with damage. Eleven (52.4%) intermediate divers damaged the reef and in contrast 22 (66.7%) experienced divers also damaged the reef. It appears that more experienced divers were more prone to damage the coral reef. However, these differences were not significant when tested with a Chi-Square for identifying a relation with contacting the reef with damage or not (χ^2= 1.702, d.f.=2, p=0.427). Also, no correlation was found (Fig. 9) between the number of logged dives and the number of contacts with damage / 30 minutes (Spearman's rank correlation, r=0.05, p=.540, n=155).

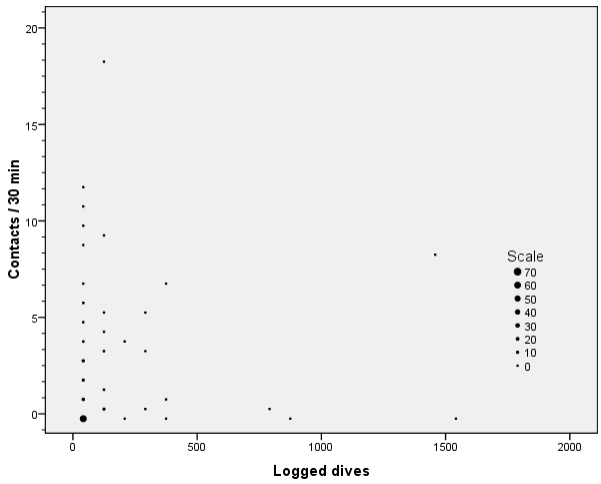


Figure 9 – Scatter-plot for diver history variable: number of logged dives, against number of contacts per 30 minutes of the dive.

3.1.3 Diver Environmental Characteristics

Environmental Awareness Level

Regarding the environmental awareness of divers, this qualitative variable resulted from the conjugation of three surveyed variables (see Methods and Materials) and has two groups: low level and high level. Subsequently, 110 (71.0%) of the divers were considered as having a low environmental awareness level. The others 45 (29.0%) were divers with a high level of environmental awareness. 56 (51.4%) of divers with a low

level of environmental awareness made some contact with damage to the reef. In contrast, 22 divers (47.8%) with a high level of environmental awareness caused damage to the reef. Nevertheless, this difference was not enough to be significant (χ^2=0.163, d.f.=1, p=0.686), hence no relationship was found between these variables. A mean of 2.19±0.62 (95%CI) and a median of one contact with damage were found for divers with a low level of environmental awareness, and a lower mean of 1.46±0.74 (95%CI) and a median of zero for divers with a high level of environmental awareness. However, when tested for significance, no differences were found between divers who had different levels of environmental awareness and the number of contacts with damage per 30 minutes (Mann-Whitney U test, p=.305).

Table 6 - Summary of effects for the total number of divers and diver/reef interactions recorded over the whole study period by environmental characteristics variables: Environmental awareness level, knowledge of Greenfins and existence of a pre-dive environmental briefing.

		Contact with substrate		Contact with damage	
		No. Divers	%	No. Divers	%
Environmental awareness level	Low (n=109)	60	55.05	56	51.38
	High (n=46)	28	60.87	22	47.83
Previous knowledge of Greenfins	No (n=114)	67	58.77	60	52.63
	Yes (n=41)	21	51.22	18	43.90
Pre-dive environmental briefing	No (n=73)	42	57.53	36	49.32
	Yes (n=82)	46	56.10	42	51.22

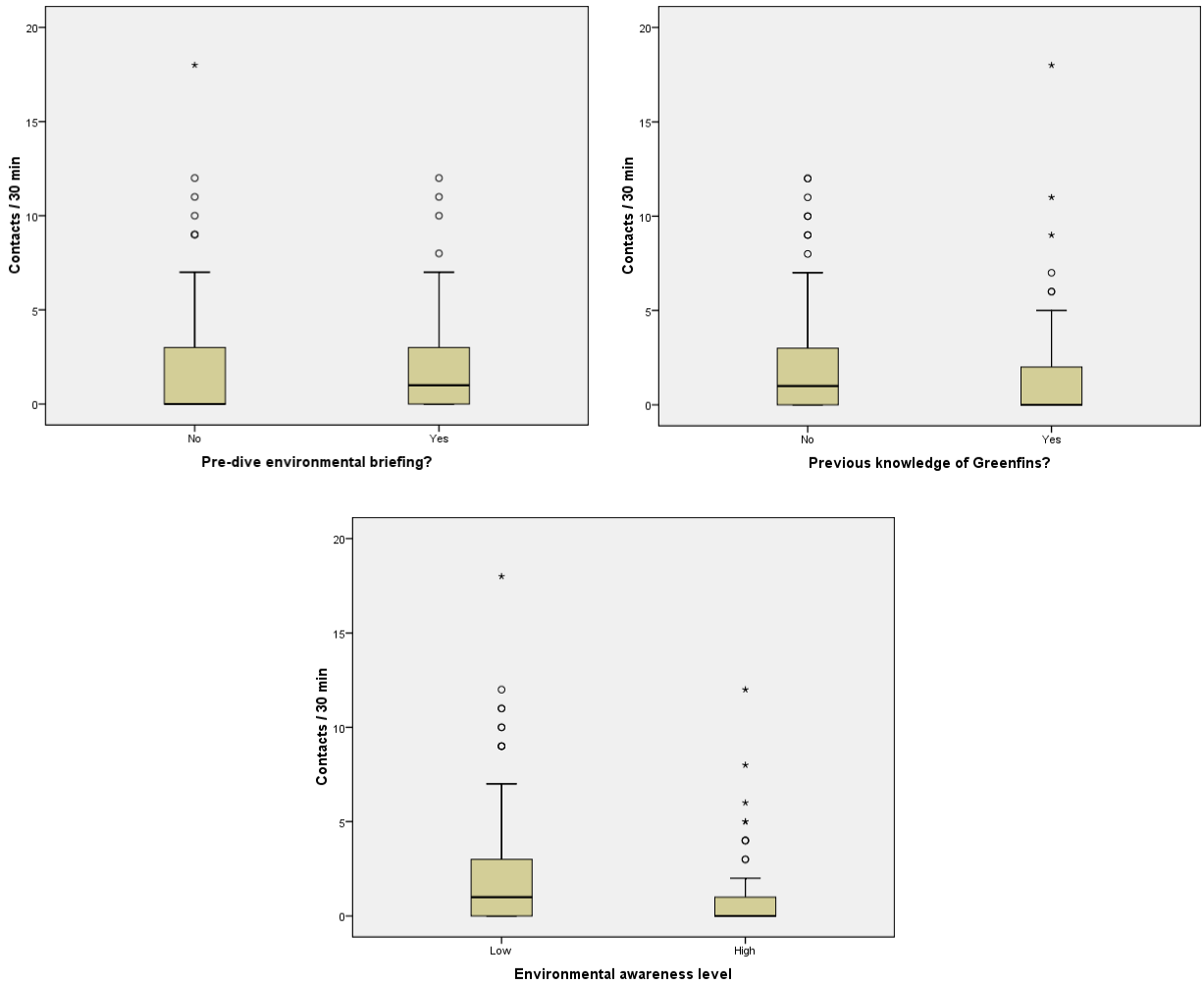


Figure 10 – Box-plots for the environmental background variables: Environmental awareness level, previous knowledge of Greenfins and pre-dive environmental briefing, against number of contacts with damage per 30 minutes of the dive.

Previous Knowledge of Greenfins

Some of the divers (n=41, 26.5% of the sample) had a priori knowledge of the existence and nature of the Greenfins programme and the respective affiliation of the chosen dive operator. 114 (73.5%) did not have any previous knowledge of Greenfins.

Although the amount of divers (n=18, 43.9%) who had previous knowledge of Greenfins and damaged the reef was lower than those who did not have any previous knowledge (n=60, 52.6%), no significant relationship was found (χ^2=0.919, d.f.=1, p=0.338) between the diver's previous knowledge of Greenfins and the occurrence of contact with damage to the reef (see Table 7).

Studying the difference between divers with previous knowledge of the Greenfins programme and divers with no previous knowledge, with the amount of contacts made by divers (Fig. 10), the results showed that those who had previous knowledge had a higher mean average of contacts [2.10±1.20 (95%CI)] than those without previous knowledge [1.93±0.52 (95%CI)]. However, the median of zero contacts was lower for divers who were introduced by the dive centre or who knew about the programme than for those with no knowledge (median=1). Within the global sample this result did not show any significant differences in the number of contacts with damage per 30 minutes (Mann-Whitney U test, p=.521).

Table 7 – Rates of damage per 30 minutes of the dive by the diver environmental characteristics variables: Environmental awareness level, knowledge of Greenfins and pre-dive environmental briefing

		No. contacts with damage / 30 min					
		Total	Mean	S.E. of Mean	Minimum	Maximum	Median
Environmental awareness level	Low (n=109)	239	2.19	0.32	0	18	1.00
	High (n=46)	67	1.46	0.37	0	12	0.00
Knowledge of Greenfins	No (n=114)	220	1.93	0.26	0	12	1.00
	Yes (n=41)	86	2.10	0.59	0	18	0.00
Pre-dive environmental briefing	No (n=73)	165	2.26	0.42	0	18	0.00
	Yes (n=82)	141	1.72	0.29	0	12	1.00

The amount of voluntary contacts with damage presented statistically significant differences regarding the possession of previous knowledge of Greenfins (Mann-Whitney U test, p=.024). In fact the mean rank of damage contacts is higher when the divers did not possess any knowledge of Greenfins. This suggests a possible link between knowledge of Greenfins and being more concerned about avoiding contact and damage with the reef.

Pre-dive Environmental Briefing

82 (52.9% of the sample) divers had received a pre-dive environmental briefing compared with 73 (47.1%) who did not. Unexpectedly, the group of divers who were

not delivered an environmental friendly briefing were found to have a lower percentage of divers who damaged the reef, accounting for 36 divers or 49.3%. On the other hand, 42 divers (51.2%) who did receive an environmental friendly briefing contacted the reef with damage at least once (Table 6). This difference was not statistically significant (χ^2=0.056, d.f.=1, p=.813).

The occurrence of a pre-dive environmental briefing or not did not result in significant difference in the number of contacts with damage per 30 minutes (Mann-Whitney U test, p=.731). In the sample the occurrence of a pre-dive environmental briefing had a slightly lower mean average of contacts but a higher median result [1.72±0.58 (95%CI); median=1] than the divers who did not receive an environmental briefing [2.26±0.83 (95%); median=0] (Table 7).

3.1.4 Dive Characteristics

Reef Topography

Most of the divers (n=59, 38.1%) dove in garden reef topographies during their dives. Reef slopes had a count of 43 (27.7%) of the diver observations. 22 (14.2%) of the divers were observed while diving in a varied reef topography during their dive. The less dived reef topographies were pinnacles and walls which accounted for 21 (13.5%) and 10 (6.5%) of the total observations respectively.

The dive sites with a topography of a pinnacle had less divers contacting with damage the reef (n= 4, 19%), along with walls which had 3 (30%) divers damaging the reef. Reef slopes and gardens had a greater proportion of divers damaging the reef, 25 (58.1%) and 32 (54.2%) respectively. When divers were diving on a varied topography, 14 (63.6%) damaged the reef (see Table 8). Those differences showed a significant relation between reef topography and the occurrence or not of damage contact (χ^2=12.841, d.f.= 4, p=0.011).

Table 8 - Summary of effects for the total number of divers and diver/reef interactions recorded over the whole study period by dive characteristics variables: reef topography, current and dive group size.

		Contact with substrate		Contact with damage	
		No. Divers	%	No. Divers	%
Reef Topography	Slope (n=43)	25	58.14	25	58.14
	Garden (n=59)	38	64.41	32	54.24
	Pinnacle (n=21)	7	33.33	4	19.05
	Wall (n=10)	4	40.00	3	30.00
	Varied (n=22)	14	63.64	14	63.64
Current	None (n=30)	18	60.00	17	56.67
	Weak (n=66)	33	50.00	30	45.45
	Moderate (n=33)	22	66.67	17	51.52
	Strong (n=26)	15	57.69	14	53.85
Dive group size	Small (n=45)	27	60.00	25	55.56
	Medium (n=105)	58	55.24	50	47.62
	Large (n=5)	3	60.00	3	60.00

Different reef topographies have also shown significant differences between the number of contacts with damage per 30 minutes (Kruskal-Wallis test, p=.016). When topographies were compared independently using pairwise statistical techniques, the number of contacts made when diving at a pinnacle was significantly lower than when diving at other topographies (Mann-Whitney U tests, $p<0.05$). The exception was when comparing with wall topography (Mann Whitney U, p= .457) (see Fig. 11 and Table 9).

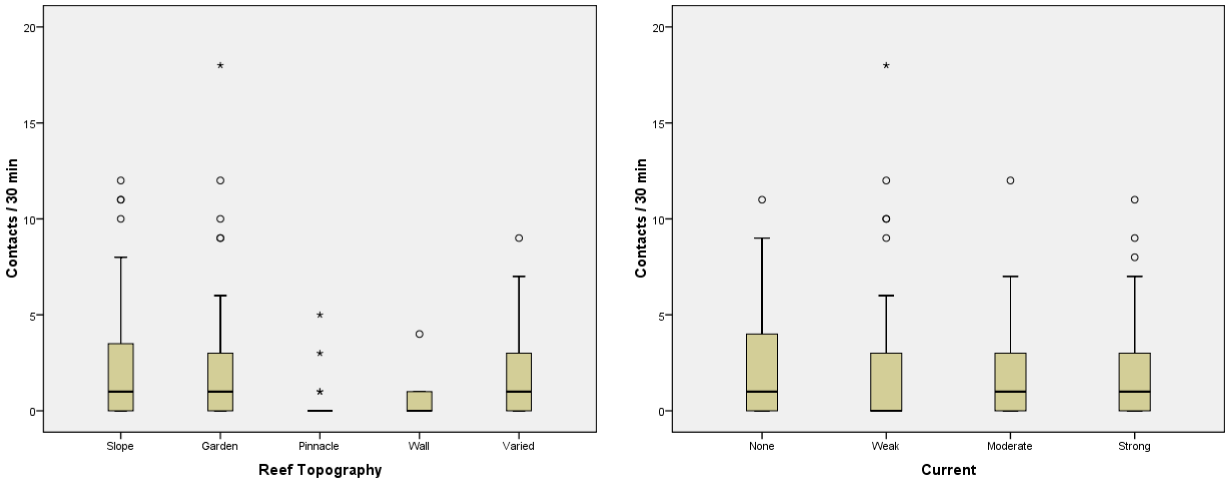


Figure 11 - Box-plots for the dive characteristics variables: reef topography, current and dive group size, against number of contacts with damage per 30 min of the dive.

Current

The current was weak during the majority of the diver observations (n=66, 42.6%). 33 (21.3%) divers were observed under moderate current and 26 (16.8%) under a strong current. 30 (19.4%) dove without current.

Dives without current resulted in 17 divers (56.7%) causing damage to the reef. Most divers dove in weak current (n=66) and from those, 30 (45.5%) damaged corals during their dive. Moderate and strong current dives had 17 (51.5%) and 14 divers (53.8%) causing damage to the reef, respectively. Regardless of these slight differences, including the lower number of divers damaging the reef under weak currents, this result was not statistically significant (χ^2=1.257, d.f.=3, p=0.739) and these variables appear not related (see Table 8).

With a mean of 2.19±1.37 (95%CI) and a median of one contacts per 30 min, dives under strong current resulted in the most damage, followed by dives without current which had a mean average of 2.07±1.06 (95%CI) and a median of one. The presence of a weak or a moderate current accounted for a mean of 1.98±0.84 (95%CI) and median of zero, and 1.70±0.95 (95%CI) and median of one, respectively. However, no significant differences were found between different levels of current and the number of contacts with damage per 30 min (Kruskal-Wallis test, p=.843) (see Fig. 11 and Table 9).

Dive Group Size

Divers were mostly observed while diving in groups of five (median and mode of 5) and a mean of 4.29±0.24 (95%CI). The maximum dive group size observed, excluding the dive guide, was nine divers and the minimum was one.

Categories were selected to classify the amount of divers in the group, with small groups accounting for one to three divers, medium sized groups with four to six divers and large groups with more than six. 29.0% (n=45) of the observations were conducted on small groups, 67.7% (n=105) were with medium groups and 3.2% (n=5) were with large groups. Observations of divers in small groups found that 25 (55.6%) of those

contacted the reef with damage. Observations of divers in medium groups found that 50 (47.6%) contacted the reef with damage and three divers (60%) from large groups also contacted the reef with damage (see Table 8). As a result, there was no relation between the dive group size and the event of contacting the reef with damage (Fisher's Exact Test χ^2=1.052, d.f.=2, p=0.636). This may be related with the smaller sample of observations made on large groups. There was no correlation between the number of divers in the group and the rate of contacts with damage (Spearman's rank correlation, r= -.027, p=.737, n=155) (Fig. 12).

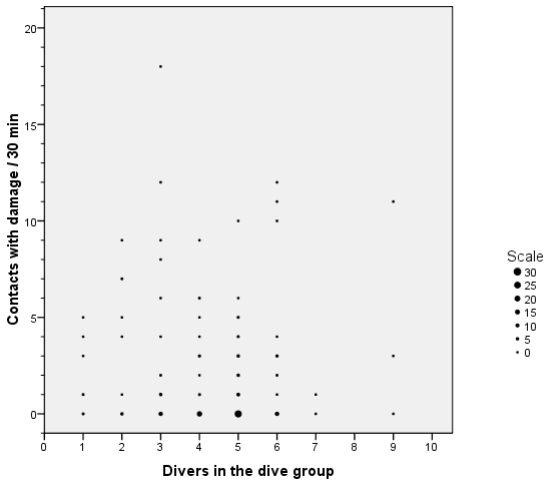


Figure 12 – Scatter-plot for the variable dive group size against number of contacts with damage per 30 min of the dive

Table 9 – Rates of damage per 30 minutes of the dive by the dive characteristics variables: Reef topography, current and dive group size

		No. contacts with damage / 30 min					
		Total	Mean	S.E. of Mean	Minimum	Maximum	Median
Reef Topography	Slope (n=43)	112	2.60	0.52	0	12	1.00
	Garden (n=59)	126	2.14	0.45	0	18	1.00
	Pinnacle (n=21)	10	0.48	0.27	0	5	0.00
	Wall (n=10)	12	1.20	0.76	0	7	0.00
	Varied (n=22)	46	2.09	0.55	0	9	1.00
Current	None (n=30)	62	2.07	0.52	0	11	1.00
	Weak (n=66)	131	1.98	0.42	0	18	0.00
	Moderate (n=33)	56	1.70	0.47	0	12	1.00
	Strong (n=26)	57	2.19	0.62	0	11	1.00
Dive group size	Small (n=45)	114	2.53	0.58	0	18	1.00
	Medium (n=105)	177	1.69	0.25	0	12	0.00
	Large (n=5)	15	3.00	2.07	0	11	1.00

3.2 Contacts with the Total Substrate

Parallel to these results, the data collected on total contacts with the substrate was also analysed statistically in order to attempt to detect any relationship between the independent variables and the occurrence or not of contact with the total substrate. Differences in contact rates within the independent variables were also analysed. None of these analyses resulted in significance at the p=0.05 level. For example, reef topography did not show a significant result for differences in damage contact rates (Kruskal-Wallis test, p=0.070), but it suggests that the significance of the results regarding damage contacts may be related with differences in abundance and diversity of corals on certain sampled topographies, rather than due uniquely to the shape of the reef itself. Although these differences may not have been significant they were important to report. In fact, when examining the contacts with the substrate, 64.8% of the body contacts were voluntary, contrasting with only 38.3% of body contacts that were voluntary in terms of damaging contacts. This suggests that some parts of the reef were and can be contacted without apparent prejudice to the corals

3.3 Predicting Damage Contact (logistic regression)

Logistic regression was used to check for the existence of predictor variables for the occurrence of damage contact to the reefs. After the model was re-run by forward stepwise method, the final model was re-drawn and the results are presented in Table 10. Again, the only variable that was found to have a significant relationship with damaging the reef was reef topography. The overall accuracy of the model was moderately good and explained for 61.3% of the variation. Therefore reef topography may be used to predict for the population of divers who would damage the reef and who dived with Greenfins dive operators, in Thailand. The topography pinnacle could be used to predict for the population in terms of odds of contacting with damage to the reef. When diving at pinnacles compared to other reef topographies the odds of contact with damage to the reef decreases by 0.30. In contrast, when diving on a reef which has a mix of different topographies, defined in this study as "varied", the odds of contact with damage to the reef when compared with other topographies, increases 2.24 times.

3.4 Differences between Distinct Periods of the Dive

As predicted, the first 10 minutes period of the dive showed more contacts with damage [mean of 0.75±0.22 (95%CI)] than the following periods of the dive. The second period had a mean of 0.66±0.20 (95%CI) and the third period had a mean of 0.57±0.25 (95%CI). However all medians were equal with a value of zero. Analysis was made on the mean ranks. The first period had a mean rank of 2.07, the second had a mean rank of 2.06 and the third a mean rank of 1.87. The difference of the mean rank contacts with damage was significant for the three 10 minute periods (Friedman test, $p=0.009$).

Wilcoxon tests were performed *a posteriori* on the mean ranks, between the three different periods independently and resulted in significant difference between the first and the third periods ($p=0.033$), but not between the first and the second ($p=0.679$) or the second and the third ($p=0.112$).

Table 10 – Logistic regression results for relationship between the independent variables and the occurrence of damage contact to the reef

Model if Term Removed				
Variable	Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1 Reef_topog	-107,435	13,527	4	,009

Variables in the equation	B	S.E.	Wald	df	Sig.	Exp(B)
Reef Topography			11,283	4	0024	
Reef_topog(1) "Garden"	0,417	0,295	2,005	1	0,157	1,518
Reef_topog(2) "Pinnacle"	-1,200	0,481	6,228	1	0,013	,301
Reef_topog(3) "Wall"	-0,600	0,576	1,086	1	0,297	,549
Reef_topog(4) "Varied"	0,807	0,405	3,978	1	0,046	2,241
Constant	-0,247	0,214	1,334	1	0,248	,781

Variables not in the equation	Score	df	Sig.
Gender (1)	0,271	1	0,602
Age	0,177	1	0,674
Photography (1)	0,359	1	0,549
Certification Level	0,146	3	0,986
cert_l(1)	0,029	1	0,864
cert_l(2)	0,046	1	0,830
cert_l(3)	0,075	1	0,785
Number of logged dives	0,495	1	0,482
Environmental awareness level (1)	0,350	1	0,554
Greenfins knowledge (1)	1,835	1	0,176
Environmental briefing (1)	0,080	1	0,777
Current	2,355	3	0,502
Current(1)	1,644	1	0,200
Current(2)	0,070	1	0,791
Current(3)	0,145	1	0,703
Number of divers in group	0,200	1	0,655
Overall Statistics	6,969	14	0,936

3.5 Differences in between Diving Areas

The Andaman Sea accounted for 54 of the diver observations and the Gulf of Thailand for 101 of the total 155 observations. The mean average of contacts with damage in the Andaman Sea was 1.85±0.71 (95% CI) and a median value of one. In the Gulf of Thailand the mean of the number of contacts per 30 minutes was 2.04±0.66 (95% CI) and the median was zero. When tested for independence, no significant differences were found between both distributions of the sampled areas (Mann-Whitney U test, p=0.849).

Nevertheless, the global sample was split into two samples in order for both to be independently analysed. The Andaman Sea and the Gulf of Thailand were both examined to look for differences in damage contact rate within the independent variables and for possible relationships within those variables and the occurrence of damage contact. Statistical tests were performed independently on both samples and significant results were reported accordingly.

In the Andaman Sea, looking for a relationship between the independent variables and the occurrence of damaging contact, the levels of environmental awareness revealed significant results, (χ^2=6.567, d.f.=1, p=0.010) with less divers with a high environmental awareness damaging corals. Also in the Andaman Sea, possessing knowledge of Greenfins or not showed a significant relation with occurrence of damage (χ^2=3.865, d.f.=1, p=0.049). There were a higher proportion of divers (60.5%) who had no knowledge of Greenfins damaging the reef than the proportion of divers who damaged the reef and had knowledge about the Greenfins programme and its contents (31.2%). In the Gulf of Thailand, reef topography showed a significant relationship with the occurrence of damaging contact (Fisher's Exact test χ^2=15.059, d.f.= 4, p=0.003). Apparently the size of the sample was not enough to show a significant relationship for the variable reef topography, in the Andaman Sea. All other tests performed on the split data, recurring to Chi-square analysis, resulted in non-significant at α=0.05 level.

Searching for differences in the number of damaging contacts per 30 minutes of the dive by the various independent variables, the Andaman Sea resulted in a significant difference between the levels of environmental awareness and the damaging contact rate (Mann-Whitney U test, p=0.028). It showed a higher contact rate for the divers with low environmental awareness. In the Gulf of Thailand, reef topography was the only

variable that presented differences in the damaging contact rate (Kruskal-Wallis test, p=0.005).

3.6 Differences in between having Knowledge or not of Greenfins

Similarly, data was split to analyse independently if there were differences in the two samples: divers with previous knowledge of Greenfins and divers without previous knowledge of Greenfins. There were 41 divers with previous knowledge of Greenfins and 114 divers that had no knowledge of Greenfins.. Analysing the divers with previous knowledge of Greenfins, that sample showed a significant relation of gender with damaging the corals. More females damaged the corals (χ^2=6.567, d.f.=1, p=.010). Also found was a significant difference between males and females in terms of damage contact rate (Mann-Whitney U test, p=0.016), with males showing a higher mean rank than females. In the sample of divers that did not have knowledge of Greenfins, reef topography showed a relation with damaging the reef. Less of those divers damaged the reef when diving in pinnacles and that relation was statistically significant (χ^2=17.178, d.f.=4, p=0.001). In the sample of divers that knew about Greenfins, that variable did not show statistical significance.

Considering the global sample study, the divers with Greenfins knowledge presented a lower percentage of divers damaging the corals (43.9%), though this difference was not enough to be significant. Nevertheless this appears to suggest that divers with Greenfins knowledge may have had more concerns in trying to avoid damaging the reef. In terms of damage contact rate, the sample without knowledge of Greenfins, showed significant difference for different reef topographies (Kruskal-Wallis test, p= 0.009), but no statistically significant differences were found in the sample with knowledge of the programme. All other statistical tests performed on the split data resulted in non-significant results at α=0.05 level.

3.7 Influencing Characteristics of Diver Behavior and Affected Substrate

339 (78.8%) of all contacts with the substrate were produced involuntarily by the divers and (21.2%) by voluntary action. Fin kicking was by far the most common form of contact (72.6%), followed by body contact (21.2%) and equipment contact (6.3%). Regarding the body contacts, most were voluntary, while for the other forms of contact most were involuntary. Considering the contacts with the total substrate, the most common types of reef substrates contacted by divers were hard corals (24.2%) and soft corals (26.7%), accounting for the majority of the contacts with the substrate. Other living reef organisms were contacted in 15.6% of times (not considered in this study for damage quantification) and the remaining contacts were with non-living substrata.

Since the purpose of this study was mainly to quantify the damage to the coral reefs, from all substrate contacts made, 306 (71.2%) were considered as damage contacts, including direct (bumps and breaks) and indirect (raised sediments) contacts with living corals. Of those, 270 (88.2%) were involuntary contacts and 36 (11.8%) were voluntary contacts. In regards to the specific kind of contact, 69.9% were bumps, 1.6% were breaks and 28.4% was the re-suspension of sediment over living corals. Most forms of contact were made with many different types of coral (e.g. massive, sub-massive, branching, encrustrated, leafy, etc) and depending on availability, but all five breaks recorded were involuntary and occurred exclusively with branching coral, one with *Echinopora horrida* and four with *Acropora sp.*.

Loose dangling equipment (gauges, alternative air sources and reels) dragged against and knocked into the reef, was also a potential problematic damaging behaviour, but only observed in three of the cases. In the majority of the times, dive guides would notify that divers about the situation before any damage occurred.

Although usually forbidden by dive centres, the use of gloves by divers was still observed on two occasions. Six other divers used UW flashlights during their dives. Fifty (75.7%) of the dive guides in this study were Divemasters or Instructors who had more than one year of experience in the field. Also, in fifty (75.8%) of the 66 sampled dives, the dive guides intervened when the divers would be contacting or about to contact the reef. This pre-emptive reaction may have avoided or minimized diver

contact with the coral reef. This protective intervention was observed by Barker and Roberts (2004) and was significant in terms of reducing contact rates with the coral reefs. However, this relationship was not investigated within this study.

The majority of divers, 77.4% of the sample were European divers. 87.7% of the sample divers had a higher education or secondary school education. 85.2% of the divers had been diving within the last week. 74.7% of the divers answered that they would choose an environmental centre to dive with over others. This may reflect the increasing trend of divers to choose an environmentally friendly dive operator, suggesting that they already possess an interest in reef or environmental conservation.

On average the dive centres used in this study operated two dive boats and the average number of divers on each boat was 17. The average number of dive boats at a dive site at any one time was four. In the Andaman Sea, the average number of divers on each boat was 24 and the average number of dive boats at a dive site at any one time was two. In the Gulf of Thailand, the average number of divers on each boat was 14 and the average number of dive boats at a dive site at any one time was five. In both the Andaman Sea and the Gulf of Thailand the amount of dive boats operated by the dive centres was two on average.

This study roughly estimates that on a regular SCUBA dive of 48 min at a depth of 11-12 m, each recreational diver makes on average three contacts with damage to the reef.

Considering that around 550000 SCUBA divers visit Thailand every year and that each diver makes at least 2 dives during that trip, this represents a minimum estimate of around 1.1 million dives. If every diver was a Greenfins diver making on average three damaging contacts, hence an minimum estimative of 3.3 million damaging contacts resultant from SCUBA diving are made in the coral reefs of Thailand each year.

In the Andaman Sea, in each day of diving, the average number of divers on the dive boats was 24 divers and on average two dive boats were moored per dive site at the same time. Therefore it can be estimated that 48 divers would be diving at the same time in the dive site. If each diver were a Greenfins diver and produced three contacts, hence the total would be 144 damaging contacts in that dive site in that period of the day. In general the amount of boats parked over the same dive site at instantaneous periods of the day would vary from one to five. Most dive operators organize two dives per day. For example, Phuket, in the Andaman Sea, has around 85 dive operators and 15

main dive sites. In the Gulf of Thailand, Koh Tao has more than 30 dive centres organizing day trips twice a day with two dives each trip. The dive boats transport on average 14 divers per dive trip and five dive boats were moored at the same time in the dive sites. Many times the dive sites would have more than 50 divers diving in the same reef area of 50x50m (personal observation).

4 Discussion

In Thailand, recreational divers from Greenfins dive operators contact the reef with damage, more often in the first 20 minutes of the dive and while diving in horizontal topographies (i.e. reef slopes and gardens) or mixed topographies. The results of this study appear to contradict other studies that reported a much higher rate of contacts (Worachananant, 2007; Rouphael & Inglis, 1997; Zakai & Chadwick-Furman, 2002; Barker & Roberts, 2004; Medio et al. 1996), as with divers showing a considerable amount of respect for the coral reefs and environment in general. Nevertheless the results still represent a certain magnitude in the panorama of SCUBA diver damage in the coral reefs.

Medio et al. (1996) stated "more could be achieved if environmentally aware diver education programmes were initiated by diving federations and associations such as PADI and CMAS, and by tour operators, as well as by individual dive schools and instructors". After the implementation of Greenfins programme in Thailand, this is the first study attempting to quantify the effect of this programme on diver behaviour and compare it with other previous studies. Consequently, the results imply that the average damage produced by SCUBA divers from Greenfins dive operators is lower than from non-Greenfins divers. Studies in Thailand on diver behaviour and contact rates are few but showed a relatively higher rate when compared with those from this study. Worachananant (2007) for example, reported an average of 3.1±0.4 contacts per 10 minutes (19 contacts with corals per dive). Comparing with the average of 1.97±0.49 contacts per 30 minutes and a median of one contact per 30 minutes of this study, that result appears much higher. In Australia, Rouphael and Inglis (1997) reported an average of 5.41 damaging contacts over a ten minute period, representing an overall 27 contacts over an average 50 minutes dive. Also in Australia, Harriot et al. (1997)

reported that the mean number of contacts with the substrate per 30 minute dive at each site ranged from 35 to 121, with a maximum of 304 in a single dive and concluded that most damage was attributable to only a small number of divers. Zakai and Chadwick-Furman (2002) in the Red Sea reported 2.5 to 5.5 contacts per 10 minutes, depending on the reef topography. Medio et al. (1996), while studying the effect of briefings on rates of damage to corals, reported 1.0 to 2.2 contacts per 7 minutes for the dives without briefing and an average of 0.24 to 1.0 contacts for the dives with briefing. Barker & Roberts (2004) reported a mean contact rate of 0.25 contacts per minute and a median of 0.09 contacts per minute, representing roughly an average rate of 7.5 contacts in a dive of 30 minutes and a median of 2.7 contacts per 30 minutes. More recently, Uyarra and Côté (2007) reported an average of 1.8 contacts per 10 minutes, however while diving in the vicinity of charismatic species the average would be even higher by 45-fold.

As mentioned before, those studies were produced with random divers from random dive centres with no reference to an affiliation with environmental awareness programmes and in particular with programmes following a Greenfins model.

In order to analyse the importance of the results it was necessary to identify influential characteristics and to relate them with diver damage. Furthermore, it was necessary to compare those results with previous findings. The following variables were isolated in order to achieve these aims:

4.1 Gender

In this study, no relationship was detected between the gender and the occurrence of damaging contact with the reef. Also no differences between genders were found in the damage contact rates. These results are in agreement with Liew et al. (2001) who also did not find any relationship between gender and the amount of damage to the corals by SCUBA divers. In Egypt, Thompson (2004) reported a slight difference, although it was not significant. More males were recorded to contact the reef than females, but no difference was found in terms of number of contacts per week between the genders. A study by Rouphael & Inglis (2001) in Australia showed that male divers were producing more breaks and more damage on average than females, but females were more likely to hold or touch benthic substrata than males. In Thailand, in the Surin Islands,

Worachananant (2007) reported 75% of the females damaging corals and only 36% of the males, and concluded that females are more likely to have contact with coral and cause more damage than males. He explained this with the generalization that females have less physical strength than males, therefore more prone to contact with the coral substrate under certain conditions such as strong currents. This study does not corroborate that theory.

When considering certain dive sites with the presence of charismatic species such as seahorses and frogfish, Uyarra (2007), in Bonaire National Marine Park, did not detect any effect on the change in frequency of coral contact by divers. However, when in the vicinity of this species, female divers exhibited greater increases in time spent in contact with the substratum. In absolute terms, women contacted the reef twice as frequently (114.4±76.3 times per 10 minutes) as men (68.4±100.2 times per 10 minutes).

4.2 Age

The relationship between the differences of age and the damaging behaviours by SCUBA divers on coral reefs has not been looked at in previous studies. This analysis was done to test and try to identify new characteristics, and because it was suspected that differences could exist, such as younger divers being more careless or older divers having more difficulties in achieving good buoyancy and mobility control, resulting in more damage.

However, in this study it was found that age is not related with either contacting the reef with damage or the contact rate of damage corals. However, in the sample the proportion of divers damaging the reef who were under 21 and over fifty years old was slightly higher than the proportion of divers damaging the reef between the ages of 21 and fifty. Yet this difference was not sufficient for statistical significance and also maybe due to the relatively smaller size of the under 21 and over fifty sample groups.

4.3 Photography

Many authors (Salm, 1985; Dixon et al., 1994; Medio et al., 1996) pointed to UW photography as one of the activities that can be amongst the worst offenders of damage in recreational reef diving. Unexpectedly, the present data shows a different trend and does not support this view. The proportion of photographers that contacted the reef was less than non-photographers and also presented a lower median average of damaging contacts. Nevertheless, photographers showed a higher mean of contact rate than non-photographers, but this appears to be due to the fact that some individual photographers had a higher rate of contacts, increasing the overall average.

Therefore the results indicate that the previous tendency for photographer divers to produce higher damage to the coral reefs may be changing. This change could be due to the easier manipulation of the new and small underwater photography equipment. However, it should not be disregarded that some isolated cases may be responsible for most of the damage to the coral reefs.

In an experiment by Rouphael & Inglis (2001), divers who were issued with cameras at random caused impacts no more frequently or severely than a control group who were not engaged in photography during their observed dive. They concluded that inexperienced UW photographers do not necessarily create a greater risk of damage to sensitive dive locations. Nevertheless, specialist UW photographers using more expensive, heavier and bulkier equipment proved to be among the most damaging divers. Contrary to that study, Barker & Roberts, (2004) found that divers using a camera contacted the reef significantly more frequently than non-camera users, but no difference was found between specialists or non-specialists. Alternatively, photographer status was the only predictor of breakage rate in their study variables and so they concluded that photographers were far more likely to contact the reef and to cause a coral breakage, usually whilst holding onto or kneeling on the reef when steadying themselves to take a picture. Those authors suggested that the unique opportunity of watching or taking a photograph of an unusual marine subject overcomes the environmental concerns of the divers and may drive them to produce more damage to the corals. Another corroborating study (Medio et al. 1996) found that divers using cameras or videos accounted for 72.4% of all contacts and these differences were highly significant. Uyarra and Côté (2007) also found no effect on the change in frequency of

coral contact of photographer divers. However divers with cameras exhibited greater increases in the time spent in contact with the substratum when photographing benthic charismatic species.

A recent study in Thailand (Worachananant, 2007) found that 77 % of the divers who used UW photography damaged corals. This figure contrasted with the 53% of non-photographers who caused damage. However, the non-photographers who damaged corals had a higher damage rate than photographers. The average of corals damaged by UW photographers was slightly fewer than for non-photographers, but not significant.

4.4 Certification Level

It was hypothesised that the certification level of divers would be influential in the way that divers behave and subsequently contact the reef.

For some investigators the use of certification level is unreliable as an indicator of the experience of the divers, because a diver with a certification such as the advanced level, may have only nine logged dives, whereas an open water certified diver may have more than one hundred dives logged. Hence many authors (Harriot et al., 1997; Barker & Roberts, 2004; Thompson, 2004) did not find any differences or relationship between certification level and the amount of damage to the reef.

The quality of the training is also an important issue. If a diver has had a comprehensive open water training in terms of buoyancy control and environmental concerns, or alternatively completed the advanced course with a good peak performance buoyancy dive or naturalist dive, then the resultant diver control and posture may differ.

4.5 Experience (number of logged dives)

Experience of the diver, as measured by the total dives in whole dive history did not show a significant relation with occurrence of damage to the corals, and also did not influence damage contact rate.

In Liew's (2001) study, divers with less experience had more tendencies to contact reefs, with 62% of the divers with less than 40 dives contacting the reef, but the relation was not significant. In Barker & Roberts (2004) no significant correlation with contact rate

was found. Rouphael & Inglis (2001) also did not find any correlation between relative experience and the number of times divers made contact with or damaged corals. Another study in Australia (Roberts & Harriot, 1995) found that the number of contacts declined with increasing diver experience and there was a trend towards fewer contacts with advanced diver training. Nevertheless in a posterior study carried out by Harriot et al. (1997) this pattern was not repeated. Uyarra and Côté (2007) reported recently that there was no effect of experience on the change of frequency or length in coral contact of divers.

However, in Thailand, there was a correlation between the level of experience and the number of divers that contacted with or damaged corals according to Worachananant (2007). The number of times divers damage corals decreased with increasing levels of experience.

It could be interesting to arrange the variables of certification and of experience in order to create another variable which could be used to better quantify global experience and test against diver damage.

4.6 Pre-dive Environmental Briefing

In an experimental study in the Red Sea, Medio et al. (1996) concluded that diver behaviour can be influenced by the use of educational tools and therefore that scuba diver impacts on the corals could be significantly reduced. The present study findings did not corroborate Medio et al.'s results. No significant effect was found on the frequency of damaging contacts and number of divers damaging the reef by the occurrence of an environmental pre-dive briefing. Voluntary contacts showed some reduction compared with non briefed divers, but this was not enough to be statistically significant. All divers received a short pre dive briefing from dive guides and most of the briefings included an explanation on reef coral biology and vulnerability (52.9%). In general, when an environmentally friendly briefing was delivered it would include short references to the vulnerability of the reef and instructions of how to avoid contact with the reef at any time of the dive. This includes control of fins, equipment and buoyancy control, with particular note to photographers. Contrary to Medio et al (1996), these briefings would be conducted by dive guides in a way which was unique to each individual leader, and were only considered for this study if containing a

minimum requisite of environmental instructions. This reflects the reality of the dive operations where every dive leader provides their own individual and non-identical dive briefings. Also in Thailand, Worachananant (2007) reported that 39 divers (52%) who attended a pre dive briefing damaged corals, and in comparison, 32 divers (97%) who did not attend the briefing and caused damage. The average number of corals damaged by non briefed divers was greater than damage caused by briefed divers. Precautionary briefings are likely to be more effective if they explain the potential for damage to the reefs from the cumulative impacts of many divers, as opposed to simply focusing on the isolated and often minor effects from each individual diver (Rouphael and Inglis, 2001).

4.7 Greenfins Knowledge

This study hypothesised that there could be a direct influence on the damage produced by the divers, with respect to having or not having previous knowledge of Greenfins. However in the global sample, damage contact and damage rate did not vary with the fact that divers had previous knowledge of the programme Greenfins. These results suggest that having knowledge of Greenfins may not directly reduce by itself the proportion of divers damaging the reef or the damage rate, in Thailand.

However, when isolating and studying the sample of the Andaman Sea, the proportion of divers with knowledge of Greenfins damaging the corals was smaller than the divers without knowledge of Greenfins. This influence was not found in the Gulf of Thailand. This may suggest that Greenfins is better established in the areas that operate in the Andaman Sea and that it may be related with a more active position of the dive operators to present and sustain the aims of the programme. Thus, this suggests that the interaction and assertiveness with the target public in the Andaman Sea may be higher and more effective in comprehension of the programme, resulting in a lower damaging behaviour.

Therefore to a certain extent, these results support the initial hypothesis and show that the establishment of the Greenfins programme is well advanced and producing positive results in terms of diminishing the damage from divers, but may still be dependent on the particular areas of implementation and the current active status of the members.

The study also analysed separately two samples, the one with knowledge of Greenfins and the one without knowledge of Greenfins. From the sample of divers with Greenfins

knowledge, more females contact with the corals at least once, but males produce more damaging contacts during the dive than females. Considering the sample of divers with knowledge of Greenfins, the results appear to indicate that more females are prone to accidentally contacting the corals maybe because of sporadic events during the dive, while males produce more overall damage because they are more adventurous and stay closer to the substratum during their dives (Rouphael & Inglis, 2001).

4.8 Environmental Awareness Level

From the analysis of this built-in variable in the global sample, the study suggests that environmental awareness based on this study qualification, has no effect in the damage to the coral reefs. However these results may be due to the quality of the chosen variables used to quantify the level of environmental awareness. Those chosen characteristics (i.e. reader of marine life magazines, preference for environmental-friendly centres and affiliation with an environmental organization) may not be the most appropriate, hence not reflecting the actual environmental awareness of the divers which can further be assessed by many other indicators.

Nevertheless, when isolating the sample of the Andaman Sea, it was found that the environmental awareness level has a relationship with the damaging behaviour. Indeed, there is lesser proportion of divers damaging the reef that have a higher environmental awareness level, than divers who have a lower environmental awareness. Also, the results suggest that divers with higher environmental awareness are less damaging to the coral reefs in terms of contact rate. Therefore to a certain extent, it appears that some characteristics may be important and influence the divers damage behaviour, such as reading about marine life or being a member of an environmental organization, which may increase the knowledge and concerns for reef conservation (Barker & Roberts, 2004).

4.9 Reef Topography

The results of this study contradict those of previous investigations (Rouphael & Inglis, 1997; Zakai & Chadwick-Furman, 2002; Barker & Roberts, 2004) which have shown

that reef topography does not affect the rate of damage and the amount of divers contacting the reef. The present study analysed the effect of five different topographies instead of three as Rouphael & Inglis (1997) that studied the diver damage at pinnacles, shoulder and garden topographies. Zakai & Chadwick-Furman (2002) chose to analyze four topographies, namely the reef flat, gradual slope, steep slope and patch reef. Also Barker and Roberts (2004) classified the reef topographies as plateau, sloping, wall and varied.

The results of this study suggest that diving at vertical topographies such as pinnacles and walls has an effect in reducing the amount of divers damaging the reef and the damage contact rate. A possible explanation may be that divers diving at vertical topographies expose less of their bodies to contact with the reef surface, because divers usually assume a horizontal diving position. Also divers tend to be steadier in the water column in order to avoid descending uncontrollably to the bottom and in general are more aware of their buoyancies during the dive.

One problem is that most of pinnacle and wall dives are recommended for more expert divers for safety reasons, because of the lack of a physical depth barrier, the need of keeping stability at a certain depth and the occurrence of prevailing currents. Hence in most dive sites, this potential way of managing and reducing the damage can be inadequate for the dive operators to promote to inexperienced divers.

Also some authors agree that diver's damage may be better related more with the benthic composition and the morphology and the abundance of corals rather than the topography of the reef itself (Rouphael & Inglis, 2001; Uyarra & Côté, 2007; Zakai & Chadwick-Furman, 2002; Rouphael & Inglis, 1997). However, reef topography appears to be the only variable in this study which can be used to predict the amount of divers contacting the coral reef with damage at least once during the dives.

This variable was used to model the probability of damaging the reef. The model can be used to predict the odds of contacting the reef with damage, for the population of divers diving in Thailand with a Greenfins operator. Therefore, for a diver diving at pinnacles compared with other topographies, the odds of contact with damage to the reef is 0.30 less. For a diver diving in a varied topography (i.e. a combination of different topographies during the same dive) the odds of contact with damage are 2.24 times greater than while diving at other topographies. This seems to indicate that is preferable for dive operators to promote diving in pinnacles if the aim is to reduce diver's damage and to avoid diving in a varied reef which appears to increase the probability of divers

damaging the reef. However, this is not always possible due to the availability of dive sites and the experience of the divers.

While diving at horizontal topographies (e.g. reef slope, garden or varied), one possible explanation for the higher damage probability could be the fact that many divers look comfortably underneath boulders and corals searching for specific marine life, while landing their body or fins on the surrounding corals.

4.10 Current

This study found no relationship or differences between levels of current and coral damage and damage rate, which is in agreement with Barker & Roberts (2004) who also did not find differences between current speed and the rate of contact with the reef. Therefore it is to be assumed that currents have no influence on the damaging behaviour. Geographically, the occurrence of current and its speed varies greatly in Thailand and many divers while diving in conditions with a current usually try to avoid uncontrollable contact with the reefs, to avoid injury. However, sometimes the divers take a deliberate action to stop in one place and hold on to the reef, thereby possibly causing coral damage (personal observation; Hawkins & Roberts, 1992).

4.11 Dive Group Size

Barker and Roberts (2004) observed that the size of the dive group could influence the ability of diver leaders to perform their supervisory role, so smaller groups are better for the health of the reef. In this study it was attempted to test the effect of the size of the diving group on the occurrence of damage contact and the damage contact rate on the corals. None of those effects were found to be significant but in the sample it was found that larger groups had a tendency to have a higher proportion of divers damaging the reef and higher contact damaging rates, but this relation was not found to be significant.

However, it appears that dive leaders guiding large groups may have more difficulties in intervening and controlling divers during their dives, especially when a problem occurs with one of the divers and the dive guide may become distracted. A reduction in the

maximum number of divers allowed in each dive group would also be highly beneficial as not only would it help the dive leaders to take more control over the divers (Barker & Roberts, 2004; Uyarra and Côté, 2007) but it would also make the dive more enjoyable for the divers (personal observation).

4.12 Other Influencing Characteristics of Divers and Diver Damage

Most contacts damaging the coral reef were made by fin kicks (79.7%) and most resulted in raising sediment, confirming findings in the Red Sea (Prior et al., 1995; Zakai & Chadwick-Furman, 2002), Australia (Roberts & Harriot, 1994; Harriot et al., 1997; Rouphel & Inglis, 2001), Malaysia (Liew et al., 2001) and most recently, in Thailand (Worachananant, 2007). The largest proportion of contacts were involuntary and seemed to be caused by ignorance, poor buoyancy and swimming control. This also confirms the findings of Uyarra & Côtés' (2007) study on diver damage on sites with charismatic species, the study of Barker & Roberts (2004) in St. Lucia, and many others dealing with diver damage quantification. Most of these damage contacts are produced by the fins of the divers when standing on or inadvertently kicked corals.

This study results showed a very low percentage of voluntary contacts, suggesting that divers from Greenfins operators mostly contact or damage corals accidentally (involuntary). Most voluntary contacts were also produced with non-vulnerable substrate, showing a certain level of awareness and discretion while contacting the reef.

Most of the contacts with the substrate involved non-living substrata, followed by soft corals, hard corals and other reef living organism. The higher percentage of bare substrate contacts may be raised by the number of contacts with the sand which however may have resulted in indirect damage to the corals and was considered in the study. Also the higher availability of soft corals in the majority of sites may have been fundamental for this result. In many parts of the dive sites used for the study, high abundances of whip coral, sea fans and other flexible forms of corals were noted, which besides having higher resistance to impacts (Tratalos & Austin, 2001)), and this availability could have been responsible for a higher amount of damage contacts reported for soft corals.

Very few contacts resulted in breakage of the corals (1.6%) and those were mainly in branching types of coral, suggesting that branching corals are more susceptible to

damage by breaking and diving in areas with high abundance of those corals may increase the number of dead coral rubble (Hall, 2001; Plathong, 2000; Talge, 1990; Tratalos & Austin, 2001). Most damaging contacts were bumps (69.9%), especially against massive hard corals and soft corals suggesting a greater susceptibility of massive corals to the bumps of divers, with the potential of damage to the polyps and slow recovery of the coral. Another form of impact was the re-suspension of sediment over corals, which accounted for a significant part of the quantified damage (28.4%). In fact this form of contact may inflict a certain amount of damage to the corals as suggested by some authors (Barker & Roberts, 2004; Rogers, 1990) and seems to be due to a lack of awareness or carelessness with the fins.

To improve the knowledge of the quantification of diver damage it would be advisable to follow up with a study directed specifically to assessing and comparing the substrate composition and abundance with the diver's damaging behaviour. In this study that was not possible to investigate due to logistics of the dive operation and the impossibility of performing the necessary scientific surveys suggested by English et al. (1997), such as the Line Intercept Transect.

Although only a small number of divers (two) were recorded using gloves, and only six were recorded using UW flashlights both accessories may increase the risk of contact with the reef. It has been observed that divers wearing gloves have a tendency to hold onto corals, while divers with UW flashlights have a tendency to increase their proximity to the reef in order to peer into cervices, while contacting the reef to gain stability (Talge, 1990). However, in Thailand at present, these behaviors appear to be far from being a problem, since it appears that most of the dive operators already monitor the use of such equipment.

4.13 Differences between the Periods of the Dive

This study findings show that the first period of the dive are the most damaging, confirming previous studies by Barker and Roberts (2004), Harriot et al. (1997) and Rouphael and Inglis (1997). The study results show that the damaging contact rate is higher in the first ten minutes period. However the difference between the first ten minutes and the second ten minutes period was not enough to be significant. Generalizing, it appears that the first 20 minutes of the dive are crucial and account for

the highest amount of damage to the corals. Usually, the first minutes of the dives right after the descent, are used for adjusting the equipment, establishing buoyancy and adapt to the environmental conditions. Those actions appear to facilitate and increase the amount of damage to the reef in the first periods of the dive, if those actions are taken in coral areas. Therefore dive operators and dive guides should prepare and plan their dives taking those results into account and prefer to organize the beginning of the dive in a less vulnerable part of the reef.

4.14 Recommendations for Dive Operators to Reduce Damage

Some studies (Harriot et al., 1997) recognized that for the sustainability of diving at particular sites, consideration must be given to the following: the capacity for the coral to recover and grow; the present and likely future levels of diving activity; and to certain influential characteristics of the dive users (Barker & Roberts, 2004).

Special rules are already implemented by some dive operators and should be implemented by others in order to reduce diver impacts. Such foresighted measures are also beneficial for the dive operators as they improve their public image as an environmentally friendly dive operator while simultaneously working to protect the substance (i.e. coral reefs) of their business.

For example, many operators now forbid the use of gloves in order to dissuade divers from contacting the coral or from touching the marine life. Likewise, limitations on the use of UW flashlights to particular dive sites or to divers with a certain level of experience would help to minimise diver contact. Another direct measure that can be implemented by the dive operators is to limit the use of some particular vulnerable dive sites to the level of experience, limiting some particular activities such as photography, and avoid promoting diver training activities in those sites. Another recommendation to improve SCUBA divers management could be the use of alternative artificial dive sites (such as wrecks or underwater parks) to release the effort from the most frequented natural dive sites (Treeck & Schuhmacher, 1998).

It appears that in Thailand, specifically in the sampled areas, dives are not in general initiated from the shore, but from dive boats, bringing divers to dive sites located off shore and away from populated areas (personal observation). This type of boat entry, may avoid the damage resulting from shore entries such as trampling over the corals

(Hawkins & Roberts, 1993; Plathong et al., 2000; Barker & Roberts 2004), However, boat diving does simultaneously increase the number of boats over the coral reefs, and brings various associated problems. The discharge of dive boat pollutants, such as oil and gas residue, garbage, sewage, wash-water, and food onto the reef continue to be serious threats in many regions (Harriot et al., 1997). Dive operators should make an effort to reduce the discharges into the sea and submit to more environmental practices such as the use of tanking holds and recycling the garbage on land.

Another scheme with multiple benefits for both the reefs, dive operators and clients, is the establishment of new mooring buoys, such as implemented by the Greenfins programme. This discourages boats from dropping anchor at a dive site, which can be very destructive to the corals (Saphier & Hoffmann, 2005). Another aim is to regulate the number of mooring buoys at each dive site, and the number of boats allowed to moor at each dive site per day. Each mooring buoy was designed to carry only one boat and should be a limitation to the number of visitors to the dive site, managing the number of mooring buoys per dive site. In general, in Thailand dive boats moor next to the others in the same mooring buoy, sometimes increasing the possibility of damage to the buoy and reef, and also crowding the dive sites (personal observation). The dive operators and the dive guides should be advised to take the divers to descent on a mooring buoy and the first minutes of the dive should be in a non-sensitive area of the reef. Another strategy that could also be used is a system of rotation between dive sites, for example over the seasons, in order to reduce the focused dive impact and activity at popular dive sites. This could be achieved if the policy makers and dive operators would agree and submit to a system of quotas in dive site usage. For those regulatory and non-regulatory measures to work, Thailand needs to be efficient in law enforcement and surveillance of the recreational marine areas (UNEP, 2002).

Because dive certification is life-time issued, one beneficial practice that dive operators in this region could implement is a compulsory check dive, whereby the clients are taken on a short dive in a shallow area away from living corals. The check dive has the dual result of allowing the client the opportunity to adjust their buoyancy, becoming comfortable in the water without the risk of contacting damage and of allowing the dive leader an opportunity to assess the suitability of the clients for the proposed topography and difficulty of the respective dive sites.

Other protective measures which the dive operators could implement include scheduling dive sites according to the experience or certification level of the clients. In some cases

check dives are accompanied with refresher dives where inexperienced divers, or divers who have been out of the water for a long period of time, receive a short review of skills and, if necessary, are encouraged to take further training. This could be a good protective measure to introduce prior to every diver's first dive in the region. Such additional training could include the advanced course or relevant specialities designed to increase diver control and environmental awareness, such as the peak performance buoyancy, naturalist courses and even training on reef monitoring (as implemented by Reefwatch, 2004, see introduction for more details).

By increasing diver awareness it is also hoped that the attitude towards recreational changes, with interactions between the diver and the coral reefs becoming more respectful and controlled (Hawkins & Roberts, 1997), therefore increasing the carrying capacity of the dive sites. Another way to do this would be via the promotion of environmental awareness campaigns, including the initiation of both underwater and beach clean ups.

Increasing responsibility should also be given to dive leaders - especially those guiding clients for multiple days – in regards to pre-emptive intervention (as recommended by Barker and Roberts, 2004). The influence of the dive leader can also be extended to the clients through environmental briefings, by their own example under the water such as the collection of underwater souvenirs refuse and a strict no touch policy. It is also hoped that the continued emphasis on the knowledge and responsibility of the individual dive leaders will deepen their sense as a stake holder and protector of the coral reefs (Personal observation; Barker & Roberts, 2004; Medio et al., 1999; Dearden et al. 2007). Indeed a standard training developed and made compulsory for the dive guides recently employed by the dive centres should be recommended. Many dive guides lack proper training in reef biology and its vulnerability and may not be the most adequate role-models. This is another example where the influence of the dive leader as a role model should not be under estimated and should be a matter of concern for the "green" dive centres.

At this point in Thailand's booming tourism industry, it is essential that non-regulatory protective policies such as these are implemented throughout all dive operations as soon as possible. Without immediate action, the sustainability of its coral reefs and the associated environmental resources (namely its diverse marine life) risk rapid devastation. Ultimately, unless the health of the coral reefs is protected then the future growth of the tourism industry can not be guaranteed. Without the pull factor of this

valuable resource, divers and snorkelers will cease to visit the popular coastal areas of Thailand. However, in order to be effective, such dive practices must be implemented by all dive operators, without exception. One major obstacle to this is the implementation, regulation and the need of incentives for the dive operators (e.g. improving the image and benefits of being a "green" dive centre). A possible solution would be the development of additional supervisory governmental programmes or even non governmental or private organisations.

Additional funding is already collected from a dive tax paid by each diver, in certain Thai National Marine Parks, such as the Mu Koh Similan National Park (UNEP, 2002) and should be expanded to many other recreational areas under dive tourist pressure to support the national coral reef management. However, the collection of the user's fees should be improved, and the benefits of the user's tax should be followed and applied in important matters of reef conservation for the improvement of the target areas.

Therefore, other emergent actions are required such as an improvement in political will at the highest levels of government to better regulate reef tourism; the law enforcement and surveillance of the recreational marine areas; and in the functionality of reef conservation at the local level.

4.15 Greenfins Final Comments

Since the initiation of this research, Greenfins is now a well established regional and international reef conservation network. It has recently expanded to include Malaysia, while a new management has began to fully implement the programme in Indonesia. The results of this study fully support the original aims of Greenfins, which include improving coral reef conservation through diver and dive operators education. Specifically in Thailand, the number of Greenfins members has continued to grow while some of its original members have strengthened their commitment through further marine and conservation training.

This study shows that an increased awareness of Greenfins is related to a reduction in the damaging contacts made by recreational divers regardless of ages, sex, diver certification level or camera use in two of the main dive and tourist centres of Thailand. It is hoped that these results can be used to encourage dive operators to establish diver education programmes; develop and support Thailand's environmental policies and in

particular in regards to the tourism industry; and finally to be utilized by Greenfins to continue their conservation of Thailand's abundant and yet fragile coral reefs. Nevertheless, studies on carrying capacity of dive sites due to human pressure are still needed to compare with the actual state and evaluate the importance of the produced damage resulting from this particular recreational activity. Eventually the aim is to reduce diver damage to a relative minimum, promoting the sustainability of the recreational activity. The results of this study (i.e. diver's damage and damage rate) may be used in the future to check if the current level is within the acceptable carrying capacity of reefs in Thailand and will confirm that Greenfins is actually beneficial towards the dive operation impact.

Greenfins programme could be better supported through annual budgets and sustained through forward planning. Funding support from the private sector will help fund activities and monitoring of the programme. Ultimately the success of the programme will depend on the extent to which it can be sustained (TAT, 2008).

As the distribution of information appears to develop the interest and environmental awareness of the diver it would be beneficial for the dive operators to display in their shops and boats relevant paraphernalia. The distribution of environmental information in the form of marine life posters, books, guides, pamphlets summarising environmental programmes, marine life and conservation videos, is highly recommended. Greenfins have implemented this as part of its Code of Conduct (see Appendix).

It was not possible to confirm the recent findings by Worachananant 2007 in the Surin Islands, where most of the factors analyzed were found to be significant in terms of different contact rates and amount of divers contacting the reef. This may be because the populations of divers differ significantly in terms of some unknown confounding variable (such as the nationality of the divers for example). Nevertheless the current study showed a lower damage contact rate and number of divers contacting the reefs comparing with many other previous studies. In fact, this may indicate that Greenfins is already exerting an influence in terms of behavior of divers in Thailand, and these kinds of environmental programmes are a healthy management strategy to follow in the future.

4.16 Study Limitations and Recommendations for Further Studies

Thailand receives many tourists looking for a first diving experience or to get a certified diving course (Worachananant, 2007). The results and anecdotal evidence suggest that a follow up study may be important in order to develop and to assess the amount of damage produced by SCUBA divers students during training. Having students in the groups at the same time as guiding other divers may also contribute towards a reduction in the awareness and supervision of the divers and increase the diver damage. Therefore, in further studies it would be interesting to analyze the influence of some other variables (e.g. student divers, flashlight users and divers monitoring the reefs) on the diver damage behavior in greater depth.

As mentioned before, some other pollution issues should be studied as well in heavy use areas, such as the use of body lotions, sunscreens, fish food, and boat discharges (Talge, 1992).

Also, in order to compare directly the results of diver damage from Greenfins operators with a control, the same study could be repeated with dive operators' who are non-members of Greenfins in Thailand. More studies are recommended to repeat the assessments on diver damage quantification, and more studies on carrying capacity, including estimates on number of divers and dive site usage, and specifically in certain popular areas such as Koh Tao. It is possible that some of the areas used in this study are already exceeding the carrying capacity of the dive sites beyond sustainable levels. A future study in which dive site selection is possible and made on the basis of an assessed percentage cover and coral characteristics would also enable the research to be refined.

The current study had some uncontrollable limitations. For example, dive site selection was not possible to control due to the impositions of the dive operators. It would be beneficial for studies with more limited dive sites, similar characteristics and with a control dive site in the same area.

Overall, one of the main limitations to the study was the small size of the sample. More sampling would allow more in-depth study of the chosen variables and more reliable predicts for both populations (i.e. Andaman Sea and Gulf of Thailand).

Regardless of the significance of results achieved from scientific research at the present time, it is generally recognized that the human population must develop and adapt a

much more conservationist and sustainable approach to the use and care of our natural resources (Sale, 2008). Specifically in regards to the rapidly increasing diving industry, dive operators and recreational divers should follow a precautionary approach, minimizing their impact on the coral reefs. This is of particular importance since much has still to be learned about the short and long term damage produced by SCUBA diving and its associated tourism on the coral reef ecosystems.

5 References

Bennett, M. 2002. Dive Tourism in Phuket, Thailand: Pursing Sustainability. Department of Geography, Victoria, BC, University of Victoria, MSc Thesis.

Brander, L. M., Beukering, P. V. and Cesar, H. S. J. 2007. The recreational value of coral reefs: A meta-analysis. Ecological Economics 63:209-218.

Burke, L., Spalding, M. & Selig, E. 2002. Reefs at risk in Southeast Asia, World Resources Institute; Kogan Page, Washington, D.C.

Cesar, H.S.J., 2000. Coral reefs: their functions, threats and economic value. In: Cesar, H.S.J. (Ed.), Collected Essays on the Economics of Coral Reefs.

COBSEA – Coordinating Body on the Seas of East Asia, 2005. Case-Studies of Coral Reef Monitoring and Management Projects (2004 – 2005), UNEP East Asian Seas Regional Coordinating Unit

CPAD, 2006. Koh Tao Ecology Monitoring Program (EMP), Coastal Preservation and Development Foundation (CPAD), CPAD News, Issue 4, Quarter 3, 2006

Davis, D. & Tisdell, C. 1995. Recreational SCUBA diving and carrying capacity in marine protected areas. Ocean & Coastal Management, vol. 26, no. 1, pp. 19-40.

English, S., Wilkinson, C. and Baker, V. 1994. Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science, Townsville.

GESAMP 2001. A sea of troubles, GESAMP reports and studies No. 70, IMO/FAO/UNESCOIOC/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection(GESAMP), Rome.

Greenfins 2007, Greenfins programme, United Nations Environmental Programme, Green Fins project and Phuket Marine Biological Center (PMBC), viewed 16 August 2007 < http://www.greenfins-thailand.org/mainPage.php>.

Hall VR. 2001. The response of Acropora hyacinthus and Montipora tuberculosa to three different types of colony damage: scraping, tissue mortality and breakage. Journal of Experimental Marine Biology and Ecology 264: 209–223.

Hall, V.R., 1997. Interspecific differences in the regeneration of artificial injuries on scleractinian corals. J. Exp. Mar. Biol. Ecol. 212, 9–23.

Harriott, V., Davis, D., Banks, S., 1997. Recreational diving and its impact in marine protected areas in Eastern Australia. Ambio 26, 173–179.

Harriott, VJ. 2002. Marine tourism impacts and their management on the Great Barrier Reef. CRC Reef Research Centre Technical Report No 46. CRC Reef Research Centre, Townsville.

Hawkins, J. P., and C. M. Roberts. 1992. Can Egypt's coral reefs support ambitious plans for diving tourism? Proceedings of the 7th International Coral Reef Symposium, Guam 2:1007-1013

Hawkins, J., Roberts, C.M., 1992. Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. Biological Conservation 62, 171–178.

Hawkins, J., Roberts, C.M., 1997. Estimating the carrying capacity of coral reefs for SCUBA diving. Proceedings of the Eighth International Coral Reef Symposium 2, 1923–1926.

Hawkins, J.P., Roberts, C.M., Van't Hof, T., de Meyer, K., Tratalos, J., Aldam, C., 1999. Effects of recreational SCUBA diving on Caribbean coral and fish communities. Conservation Biology 13, 888–897.

IYOR 2008, International Year of the Reef, viewed in 3 July 2008 <http://www.iyor.org/>

Kenchington, R.A., 1993. Tourism in coastal and marine environments — a recreational perspective. Ocean and Coastal Management 19 (1): 1–16.

Liew, H. C., Chua Y. S. and Chan E. H. 2001. The impact on coral reefs by leisure divers in Redang. Paper submitted to the National Symposium on Marine Park and Islands in Terengganu: Towards Sustainable Usage and Management of Islands, 12 – 13 February 2001.

Main, M., and Dearden, P. (2007). Tsunami Impacts on Phuket's Diving Industry: Geographical Implications for Marine Conservation. Coastal Management. 35 (4):1-15

Medio, D., Ormond, R.F.G., Pearson, M., 1997. Effect of briefings on rates of damage to corals by SCUBA divers. Biological Conservation 79, 91–95.

Neil, D. 1990, Potential for coral stress due to sediment resuspension and deposition by reef walkers. Biological Conservation, vol. 52, no. 3, pp. 221-227.

PADI, 2008. PADI Statistics, viewed in 5 August 2008

<http://www.padi.com/padi/en/footerlinks/padistatistics.aspx>

Phongsuwan, N., and Chansang, H. 1992. Assessment of coral communities in the Andaman Sea (Thailand). Proceedings of the 7th International Coral Reef Symposium, Guam, 22 – 27 June 1992

Phongsuwan, N., Yeemin, T., Worachananant, S., Duangsawasdi, M., Chotiyaputta, C. & Comley, J. 2006, 'Post-Tsunami status of coral reefs and other coastal ecosystems on the Andaman Sea Coast of Thailand', in C. Wilkinson, D. Souter & J. Goldberg (eds), Status of Coral Reefs in Tsunami Affected Countries: 2005, pp. 63-78.

Plathong S., Inglis G., Huber M. 2000. Effects of self-guided snorkelling trails on corals in a tropical marine park. Conservation Biology 14(6):1821–1833

Prior, M., R. Ormond, R. Hitchen, and C. Wormald. 1995. The impacts on natural resources of activity tourism: a case study of diving in Egypt. International Journal of Environmental Studies 48: 201 - 209

Roberts, L., Harriott, V.J., 1994. Recreational scuba diving and its potential for environmental impact in a marine reserve. In: Bellwood, O., Choat, H., Saxena, N. (Eds.), Recent Advances in Marine Science and Technology 1994. James Cook University of North Queensland, Townsville, Australia, pp. 695–704.

Rogers CS, McLain L, Sullo ES (1988) Damage to coral reefs in Virgin Islands National Park and Biosphere Reserve from recreational activities. Proc 6th Intl Coral Reef Symp, Townsville pp 405 - 410

Rogers, C.S., 1990. Responses of coral reefs and reef organisms to sedimentation. Marine Ecology Progress Series 62, 185–202.

Rouphael, A. B., G. J. Inglis. 2002. Increased spatial and temporal variability in coral damage caused by recreational scuba diving. Ecological Applications 12:427-440

Rouphael, A.B., Inglis, G.J. 1995, The effects of qualified recreational SCUBA divers on coral reefs, Technical Report No.4, CRC Reef Research Centre Ltd, Townsville.

Rouphael, A.B., Inglis, G.J. 2001, Take only photographs and leave only footprints?: An experimental study of the impacts of underwater photographers on coral reef dive sites. Biological Conservation, vol. 100, no. 3, pp. 281-287.

Rouphael, A.B., Inglis, G.J., 1997. Impacts of recreational SCUBA diving at sites with different reef topographies. Biological Conservation 82, 329–336.

Sale, P.F., 2008. Management of coral reefs: Where we have gone wrong and what we can do about it. Marine Pollution Bulletin 56: 805 – 809.

Salm, R.V. 1986. Coral reefs and tourist carrying capacity: The Indian Ocean experience, UNEP Industry and Environment, pp. 11-14.

Saphier, A.D., Hoffmann T.C. 2005. Forecasting models to quantify three anthropogenic stresses on coral reefs from marine recreation: anchor damage, diver contact and copper emission from antifouling paint. *Marine pollution bulletin*, 51(5-7):590-8

Schleyer, M.H., Tomalin, B.J., 2000. Damage on South African coral reefsand an assesment of their sustainable diving capacity using a fisheries approach. Bulletin of Marine Science 67, 1025–1042.

Spalding M, Ravilious C, Green EP (2001) World atlas of coral reefs. University of California Press, California, USA.

Sudara, S. 1988. Conditions of the coral reef in Thailand and the potential usage in the future. Proceedings of the Fourth International Coral Reef Synposium, Manila, Vol. 1, 209 - 211

Talge, H. 1990. Impact of recreational divers on coral reefs in the Florida Keys. Pages 365-374 in W. Jaap, editor. Diving For Science 1990. Proceedings Of The American Academy Of Underwater Sciences Tenth Annual Scientific Diving Symposium, October 4-7, 1990, St. Petersburg, FL (USA)

Talge, H. 1992, Impact of recreational divers on scleractinian corals at Looe Key, Florida. Paper presented to the Seventh International Coral Reef Symposium, Guam, 22-26 June 1992.

TAT 2005, Tourism Situation Concerning Inbound Foreign Visitors in 2005, viewed 20 August 2008 <http://www2.tat.or.th/stat/download/ind/2005%20Tourism%20Situation%20(English).doc>

TAT 2006, Tourism statistic, Tourism Authority of Thailand (TAT), Bangkok, viewed 1 July 2008 <http://www2.tat.or.th/stat/web/static_index.php>.

TAT 2008, GreenFins, Eco-friendly diving in Thailand, Tourism Authority of Thailand (TAT), Bangkok, viewed 1 July 2008 <http://www.tatnews.org/emagazine/3496.asp>

Thompson, D. Take Only Pictures and Leave Only Bubbles: A study of the impact of live-a-board divers on the coral reefs of the Southern Red Sea. School of Ocean Sciences, University of Wales Bangor (UWB), MSc Thesis

Tilmant J.T. 1987. Impacts of recreational activities on coral reefs. In: Salvat B (ed), Human impacts on coral reefs: facts and recommendations, Antenne Museum EPHE, French Polynesia, pp 195-214

Tratalos, J.A., Austin, T.J., 2001. Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. Biological Conservation 102, 67–75.

Tun, K., Chou, L.M., Cabanban, A., Tuan, V. S., Philreefs, Yeemin, T., Suharsono, Sour, K. & Lane, D. 2004. Status of Coral Reefs, Coral Reef Monitoring and Management in Southeast Asia, 2004, in C.R. Wilkinson (ed.), Status of Coral Reefs of the World: 2004, Australian Institute of Marine Science, Townsville, pp. 235- 275.

UNEP (ed.). 2002. The Status of Coral Reef Management in Southeast Asia: A Gap Analysis. Report prepared by Heidi Schuttenberg, J. William Fulbright Fellow and David Bizot, Knauss Marine Policy Fellow.

Uyarra M. C., Côté I. M. 2007. The quest for cryptic creatures: Impacts of species-focused recreational diving on corals. Biological Conservation 136: 77 - 84

Vredenburgh, A. G., Cohen, H. H. 1993. Compliance with warnings in high risk recreational activities: skiing and SCUBA. In: Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 945 - 949

Walters R. D. M., Samways M. J. 2001. Sustainable dive ecotourism on a South African reef. Biodiversity and Conservation 10: 2167 - 2179

Worachananant, 2007. Management Approaches in Marine Protected Areas: A case study of Surin Marine National Park, Thailand. School of Natural and Rural Systems Management, University of Queensland, PhD thesis

WTTC: World Travel and Tourism Council, 2008. The 2008 Travel & Tourism Economic Research – Thailand, TSA Tourism Satellite Accounting. Available from <www.wttc.org>

Yeemin, T., S. Sudara, N. Krairapanond, C. Silsoonthorn, N. Ruengsawang and S. Asa. 2001. International Coral Reef Initiative Country Report: Thailand. Regional ICRI Workshop for East Asia, Cebu, Philippines, 21 pp.

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

6 Appendix

Greenfins Code of Conduct.

Greenfins promotion information and materials

FUN DIVERS - VOLUNTARY INQUIRY

Date: / /

Name (facultative):

Gender	M	F
Age		
Nationality		
Highest Diving Certification		
How many total dives in your life record?		
Job		
Level of education	No formal education	
	Primary School	
	High School	
	Bachelor	
	Master	
	PhD	
	Other	
Do you usually read marine life magazines?	Y	N
Are you a member of any environmental organization?	Y	N
When you dive, do you usually choose an environmentally friendly divecenter?	Y	N
Did the divecentre introduce you to the Greenfins Code of Conduct?	Y	N

Dive site:

Thank you very much for your cooperation.

Reference I.D. number: # _____

Greenfins Dive Operators used during the study and respective area

Phuket and Koh Phi Phi Group:

Dive Asia
Santana

Koh Lanta Group:

Skool Divers
Palm Beach Divers
Go Dive
Koh Lanta Diving Center

Koh Tao Group:

Black Tip Diving
Taa Toh
Crystal Divers
Easy Divers
Buddha View
Siam Divers
Coral Grand Divers
Planet Scuba
Carabao
LV Divers
Big Bubble
Big Blue
Asia Divers

Khao Lak (Similan) Group:

Liquid Adventures
Siam Adventure Divers
Raya Divers

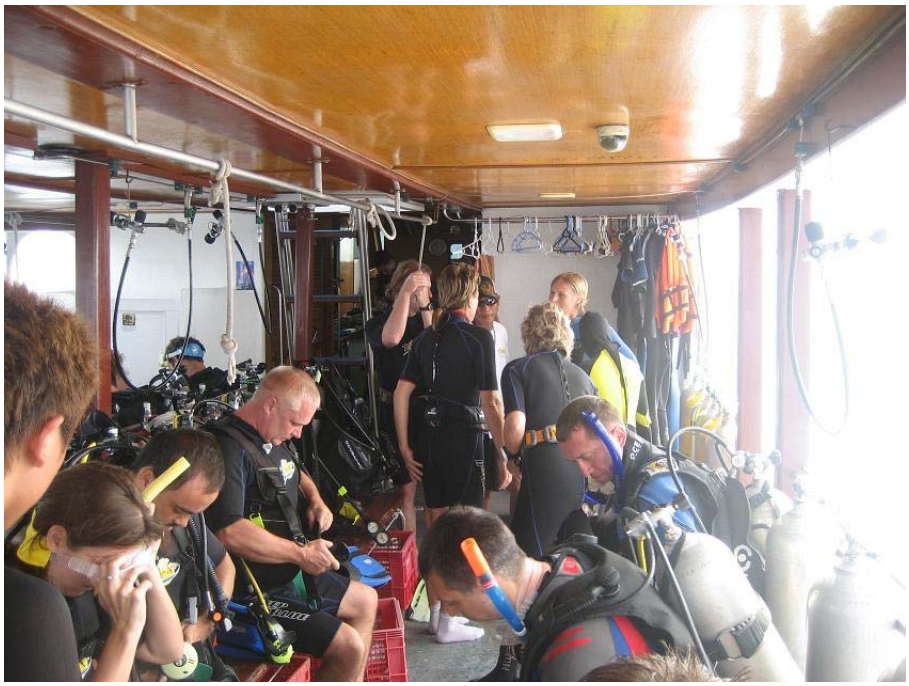
Coding of the categorical variables as used for statistical analysis.

		Variables										
		Gender	Photography	Age class	Certification level	Experience level	Environmental awareness level	Greenfins knowledge	Pre-dive environmental briefing	Reef topography	Current	Dive group size
Categories	0		No					No	No		None	
	1	Male	Yes	< 20	Student	Novice	Low	Yes	Yes	Slope	Weak	Small
	2	Female		20 – 30	Basic	Intermediate	High			Garden	Moderate	Medium
	3			30 – 50	Advanced	Experienced				Pinnacle	Strong	Large
	4			> 50	Instructor					Wall		
	5									Varied		

Random photos from dive operations and Greenfins activities during 2007

Diver with loosen equipment (octopus and submersible pressure gauge) and using a underwater camera

Large groups of divers in Thai waters. (Courtesy of Greenfins)



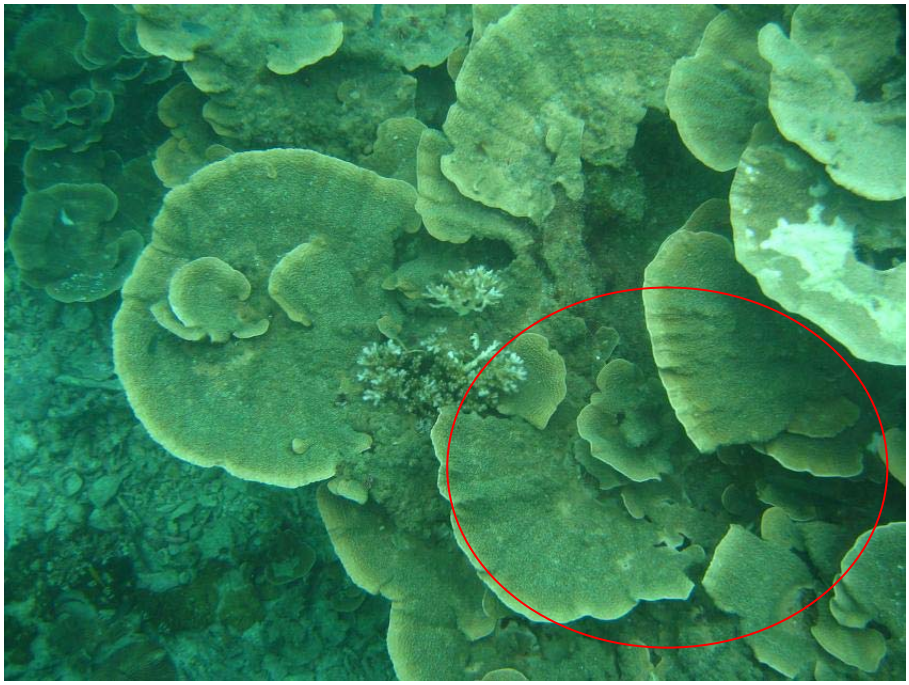
Dive operation by a Greenfins member in the Andaman Sea

Dive boats at Ao Chalong Pier in Phuket

Mooring buoy assemblage to replace and install new ones on the dive sites

Workshop on reef monitoring techniques at Koh Lanta (CHARM, ReefWatch and Greenfins)

Staff from a Greenfins dive operator receiving training in the ReefWatch monitoring technique



Broken coral resultant from SCUBA diver damage with fins