Ecological and Social Response of the Coral Reefs of Mu Koh Surin Marine National Park, Thailand, and Phuket's diving industry to the 2004 Indian Ocean Tsunami

by

Michiru A. Main
B.Sc., University of Victoria, 2001

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Supervisory Committee

Dr. Philip Dearden, Supervisor
(Department of Geography)

Dr. Dave Duffus, Departmental Member
(Department of Geography)

Dr. John Nelson, Non-departmental Member
(Department of Biology)

Dr. Tom Reimchen, External Examiner
(Department of Biology)

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(Department of Biology)

Dr. Tom Reimchen, External Examiner
(Department of Biology)

ABSTRACT

The 2004 Indian Ocean tsunami created a catastrophic disturbance at several scales along the entire Andaman Sea coast. As the first large-scale tsunami occurring in recent history, this event provided a unique opportunity to use modern instrumentation and *in situ* observation to study tsunami dynamics and effects on coastal systems. Along Thailand's coast, consequences of this disturbance were highly variable in space and time, with pronounced changes to certain coral reefs and human communities. This thesis outlines two case study-based research projects designed to gain some understanding of the ecological and social dynamics of the tsunami in Thailand. From a Geographical perspective, responses to this massive disturbance may support an incentive-based direction for marine conservation in Thailand.

The first project occurred within Mu Koh Surin Marine National Park, Thailand. Variability in the physical response of fringing hard coral reefs to the tsunami was examined using SCUBA surveys. Patterns in variability were distinct from typical hard coral responses during tropical storms suggesting differences in the nature of these

hydrodynamic disturbances. Coral colony morphologies and reef shape mainly did not influence variability in tsunami response; however, unique effects were observed on reef slopes over 45°. There was no detected influence of reef depth. Variability in effects based on the spatial location of reefs was observed: proximity to bathymetrical constrictions accounted for substantial variability, while reef aspect did not. Overall, just over 10% of sampled reef area was affected, with evidence of rapid coral recovery in the form of tissue re-growth and apical skeletal growth within four months of the event at most sites.

The second project explored the effects of the tsunami on Phuket's diving industry. The response of industry members and recreational divers to tsunami effects was examined using interviews and questionnaires as well as observational dives with dive guides and clients on chartered trips during the 2004-5 post-tsunami diving season.

A short-term reduction in the number of diving companies and diving tourism in Phuket was observed immediately following the tsunami; this can be attributed to terrestrial damage and trip cancellations. Although there were expectations for high levels of dive site damage, most recreational divers did not perceive any damage on dive sites in 2005 – even while diving on surveyed sites with as much as 76-100% of reef area reportedly affected. This low rate of perception may be partially explained by diving ability, but was more likely due to site variability and variability in tsunami response within dive sites allowing guides to preferentially avoid acutely damaged areas.

During the post-tsunami low tourism period, industry members contributed substantial resources to rescue, relief and restoration efforts along Thailand's Andaman Sea Coast. Industry members also participated in several government and university-led tsunami monitoring and rehabilitation efforts. While measurable changes to Phuket's diving industry seem to have been short-term, this response of industry members to the event may have increased potential for long-term collaboration with government and universities. Enhanced communication among these parties could facilitate future incentive-driven industry contributions toward marine conservation in Thailand.

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DEDICATION

This thesis is dedicated to Michael deRoos for too many reasons to list.

(Next time you can have a day or two off…)

CHAPTER 1: Changing Paradigms in Reef Conservation and Study Objectives

1.1. Introduction

In the world's relatively nutrient poor tropical oceans, coral reefs generate and store some of the highest biodiversity and productivity on the planet (Spalding 2001). In terms of ecological, economic and cultural values, coral reefs are highly valuable ecosystems, housing hundreds of thousands of plant and animal species (Roberts et al. 2002). These reefs act as nurseries, provide complex habitat and nutrition for many species, and they protect adjacent terrestrial communities from coastal disturbance. Communities throughout the tropics have lived intimately with the world's coral reefs for thousands of years, relying on them for sustenance, livelihoods and cultural meaning.

The first documentation of external stressors affecting coral reefs occurred in 1872 when Dana noted effects of sedimentation on corals (Risk 1999). Today, we know that coral reefs worldwide are in serious decline due to terrestrial agriculture, deforestation, coastal development and runoff, over-fishing, destructive harvesting techniques, climate change, and other factors (Roberts et al. 2002; Pandolfi et al. 2003; Bellwood et al. 2004; Birkeland 2004). Awareness that coral reef science has not checked this decline has caused some of the world's top reef scientists to re-examine the paradigms that have driven research in coral reef conservation.

It is the widely held paradigms in a field that shape scientific objectives and goals. In order to shift research focus toward new objectives, new paradigms must be designed and adopted. To address current coral reef decline, top scientists are thus leading the way toward shifting the field from a biocentric to social-ecological paradigm in order to address the human role in reef decline and conservation.

In this chapter, I will explain how these two paradigms lead to different goals for coral reef conservation and the importance of this shift toward social-ecological systems thinking to meet contemporary conservation goals. I will then outline some recent and important contributions to paradigmatic and applied coral reef conservation science and, finally, indicate where my thesis work lies within this field.

1.2. Paradigms driving coral reef conservation

1.2.1. Biological paradigm

Since Banner's (1974) observations of anthropogenic effects on coral reefs in Hawaii, science for reef conservation has entailed a considerable multi-scale effort to assess and monitor coral reefs worldwide. Just as standard methods to assess and monitor reefs have not changed considerably over the past 30 years (Risk 1999), the dominant approach to science in reef conservation remained descriptive, with the objective of assessing reef "health" (Downs et al. 2005). Under this reef health paradigm, coral reefs have been conceptualized as fundamentally ecological systems - with several sources of external stress (Risk et al. 1999; Downs et al. 2005; Hughes et al. 2005; Owen et al. 2005).

By the mid 1980s, the scientific community had become aware of the extent of damage to coral reefs that resulted from human activities and this concern was beginning to be publicly perceived (Risk 1999). Reef science continued to describe and monitor reef decline worldwide, and, in many countries, this eventually led to widespread protective legislation to conserve coral reefs by including them in tropical marine protected areas (MPAs). The number of MPAs worldwide that contain coral reefs has been increasing at a global rate of about 40 per year over the past 10 years (Mora et al. 2006). This has resulted in 980 MPAs that cover almost 19% of the world's coral reefs (Mora et al. 2006). These figures, however, are misleading since only a fraction of this area is covered by MPAs with *effective* management for conservation (Spalding 2001; Mora et al. 2006).

One problem with management, where it has been attempted, is that the goal has been to drastically reduce or remove human-caused stress on coral reefs. The reasoning for this was that if human influence could be removed, reefs should naturally recover to an optimal state of 'reef health' - usually defined in terms of maximum sustainable yield or high percent cover of living coral (Hughes et al. 2005). Managing for high fish and coral abundance, however, does not necessarily account for the functional dynamics that define coral reefs by driving essential ecosystem processes. Furthermore, management has been severely impeded by the limited human and financial resources usually available to enforce restrictions and regulate access to MPA resources – especially in the poor developing countries where the majority of coral reefs exist (McClanahan 1999). Thus, despite protective legislation, and despite the extensive number of global reef research and monitoring initiatives, coral reefs have continued to decline. While this has been the result of complex interaction of political, economic and cultural factors, Risk (1999) also attributed responsibility to a science that "failed the world's coral reefs (p831)."

1.2.2. Shifting paradigms

Risk (1999) noted that in other scientific fields addressing environmental problems, successful response typically followed a four-step pattern: identification and awareness; accumulation of resources; monitoring and research; and finally, management-policy interface. In reef conservation, according to Risk (1999), global consensus on reef decline had already been achieved; international coral reef initiatives, protective legislation and tools for management had been developed, and research and monitoring had occurred to some degree in most tropical MPAs. The reason that coral reef conservation had not mitigated the global decline of coral reefs was that the complementary shift in research paradigms that should have occurred with these first three steps had been delayed. Risk argued that by focusing so heavily on the singular discipline of biology, reef scientists had not attempted to diagnose the causes of reef decline in order to provide management options and facilitate conservation. Risk proposed that for effective management, scientists should become managers in order to close the gap between research and application (Risk 1999).

Since Risk (1999), there have been several more recent calls to shift approaches in the field of coral reef conservation (Birkeland 2004; Downs et al. 2005; Hughes et al. 2005; Owen et al. 2005; Rinkevich 2005) and a new paradigm for coral reef science is emerging. This paradigm leads to a geographical approach to conservation that aims to maintain the resilience of coral reefs as coupled social and ecological systems (Walker et al. 2004; Folke et al. 2004; Hughes et al. 2005; Adger et al. 2005).

1.2.3. Social-ecological paradigm

Since excluding human activity from coral reefs requires costly enforcement and is usually not feasible, a human inclusive paradigm that conceptualizes coral reefs as dynamic social-ecological systems has been endorsed by leading coral reef scientists like

Hughes (Hughes et al. 2004), Bellwood (Bellwood et al. 2005) and Folke (Folke et al. 2004). The objective of reef conservation under this paradigm is to understand the social and ecological components of coral reef systems and to manage the social component in the face of change in order to maintain its various ecological processes (Adger et al. 2005; Downs et al. 2005; Hughes et al. 2005).

The idea of resilience in ecological systems was first coined over 30 years ago by Holling (1973) and this ecological concept has since been utilized in coral reef science because of the dynamic nature of coral reef ecosystems. Holling defined resilience as the capacity of a system to absorb disturbance while undergoing change so as to retain essentially the same function, structure, identity and feedbacks (Holling 1973).

In terms of coral reef systems, changes in resilience can be caused by external drivers operating at different scales such as rising seawater temperatures or crashes in the market value of harvestable coral reef species. Internal drivers like disease or over-harvesting that change the relative abundance of certain species can also change resilience. These drivers can alter the system's capacity to absorb future change, its ability to adapt in order to maintain its current processes, and the likelihood that future disturbance will move it into a different state. Large-scale functional changes on many coral reefs have been causally linked to over-harvesting, pollution, and other anthropogenic effects (Bellwood et al. 2004), illustrating the disproportionately large role humans play in system dynamics. Humans can also drive change by defining "untenable" states and desirable management goals for a system – evident in the various reef restoration projects on reefs that have shifted from 'desirable' coral to 'undesirable' non-coral dominated regimes (GCRA 2006; NCRI 2006).

Two main streams of research pertaining to coral reef conservation fit within the social-ecological paradigm. These address the resilience of coral reef systems on a theoretical and applied level. The goal of research in resilience theory is to understand how reef systems respond to different types of change, while applied management works to influence change in order to maintain resilience. It has been argued that, until now, the global decline of coral reefs has not actually been addressed by scientists in the field due to a gap between marine science and management (Risk 1999). As scientists have realized this, the division between paradigmatic science and applied science in coral reef conservation is necessarily weakening and this is where the most promising work in coral reef conservation lies. In the next section, I will discuss important contributions to both sciences as they have co-evolved.

1.3. The cutting edge in coral reef conservation

1.3.1. Paradigmatic science addressing resilience

Holling's (1973) conceptualization of resilience has recently been taken on as guiding principle for coral reef conservation under a human-inclusive paradigm that aims to sustain the goods and services provided by coral reefs (Bellwood et al. 2004). To utilize this concept of resilience for conservation, social and ecological variables that define the stability landscape in coral reef systems must first be identified, then system responses must be causally linked to specific social actions in order to promote social and ecological resilience and discourage system transformations.

Much of our current understanding of coral reef dynamics can be attributed to the work of Done (1992) on phase shifts and Hughes (1994) and Connell (1997) on the role of disturbance in coral reef communities. Some important contributions in terms of conservation have been made by international coral reef conservation organizations that have provided baseline data and set up institutions for social capacity building and long-term monitoring of reefs. At the forefront, several scientists are pushing the field to develop this idea of resilience and provide an explanation for the dynamics of coral reef systems, and research has come far since global consensus on coral reef decline was reached. In terms of theoretical background, social-ecological resilience and its application to coastal systems has been clearly explained by Adger et al. (2005). Bellwood et al. (2004) have contributed toward identifying the variables that define functionality of coral reef systems. Risk (2001, etc.) has focused on developing an interdisciplinary reef science that links social activity to ecological responses of these variables. In 2001, Jameson published practical guidelines for measuring system responses to specific activities using diagnostic indicators as tools for conservation management.

Impressive international monitoring efforts by groups like the International Coral Reef Initative (ICRI www.icri.org), Australian Institute for Marine Science (AIMS www.aims.gov.au), the Global Coral Reef Monitoring Network (GCRMN www.gcrmn.org), ReefBase (www.reefbase.org) and Reefcheck (www.reefcheck.org), as well as local efforts by individual scientists, have provided ecological baselines and have contributed substantially to our understanding of the global extent of reef decline and possible causes of this decline. These studies mainly employ standard reef survey techniques described by Risk (1999), but have begun to incorporate GIS technology to look at larger than reef-scale patterns (CCC 2005). International organizations have also embarked on partnerships with other organizations and local communities to carry out research and facilitate capacity-building (Dight & Scherl 1997; UNEP 2004). The role of these institutions in coral reef conservation has been considerable since they have the capacity to work at larger spatial and temporal scales than individuals and may have more accessibility to information and resources than governments (Dight & Scherl 1997).

Since 23% of the human population currently lives within 100km of coastlines that are susceptible to natural disasters (Adger et al. 2005), understanding resilience to disasters is important. But the effect of natural disasters also gives considerable insight into resilience and the linkages within social-ecological systems (Hughes et al. 2005). Adger et al. (2005) looked at social-ecological resilience using case studies of past responses to coastal disaster. They examined the role of social-ecological resilience in responses to the 2004 Indian Ocean tsunami and hurricanes in the Caribbean. They found that the resilience of certain areas around the Indian Ocean and in the Caribbean to coastal disaster encouraged rapid response and recovery. In other areas that were subject to chronic degradation by activities like over-fishing, pollution, coral mining and deforestation for shrimp farming, recovery was much slower.

Ecologically, these activities can affect biotic processes by removing functional groups (species that carry out specific ecosystem roles), or by reducing functional group redundancy which provides a buffer against the loss of ecosystem processes (Bellwood et al. 2004). Physically, they can degrade potential barriers like mangrove forests and coral reefs (although these can be effective barriers for storm disturbance (Danielson et al. 2005) there is debate over whether they influenced the magnitude of tsunami inundation – see Kathiresan & Rajendran 2005,2006; Kerr et al. 2006). Socially, they drastically reduce the potential for alternate livelihoods within coastal communities. Adger et al. (2005) noted the role of knowledgeable, prepared and responsive institutions in areas that exhibited coastal resilience. They concluded that certain factors characterize socially and ecologically resilient systems including: sustainable use that maintains ecosystem functions, maintenance of a local memory of resource use, the ability of systems to respond to environmental feedback, ecological diversity, livelihood diversity, social capital, and inclusive governance that reduces the perverse incentives encouraging the destruction of natural capital.

In Bellwood et al.'s (2004) review of past fisheries research in the Caribbean, they address the question of scale and emphasize the importance of a functional approach to reef science. Whereas past scientific inquiry was aimed at maintaining biodiversity at the species level, they argue that focusing on functional groups is more likely to achieve conservation goals to maintain ecosystem functioning (ie. resilience). This is because managing for overall high species diversity may not maintain redundancy for some ecosystem processes – especially if certain key roles are only filled by a single species. Bellwood et al. (2004) propose that understanding ecosystem functions allows for inquiry into how coral reefs systems will respond to increasing human impact, and management to sustain these functions will increase the capacity of coral reef systems to resist phase shifts and regenerate in the face of disturbance. The change to a functional approach in coral reef science requires that past descriptive methods become diagnostic to determine the cause of functional changes.

Risk (2001) has been advocating that scientists should also be managers and his work is where the distinction between paradigmatic and applied science becomes fuzzy.

Risk is concerned with how to design a reef science that addresses causality, and in 2001, he proposed an interdisciplinary method for carrying out diagnostic reef science. He outlined two necessary steps for this process. First, stress in a system should be identified (as change to resilience), and this can be achieved locally using various standard methods for reef evaluation. He argues that each method, used properly, should detect stress at some level if it exists, but cannot determine the ultimate cause of stress. The next step would then be to diagnose the cause (the variables that drive change). This requires geochemical understanding and techniques for analyzing isotopes in coral tissue in order to detect sewage, siltation, thermal and light level effects on reefs.

Work by Jameson also straddles the paradigmatic/applied boundary in reef conservation science. Like Risk, he addresses the question of what causes coral reef decline. Jameson (2001) focuses on how to detect and measure ecological responses to influential drivers. In terms of the stability landscape, this refers to how the system is moving along its latitude of resilience. He also argues that while global reef monitoring efforts have provided considerable information, they have usually only had the capacity to identify change in conditions, not ultimate causes of these changes (Jameson 2001). By reviewing past research, he has developed a framework for selecting diagnostic indicators that can distinguish between human and environmental causation. These indicators can be powerful tools for understanding and managing the adaptability of coral reef systems (Dinsdale & Harriot 2004).

The science described thus far is fundamentally concerned with the theory of resilience. Designing or unearthing a normative theory is essential for providing unified goals within the field (Downs et al. 2005), but, at local scales, scientists must be more concerned with finding solutions to very specific problems. This has given rise to the applied stream of scientific research in coral reef conservation.

1.3.2. Applied science addressing conservation management

While external drivers can disrupt reef functioning, it is the internal components of a system that can be managed feasibly at each scale. Since human activity can overwhelm all other internal processes of coral reefs, and since human behaviour can be managed, in theory, the focus of recent work related to adaptability has been on the management of coral reef use. Important contributions to applied science relevant to coral reef conservation come from Russ and Alcala (1999) on community-based management, Roberts (2005) on marine reserves, and Hutton and Leader-Williams (2003) regarding incentive-driven conservation.

Over the past decade, management goals have been directed toward the theory of adaptive management. The stages of adaptive management are illustrated in Figure 1. The adaptive management process begins with the definition of conservation targets based on broad goals for conservation within a coral reef system. Management applications are then designed to maintain these targets for conservation and these are implemented. The system is then monitored scientifically using diagnostic indicators (Jameson 2004) to give feedback on the effectiveness of management. The idea behind this is that management itself becomes a process of scientific inquiry, breaking down traditional barriers between scientists and managers. The strength of this process lies in its ability to continually evaluate management and respond to the dynamics of social-ecological systems.

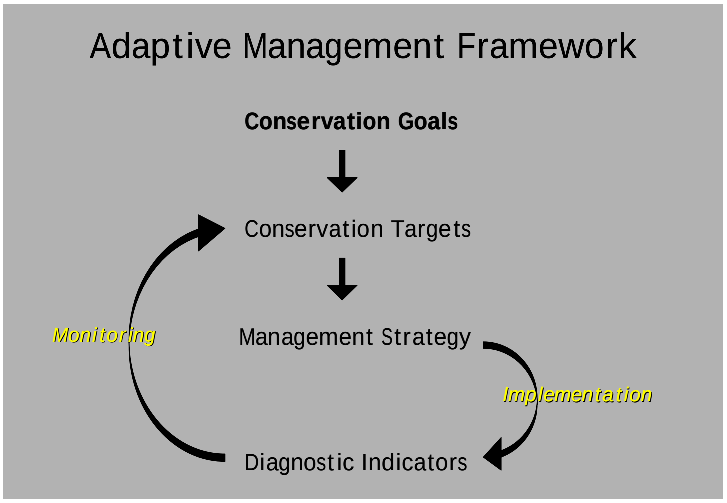

Figure 1.1 – Steps in the process of adaptive management (Dearden pers comm.)

While adaptive management is endorsed by many (Russ & Alcala 1999; Jameson et al. 2002; Dinsdale & Harriot 2004; Tompkins & Adger, 2004; Downs et al. 2005; Hughes et al. 2005), there are very few cases where management has moved beyond the design stage to actual implementation in this field. The reasons for this are many and have been discussed by several authors (Dight & Scherl 1997; Risk 1999; Russ & Alcala 1999; UNEP 2004; Downs et al. 2005). Although coral reef scientists have rarely driven this adaptive management loop (Figure 1), several tools for conservation have been developed.

Roberts has been studying the ecology of marine reserves for several years, addressing problems related to designing marine reserves in terms of size and boundaries (Roberts & Hawkins 1997; Roberts 1997), management strategies (Roberts et al. 2005) and regional prioritization (Roberts et al. 2002). Roberts argues that since global fisheries are by far the largest anthropogenic impact on coral reefs and considering the declining status of commercially important stocks worldwide, setting up an international network of marine reserves is imperative for reef conservation (Roberts et al. 2005). Roberts concludes that no-take marine reserves are essential tools that require rapid implementation in order to protect many species of coral reef fishes from imminent extinction (Roberts et al. 2001, 2005).

Other less restrictive protected areas designations exist. Since marine harvesting and tourism are the largest revenue producers associated with reefs, many tropical MPAs were designated with the objective of managing extractive use while maintaining pristine conditions for tourism (Roberts & Polunin 1991; Russ & Alcala 1999). This is a tricky balance and most tropical MPAs have not achieved either of these objectives (UNEP 2004; Mora et al. 2006). Concern over this failure has led many scientists to ask why there is this lack of effective management.

One reason commonly proposed for this is a lack of community involvement in MPA management (Jameson et al. 2002). Community-based management is advocated since people will be more likely to comply with management policies if they understand management objectives and are involved in the development of management regulations and in the implementation and maintenance of this management (Russ & Alcala 1999). Definitive work on this topic was conducted by Russ and Alcala (1999) in a comparison of almost 20 year-long management histories of the Sumilon and Apo Marine Reserves in the Philippines. They used a variety of methods including social and ecological fieldwork, interviews, communication with other scientists who had done work in the reserves and a review of available relevant scientific literature to determine what factors could contribute to reserve success. They found that all of the conservation objectives of the Apo Reserve had consistently been met, whereas the Sumilon Reserve had fluctuated between implemented management and periods of no management and had ultimately not met any of its management objectives. They concluded that the distinguishing factor in these different outcomes was the level of community support for management. At Apo, management success was clearly the result of the effective integration of institutional and community-based management for common conservation goals. This was possible because the community was able to perceive the benefits of being involved.

Community-based management is useful for coral reefs that have adjacent dependent communities. But there are many remote coral reefs that do not have potential for this kind of integrated management. Furthermore, achieving community-based management is challenging in most of the tropical countries with coral reefs because institutions are typically weak, development is prioritized over conservation and people often exploit scarce resources in order to survive. In these areas, human exclusion or strict legislation to prevent over-exploitation is neither feasible nor desirable for social-political reasons. An alternative option for implementing conservation in these scenarios is through incentive-driven means (Hutton & Leader-Williams 2003).

Hutton and Leader-Williams (2003) discuss whether a combined strategy of protection and use, or 'sustainable use,' can exist. They redefine the term 'sustainable use' into one that is workable, arguing that the common interpretation of the term is one that justifies extractive use without considering future sustainability. Since strictly protected areas and areas with managed resource extraction are not actually conserving resources, conservation must become a "competitive form of land use… driven by incentives that motivate people to conserve (p220)." These incentives do not only have to take the form of tax subsidies and penalties to encourage or discourage certain behaviours (Myers & Kent 2001). They can exist in many forms and may be social, ecological or political as well as economic (Hutton & Leader-Williams 2003). For example, marine ecotourism industries have multiple incentives to practice marine conservation since they are highly dependent upon aesthetic qualities of the marine environment (Bennett 2002; Dearden et al. 2007). In a meta-analysis of 251 ecotourism case studies, Kruger (2005) found that social, economic and cultural benefits can be even greater than extractive benefits on coral reefs.

The challenge, however, is always in creating widespread awareness of these benefits so that resource users will buy in to conservation over the long-term. For this, conservation incentives must be consistent with other existing social, political and economic incentives; and they must be perceived to outweigh conflicting incentives to exploit the resource-base. As well, the *opportunity* to perceive incentives for long-term conservation must be created.

1.4. Thesis objectives

This thesis is an attempt to build on previous research of members of the University of Victoria's Marine Protected Areas Research Group and to straddle the social and ecological divide that has existed in coral reef conservation. The overarching goal of the project was to contribute to understanding of how underlying dependencies between social and ecological systems can be utilized for coral reef conservation. This is a case study examining the individual and linked responses of two small Andaman Sea coast communities in Thailand to the 2004 Indian Ocean tsunami.

Thailand's coral reefs lie within the East Indies Triangle, an area that contains the world's highest marine biodiversity (Allen & Werner, 2002). This region is evolutionarily important as it is thought to be the origin of most Indo-Pacific marine biodiversity (Bellwood et al., 2005; Briggs, 2005). Ecologically, these reefs are dynamic systems and they have historically provided coastal communities with sustenance, coastal protection, livelihoods, recreation and cultural benefits. However, coastal population growth and improving technologies that have facilitated the over-exploitation of Thailand's coral reefs have compromised their resilience. Recently, catastrophic disturbances like the warming events in 1997/1998 and the tsunami in 2004 have further affected their resilience. Even though over 50% of Thailand's coral reefs fall within marine national park boundaries, protective regulations are rarely enforced (Lunn & Dearden 2006). Since traditional tools for marine conservation have not addressed most stresses on coral reefs, alternative strategies such as incentive-driven conservation may be very important for the future of Thailand's coral reefs (Spalding et al. 2001; Dearden et al. 2007).

The 2004 Indian Ocean tsunami created a physical and social disturbance along Thailand's Andaman coast. The response of ecosystems and human communities to this disturbance clearly illustrated the fundamental integration of society and ecology. My thesis research grew out of this observation, and it is both theoretical and applied in nature. This research addresses three key themes in a distinctly geographical approach: integration, spatial differentiation, and application.

Following this introductory chapter, I have written two papers, followed by a concluding chapter. These papers are an attempt to address some key challenges in marine conservation by straddling disciplines in an integrated ecological and social approach. In the first paper, I will examine the tsunami as a large-scale ecological disturbance on coral reefs within Mu Koh Surin Marine National Park in Thailand. The purpose of this research was to learn how reefs responded to this event and what factors may have shaped the spatial nature of this response. In the second paper, I examine the tsunami as a social disturbance for Phuket's diving industry. The purpose of this research was to learn how the diving industry responded to the tsunami's effects on coral reefs and to explore the potential of the industry to help alleviate challenges in the application of marine conservation in Thailand. In the concluding chapter, I will review the main findings of both papers and highlight the important links between them. Based on this and past research, several recommendations will be made for future management of Koh Surin's coral reefs and for fostering sustainability and incentives for marine conservation among members of Phuket's diving industry.

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CHAPTER 2: Physical response of fringing coral reefs of Mu Koh Surin Marine National Park, Thailand, to the 2004 Indian Ocean Tsunami

2.1. Introduction

2.1.1 Coral reef biology

Coral reefs are some of the most productive and biologically diverse systems in the world. The reason these systems can exist and be highly productive within nutrient-poor tropical oceans is due to the unique evolution of an association between tiny coral polyps and a unicellular zoxanthellae symbiont. This symbiont provides the nutrients that enable Scleractinian coral polyps to secrete enough calcium carbonate ($CaCO_3$) to build the massive frameworks that house corals and provide habitat for the entire assemblage of reef-associated species.

Competition is one of the main biological interactions among corals that affects reef structure by controlling local diversity and relative species abundances (Jackson 1977). There are a variety of competitive mechanisms that allow corals to replace or eliminate each other directly or indirectly. Some complex competitive strategies are extra-coelenteric digestion, the use of mesenterial filaments and sweeper cells, mucus secretion, overgrowth, shading and chemical release (Goreau et al. 1979; Rogers 1993). The outcome of these interactions depends on the species involved, the size and age of organisms, morphological diversity, and physical factors such as substrate topography and distance between organisms.

Because high productivity for corals is only possible through photosynthesis, light is a fundamental limitation for tropical coral reefs, restricting reef development to dynamic shallow waters. This means that the rate at which $CaCO_3$ secretion (i.e.

productivity) occurs must be considerable in order to balance high rates of physical (as well as biological) erosion in these systems (Goreau et al. 1979). Within this competitive and dynamic regime, physical disturbance can be viewed either as a disruptive process *or* as an intrinsically structuring one.

2.1.2 Disturbance on coral reefs

Terrestrial ecological understanding has provided the foundation for explanations of changes in species assemblages on coral reefs over time (Connell 1978; Karlson & Hurd 1993). Earlier explanations proposed that changes in relative species abundance and dominance could be expected to proceed through a predictable, biologically-driven succession toward some climax equilibrium state (Odum 1969). Underlying this theory was the assumption that environmental conditions remain relatively stable; disturbance was viewed as extrinsically disruptive, but not structuring. Although stability has been observed at some scales in terrestrial systems, marine environments are highly dynamic at most scales, and there is no compelling evidence in the literature for a stable state "equilibrium" on coral reefs. Instead, these systems appear to be defined by continuous change, with biological and environmental disturbances driving this change.

Since competition is a dominant interaction for most coral reef building species, space may be one of the most important limiting resources for corals (Jackson 1977). By creating space, therefore, disturbance can be viewed as an intrinsic process, as it constantly influences changes in abundance, diversity and the spatial distribution of species assemblages on coral reefs over time (Connell 1978; Connell & Keough 1985;

Karlson & Hurd 1993; Rogers 1993). The life-history strategies of reef-building corals seem to provide support for this theory.

As Grime (1973) proposed for terrestrial plants, individual coral species can also evolve unique strategies for long-term reproductive success in a disturbed environment (Goreau et al. 1979; Edinger & Risk 2000). They may become successful colonizers, competitors, stress-tolerators, or some combination of the three. In an environment without external stress, one would expect that competitive strategies should dominate over time. However, periodic disturbance can inhibit long-term competitive dominance to facilitate the success of different strategists and allow for greater diversity by reducing competitor abundance, clearing substrate for colonizers, and allowing stress-tolerant species to persist (Connell 1978). The fact that several coral species are morphologically predisposed toward fragmentation, and can reproduce asexually in this way, combined with the fact that well-developed reefs typically exist in highly disturbed environments, provides good reason to view disturbance as an intrinsic process (Highsmith 1982).

Change created by disturbance can be measured on reefs at all scales, but the importance of disturbance is harder to quantify. One approach for assessing the ecological significance of a particular disturbance event is to quantify change and measure significance in terms of outcome, or recovery, back to a pre-disturbance state. Done (1992) has documented several examples in which coral reefs have undergone a change to a persistent algal-dominated state after substantial stress, rather than recovering to their pre-stress state of coral dominance. It seems that whether or not recovery occurs – whether the event is ecologically significant – depends upon the scale of the event (magnitude and whether chronic or acute), and the inherent resilience of the reef system (Done 1992; Rogers 1992; Folke et al. 2004).

Resilience is the ability of a system to absorb recurrent disturbances and still maintain essential structures, processes and feedbacks (Holling 1973). Resilience is partly a function of past history; for example, coral reefs subject to chronic disturbance, with short intervals between disturbance events, will be less able to deal with future stress than reefs with a sufficient chance to recover between disturbances (Connell et al. 1997). It is also a function of natural variation in reef structure and the presence of other sources of stress. Determining the ecological significance of a single source of disturbance on a coral reef requires long-term monitoring and can be extremely challenging as other disturbances may occur simultaneously and interact synergistically (Hughes & Connell 1999).

Disturbance on coral reefs can occur at all scales and can arise from a multitude of sources. These have been categorized as 'anthropogenic' or 'natural' – although the distinction is becoming more obscure under emerging ideas of coral reefs as linked social-ecological systems (Walker et al. 2004; Adger et al. 2005). As many coral reefs are either located in close proximity to dense human populations, or are used heavily by tourists, they are susceptible to substantial stress. Some direct disturbances to coral reefs include pollution by terrestrial runoff, sedimentation, over-harvesting, noise pollution, destructive fishing techniques, mechanical damage from fish nets and garbage, anchoring, diving, vessel grounding, as well as gray and black-water pollution.

Although management is necessarily targeted at human activity, background natural disturbance regimes will influence the resilience of these systems to further stress associated with human use. Therefore, understanding the mechanisms, dynamics, and outcome of natural disturbance within these systems is highly relevant to management for coral reef conservation. Natural disturbances may be biotic, such as changes in predator-prey interactions (for example, predatory *Acanthaster plancii* outbreaks, herbivorous *Diadema* population crashes – see Done 1982), or abiotic, such as environmental fluxes (for example, nutrients, light or temperature level changes), hydrodynamic disturbance during storms, and, more rarely, tsunamis.

2.1.3 Hydrodynamic disturbance

Large-scale events such as tropical storms have been recognized as intrinsically structuring sources of disturbance in coral reef systems (Connell 1978, 1997; Rogers 1993; Connell et al. 1997; Gardner et al. 2005). Physical changes are brought about directly by high energy hydrodynamic forces associated with wave disturbance. Coral fragments and terrestrial debris carried onto the reef surface by this primary disturbance can then cause secondary mechanical damage as they are transported by wave motion and tumbled across the reef surface during storms. In these ways, tropical storm disturbance can create sudden and dramatic physical changes on reefs – and typically with overall high spatial variability, or patchiness (Woodley et al. 1981; Edmunds & Witman 1991; Rogers 1993). Typical storm damage to corals includes toppling, fragmentation, tissue damage, bleaching, and smothering (Bries et al. 2004). Several researchers have documented immediate effects of storm disturbance on reefs and noted high spatial variability linked to scale, the presence of other stresses, and natural variability among sites (Woodley et al. 1981; Rogers 1992; Dollar & Tribble 1993; Bythell et al. 2000; Bries et al. 2004; Gardner et al. 2005; Rogers & Miller 2006).

Water depth, wave exposure, site orientation, and the composition of bottom communities have all been causally linked to spatial variability in storm effects on reefs (Rogers 1992). The heaviest effects usually occur where waves break at the reef crest (Woodley et al. 1981; Rogers et al. 1992), except on steeper reefs (45° and over), where storm-generated debris can avalanche down-slope (Rogers, 1992; Dollar & Tribble, 1993). The orientation of sites to storm approach is fundamentally important in the level of damage that is sustained. Sites on leeward shores are more susceptible to storm effects than sites that are exposed to frequent weather because they are not adapted to hydrodynamic disturbance (Harmelin-Vivien & Laboute 1986; Rogers 1992; Bries et al. 2004). Bottom community composition can also influence hydrodynamic force due to variations in reef topography that control flow dynamics (Rogers 1992).

At a given magnitude of disturbance, characteristics of individual colonies – especially variation in the morphology of Scleractinian corals – can lead to variation in reef response (see Mah & Stearn 1986; Hughes 1987; Marshall 2000; Madin 2005; Storlazzi et al. 2005). Hughes (1987) compared skeletal density and morphology in ramose (branching), massive (boulder-like) and foliaceous (plate-like) corals and found that skeletal density is strongly related to growth form. He determined that branching morphologies exhibit a large range in skeletal density such that outer regions are highly brittle and readily respond to storm disturbance (this potentially facilitates asexual reproduction by fragmentation – see Highsmith 1982). Conversely, large boulder-like morphologies have low density skeletons, but their shape is highly resistant to hydrodynamic disturbance. Plate-like morphologies have the densest skeletons, but in shallow regions they are still highly susceptible to breakage. High density of these skeletons appears to be a developmental adaptation since heavy plates would collapse under a porous framework (Hughes 1987).

Because storms occur frequently over tropical oceans, there has been much opportunity to study the effects of storm-generated hydrodynamic disturbance on coral reefs. Until the 2004 Indian Ocean tsunami, however, few other sources of large-scale hydrodynamic disturbance have been documented on coral reefs. This event provided one of the first opportunities to observe the effects of tsunami disturbance on coral reefs *in situ*.

2.1.4 The 2004 Indian Ocean Tsunami

On the morning of December 26, 2004, a slip along 1600km of the Sunda and Indo-Australian subduction interface off the NW coast of Sumatra generated the ≈ M_w 9.2 Sumatra-Andaman earthquake (Meltzner et al. 2006). The massive vertical displacement of overlying seawater along the fault initiated a tsunami that reached run-up heights of 25-30m on Sumatra's NW coast (Stein & Okal 2005), and traveled through the Indian Ocean with catastrophic effects along coastlines throughout SE Asia (Figure 2.1). Most areas directly adjacent to the Sumatra/Andaman earthquake epicenter were indiscriminately affected by the synergized forces of the massive earthquake and tsunami waves. With increasing distance, however, spatial patterns in the terrestrial and marine effects of the tsunami began to emerge as energy dissipated. About one hour after the initial earthquake, the series of tsunami waves and associated surge reached the Andaman Sea coast of Thailand.

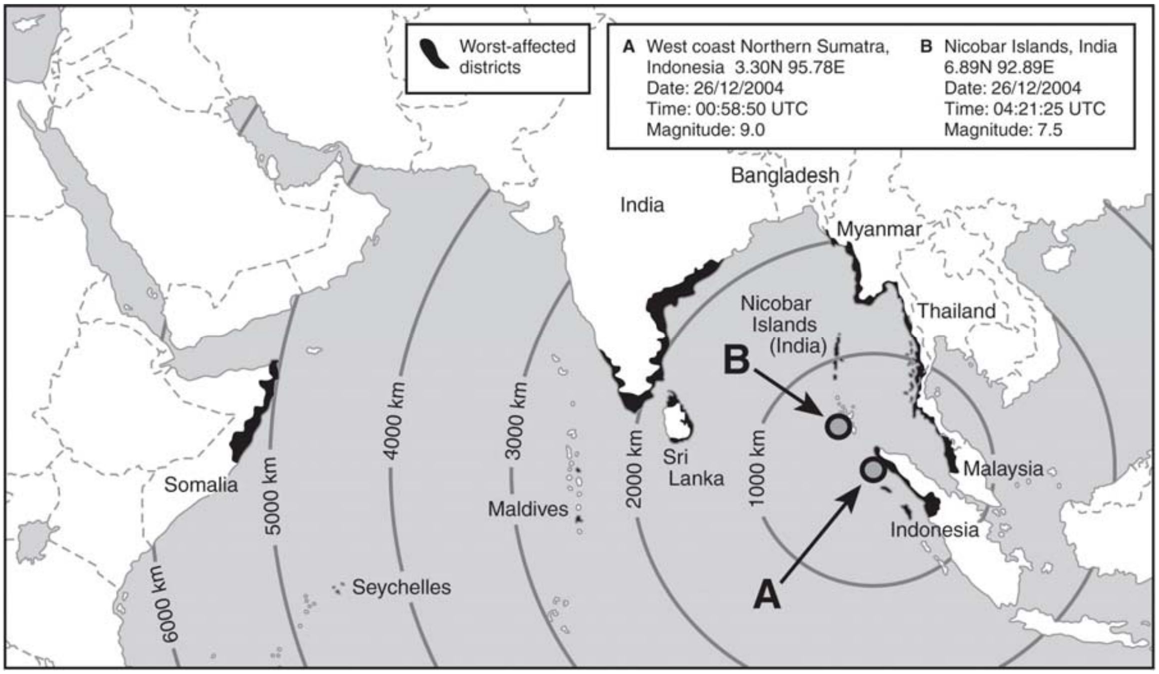


Figure 2.1. Location of the 2004 Indian Ocean earthquake and tsunami

Tidal station records and post-tsunami surveys have given limited information about tsunami wave magnitudes and run-up heights in some locations along the coast (Tsuji et al. 2006), and numerical modeling has not yet been completed due to the lack of detailed bathymetrical knowledge of this region. While details of tsunami wave properties for most of the Thai Andaman Sea are unknown, some general trends exist (Rabinovich & Thomson in press). Based on tide gauge data, it appears that the maximum wave heights occurred further along in the wave train with increasing distance from the source; tsunami energy decay times also increased with increasing distance from the source; and the wave oscillations overall were polychromatic but a dominant period of 40-50 minutes was perceptible. These generalizations correspond well with in situ observations at Mu Koh Surin, Thailand.

Mu Koh Surin Marine National Park is located off Thailand's Andaman Sea coast and about 750km from the earthquake epicenter (Figure 2.2). It is a group of five islands and two rocky pinnacles with well developed fringing limestone reefs along several coastlines. Coral reefs within the park have been well studied by national and international research teams (Simon & Chantana 2000; CCC 2005), including the University of Victoria (Theberge 2002), whose research has been supported and facilitated by park management and staff. In late December, 2004, baseline reef surveys for Kasetsart and Ramkamhaeng Universities in Thailand were being conducted by SCUBA within the park. On the morning of the tsunami, I was surveying at Ao Suthep ('AS' in Figure 2.3) with the research team. This was a shallow fringing reef site with high profile corals, low exposure and minimal current flow.

Under water, unusual currents were felt 1-2 hours after the initial quake. These currents were directionally inconsistent across the reef surface. Currents rapidly built in strength and we were carried 5-10m up to the surface and channeled through exposing massive coral heads to deeper water as shallower areas of the reef became exposed. Seawater height fluctuated about 3-5m from sea level (observed against a large boulder on shore) as the wave approached and broke along the shore in a rooster-tail from west to east. In the 25-30 minutes until the next large wave approached, there was a tremendous amount of surge with less drastic, but consistent, changes in seawater height, and smaller rooster tails along the shore from the west. The volume of the second wave appeared larger than the first and moved in a similar path. The third wave was much smaller.

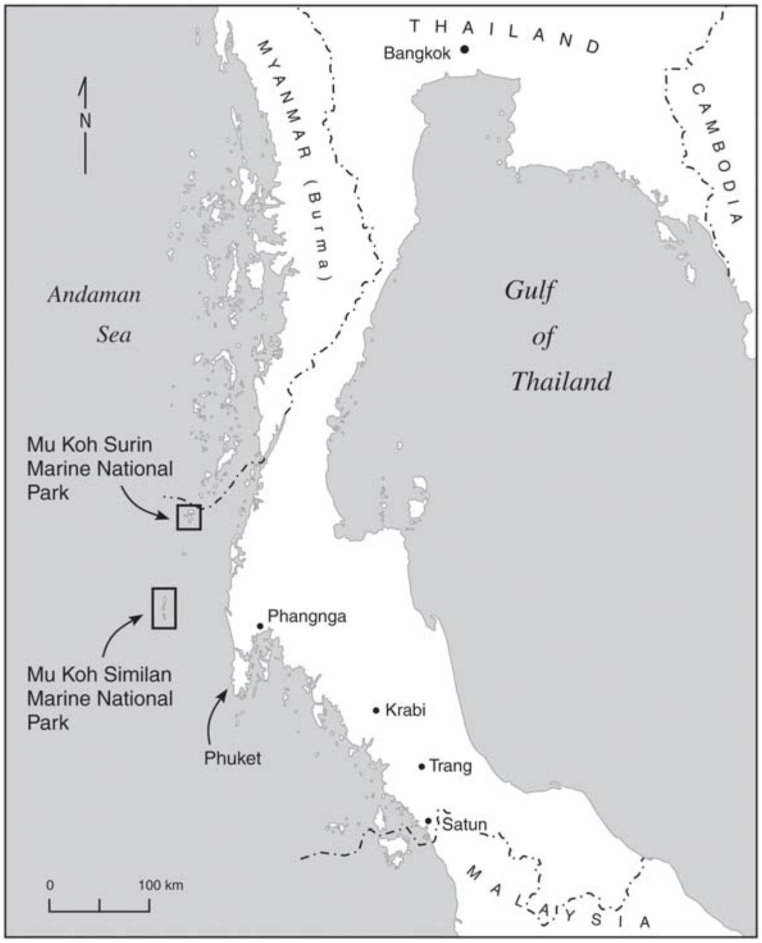


Figure 2.2. Location of Koh Surin in the Thai Andaman Sea

Surge remained quite strong over the next several hours close to shore and much terrestrially originated debris could be seen moving across shallow reef areas and floating throughout the park (about 8 hours after the initial tsunami wave, those of us staying at the park were evacuated to a cruise ship in deep water). According to visitors on land, large amplitude tsunami waves traveled from the west through the channel between the two largest islands, Surin Tai and Nua (Figure 2.3), scouring over the beach and causing large trees to fall (Figure 2.4a), destroying park buildings and dragging debris across the beach and into the sea (Figures 2.3b,c), transporting coral boulders east through the channel (Figure 2.4d) and carrying several tourists and their belongings into the water. On the beach in Mai Ngam bay (Figure 2.3), the tsunami did not penetrate far into the forest, but caused substantial erosion falling trees along the shore.

After observations of unprecedented coastal destruction, scientists expected substantial damage to the Andaman Sea's coral reefs (Brown 2005). However, effects seemed relatively minor overall, with high spatial variability at several scales. Although tsunamis have occurred in this region in the past, until this event there had been no reference to the effect of tsunamis on coral reefs in the literature. In the context of rapid global decline of coral reefs, understanding mechanisms of change is critical. The purpose of this research was to gain understanding of the tsunami as a large scale natural disturbance on fringing coral reefs of Koh Surin by describing the nature of tsunami effects and examining some geographical factors which may have contributed to variation in these effects.

The specific questions addressed by this study are:

1. What was the physical response of Koh Surin's fringing reefs to hydrodynamic disturbance associated with the tsunami event?
2. Was there a relationship between variation in the magnitude of tsunami effects on Koh Surin's fringing reefs and differences in the
    a) profile of reefs?
    b) morphology of reefs?
    c) depth of overlying water column on reefs?
    d) geographical location of reefs?

3. Which of these factors were most influential in discriminating among sites with varying levels of effect?

In the following sections, the study area will first be described and then methods of data collection and analysis will be explained. The results of this research will be reported, followed by a discussion of the findings and research design as they apply to the purpose of this study. In the conclusion, the 'ecological significance' of this research and prognosis for future recovery of reefs at the Surin Islands will be addressed.

2.2 Materials and Methods

2.2.1 Study area

Mu Koh Surin Marine National Park (Figure 2.4) is located 60km off the northwest coast of Thailand, lying within 9°3'30" - 9°21'50"N and 97°48'00" - 97°54'25"E. Two large and three smaller granitic islands comprise the terrestrial component of the park. A substantial 76%, (102km^2) of the park is marine, with up to 8km^2 of complex shallow fringing coral reef that supports one of the highest diversities of reef-associated biota in the country (Worachananant et al. 2004). Large fringing reefs have formed along more protected coastlines of the five islands and consist of a gently sloping reef flat from 1-5m deep that extends out to the reef crest and gradually slopes down to the sandy ocean floor anywhere from 10 to 23m deep at the deepest point. Shallow patch reefs are found adjacent to some fringing reefs and in the narrow channel between Surin Tai and Nua.

The coral reef system here is mainly Scleractinian with some soft corals and gorgonians in deeper areas. The families Acroporidae, Pocilloporidae, Faviidae, Poritidae, Agariciidae, Fungiidae, Mussidae and Dendrophyllidae are well represented. Low profile, wave-resistant morphologies, especially evident in branching morphologies, have developed in more exposed regions of fringing reef, while protected sites and deeper regions with minimal surge tend to support higher profile colonies that provide complex three-dimensional habitat for other benthic organisms.

The main source of natural disturbance to these reefs is storm wave stress during the annual SW monsoon which begins in late April and builds to its strongest in July and August (Theberge 2002). As a result, the west coasts of the islands are mainly bare rock and encrusting corals with a predominance of wave-resistant morphologies on more exposed reefs (Jackson & Chantana 2000). Large-scale disturbances such as the 1995 and 1998 Andaman Sea warming events (Phongsuwan 1998; Worachananant et al. 2007) have affected this area sporadically. The 1995 event led to limited bleaching and minor algal proliferations (Simon & Chantana 2000). Small groups of *Acanthaster plancii* (Crown-of-thorns starfish) have been observed on some reefs, but there have been no recorded population outbreaks. Sedimentation has also not been a substantial threat to corals as the islands are covered in dense tropical old growth forest.

Oceanic circulation is strong in the deep basin between the islands and Thailand's west coast, so mainland-based pollution on coral reefs of Koh Surin is minimal. Some anthropogenic threats to the area include nutrient inputs from sewage outflow at the park headquarters at Ao Chong Khad and from the small permanent settlement of Moken, traditional Andaman Sea gypsies, on Surin Tai and Nua (Figure 2.3).

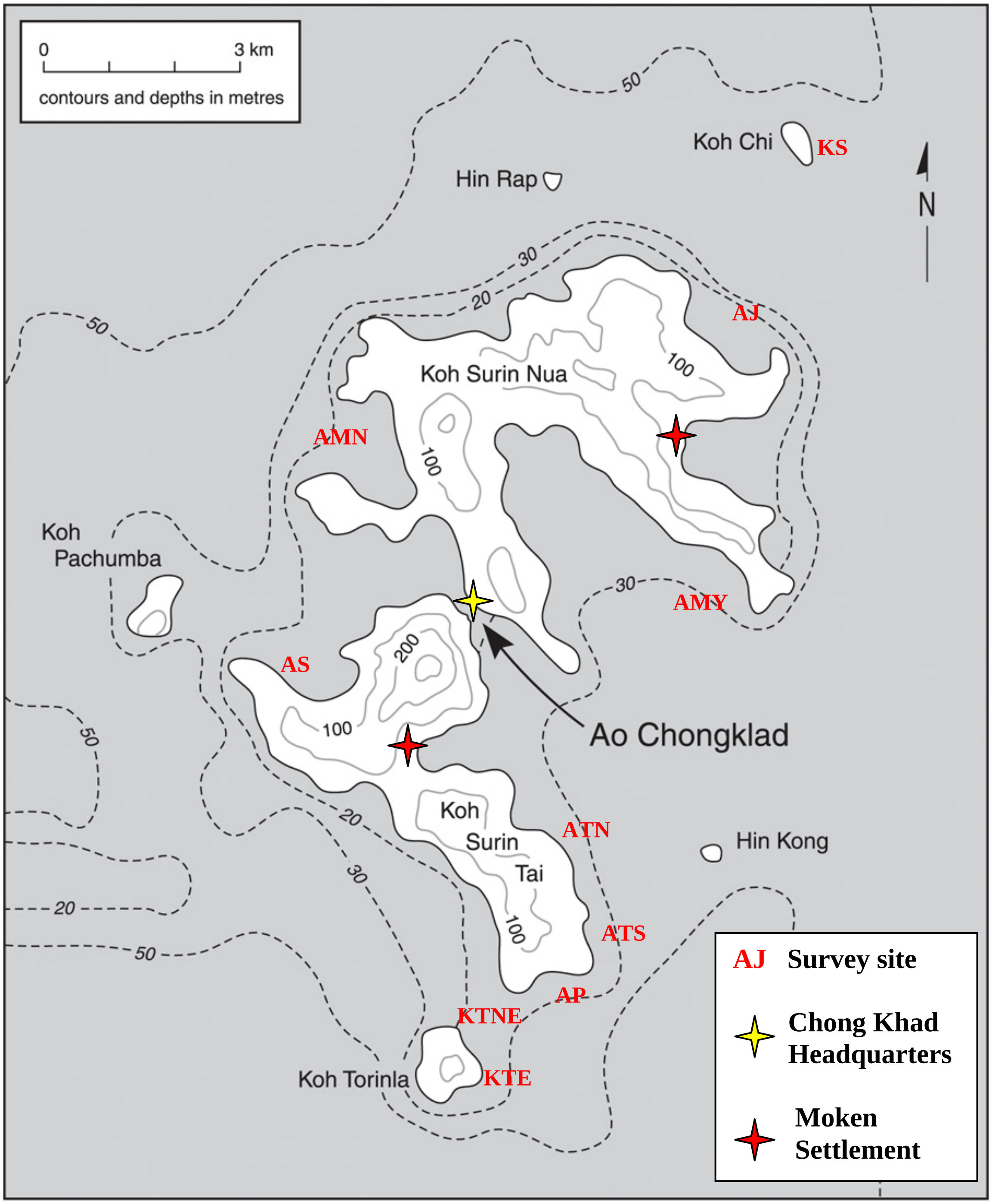


Figure 2.3. Study sites at Mu Koh Surin Marine National Park (table 2.1 – site codes)

a) shoreline erosion at Ao Chong Khad HQ

c) tsunami-transported park sign

b) tsunami-destroyed park buildings

d) tsunami-transported coral rubble

Figure 2.4a-d. Tsunami damage at Koh Surin Headquarters

Marine-based tourism is a major source of disturbance to the reefs during the high season from late October to April. Tourist activities have the potential to cause substantial stress on reefs (see Chapter 3), but due to limited accommodations, remoteness and seasonally unpredictable seas, there are only a handful of tour companies that run diving and sightseeing trips from the mainland. Small patches of dead reef at certain sites are evidence of past destructive fishing techniques and damage from anchoring that occurred mostly before 1981. Year-round subsistence fishing by the Moken and illegal commercial fishing remain a threat to the area – especially when park staff is down-sized and resources to patrol the waters are especially reduced in the non-tourist season.

Compared with other marine parks in Thailand, however, anthropogenic disturbance has been minimal, allowing for the maintenance of some of the most intact and structurally complex reefs in the country. A very small amount of recent coral damage was detected in Reefcheck surveys conducted in December 2003 and 2004 (Koh et al. (2003) and Loh et al. (2004) found less than 1% of surveyed reef area damaged in both years except for Ao Tao N which had 5.31% recently killed coral in 2004).

2.2.2 Sampling design and data collection

All reef sites were dived in early December, 2004, before the tsunami. Underwater observations and a pilot survey to examine tsunami effects began in January, 2005, one month after the Indian Ocean tsunami. Sampling for this study took place in late March, 2005. Ten sampling sites were selected (Figure 2.4, Table 2.1) based on criteria including the presence of continuous fringing reef as well as mooring buoys to facilitate sampling dives. Tsunami effects on these sites represented the full range in effect magnitudes throughout the park. Mooring buoys at which divers descended were located at GPS coordinates from Reef Check surveys completed in December 2003/4 (Koh et al. 2003; Loh et al. 2004) for pre and post-tsunami comparison.

Within each sampling site, four randomly-placed quadrats were sampled at two depths (quadrat placements were pre-determined by a randomly selected number of kick cycles, limited by time underwater). Sampled depths were consistent with 2004 Reef Check surveys at the shallow fore-reef just below the reef crest (about 3-5m deep) and on the lower fore-reef slope (from 10-20m deep).

Surveys took place between during diurnal slack water periods. Two divers descended at a mooring buoy and swam to pre-determined depths where a $9m^2$ quadrat was deployed (Appendix 1, Figure A2.1). Reef surveys typically utilize $1m^2$ quadrats or line-transect methods, but a large sampling unit size was recommended by ICRI's guidelines for tsunami damage surveys to account for patchiness in effects (ICRI 2005). During survey dives, the first diver digitally photographed the quadrat in $1m^2$ frames (small subunits for higher image resolution) from above and perpendicular to the reef surface while the second diver recorded observations in situ on waterproof paper. Observations included a qualitative description of the study site and quantitative estimations of tsunami damage categories and coral cover by morphological categories. For consistency, divers kept the same roles throughout the study. Table 1 lists the morphological and damage categories measured following Reef Check protocol with suggested ICRI modifications (2005). Allen and Steene's Indo-Pacific Coral Reef Field Guide (2002) was referenced for taxa identification.

Census dives were also conducted at several sites to collect qualitative information on a broader scale for comparison with sampling results. Data was archived in Excel and photographs were downloaded at the end of each sampling day. All entries were double-checked and *in situ* observations were referenced in later photographic analysis.

2.2.3 Data analysis

Digital images were downloaded into NCRI's coral point count software, CPCe (Kohler & Gill 2006), and frame perimeters were used for length reference in each image. In preliminary trials, 70 randomly placed points were found to consistently represent over 90% of categories present in randomly selected frames. Points were overlaid on each frame, then tsunami and morphology groups (Table 2.2) were assigned to the object lying directly beneath each point. Where points fell on the quadrat frame or could not reliably be identified, they were respectively categorized as "frame" and "unknown." Effect types were only included in this analysis if they could be confidently attributed to the tsunami. The most extremely affected site, KTNE (Figure 2.3), could not be included in the comparison of pre-tsunami morphology and effect magnitude as the 2004 GPS reference point for descent was not reliable.

Table 2.1 – Site attributes at 10 sampled reefs around Koh Surin

Reef	Slope[1]	Monsoon	Current	Constriction	Pre-tsunami activities
Ao Suthep **(AS)**	11°/29°	leeward	low	open	Some skin diving
Ao Jaak **(AJ)**	19°/14°	leeward	moderate	open	Popular skin diving/some SCUBA
Ao Mae Yai **(MY)**	11°/16°	leeward	low	open	Skin diving; anchorage
Ao Tao North **(ATN)**	28°/50°	leeward	moderate	open	Popular skin diving/popular SCUBA (night dives); near anchorage
Koh Satok **(KS)**	10°/15°	leeward	high	open	Some skin diving/some SCUBA; recently reopened for recreation[2]
Ao Phakkad **(AP)**	23°/33°	windward	moderate	nearby	Skin diving/some SCUBA
Ao Tao South **(ATS)**	38°/45°	leeward	high	open	Skin diving/popular SCUBA (night dives)
Koh Torinla East **(KTE)**	14°/13°	leeward	moderate	nearby	Some skin diving/popular SCUBA
Koh Torinla NE **(KTNE)**	6°/6°[1]	windward	high	constricted	Very popular skin diving/SCUBA; recently reopened for recreation[2]
Ao Mai Ngam **(MN)**	5°/15°	windward	low	open	Popular skin diving; anchorage; adjacent to beach campsite

[1] average estimate for shallow/deep slope at quadrat placements after the tsunami (KTNE deep reef profile had been drastically modified by the tsunami)
[2] a zoning scheme had several sites closed for recovery and/or protection (Worachananant et al. 2004). Anecdotal reports suggest zoning was not enforced.

Data (averaged values for 9m^2 quadrats) was examined visually and with one-sample Kolmogorov-Smirnov tests for parametric statistical assumptions. Pre-tsunami morphological variables (data from Loh et al. 2005) met assumptions for parametric statistical testing, but post-tsunami effect data showed non-normality (positive skew) with outliers and extreme values. Thus, non-parametric and parametric methods have been employed in this analysis. Where necessary, effect data has been normalized (ln-transformed) for parametric inferential statistical testing. Univariate and multivariate analyses (two-tailed at $\alpha = 0.05$) were computed with SPSS software version 14.0 (Statistical Package for the Social Sciences).

Table 2.2. Measured morphological and tsunami effect categories

	Indicator	Code	Notes
Morphology*	Branching coral	CB	Tree-like HC
	Digitate coral	CD	Finger-like HC
	Tabular coral	CT	Flat plate-like HC
	Foliose coral	CF	Floral/lettuce-like
	Submassive coral	CS	**
	Massive coral	CM	Boulder-like HC
	Encrusting coral	CE	Low-profile, encrusting growth forms
	Mushroom coral	CMR	Free-living mushroom-like HC
	Blue coral	CHL	*Heliopora coerulea*
	Fire coral	CME	*Millepora* spp.
	Soft coral	SC	All soft coral/gorgonians
	Fleshy algal group	FAG	Includes filamentous/leafy algae
	Turf algal group	TAG	Grass-like green algae
	Substrate	S	Reef framework (pavement, sand, rock)
	Coral rubble	R	Unfused dead coral fragments
	Unknown	UNK	Unidentifiable in photograph or under quadrat frame
Tsunami Effect**	Fragment	FRAG	Fragment of coral colony (usually branching corals)
	Recently broken colony	RBREAK	Standing colonies with obvious recent skeletal fractures (either bare or with some filamentous algae)
	Recently dead coral	RDEAD	Bleached coral points (unless Crown-of-Thorns starfish present and clearly distinct from grazing scars)
	Recently overturned coral	OVER	Entire colony dislodged or broken at base
	Tumbled coral	TUMB	Dislodged/fragmented coral transported downslope
	Rubble piling/movement	RPM	Piling of unfused coral rubble
	Recently exposed substrate	RES	Reef framework recently exposed with signs of scouring or reef framework completely removed

*See Hill (2006) for images
**See Appendix for images

The morphological composition of lower and upper reef slope communities was compared using a multivariate generalized linear model (GLM) for dominant morphologies to determine whether a nested analysis was necessary. Potential relationships between the magnitude of tsunami effect and dominant coral morphologies were then explored in scatterplots and with bivariate correlations (Pearson's R). To examine differences in tsunami effect for various reef and site attributes, a combination of independent samples t-tests, univariate ANOVA and Kruskall-Wallace tests were employed on normalized data.

A general linear model was constructed to determine the relative ability of site attributes to explain the variation in tsunami response throughout the park. Relationships between variables were examined, then independent attributes (Pearson's $R < 0.60$) which significantly explained differences in tsunami response were simultaneously entered as main effects into the model. The model was estimated for normalized tsunami effects in order to meet the assumptions of GLM.

2.3 Results

2.3.1 Benthic tsunami effects

Tsunami-attributable effects on coral morphologies were clearly distinguishable at Koh Surin since there were no recent mechanical disturbance effects to coral observed in the park on dives prior to the tsunami (all survey sites were dived by the author in December, 2004, before the tsunami; pre- and post-tsunami census observations are summarized in Table 2.3.). The magnitude of tsunami effects were highly variable (or patchy) among different locations throughout the park during census dives. Overall, this patchiness appeared consistent among sites and at all depths of the reef slope. Effects were distinct, however, in the two most drastically affected locations.

Off the NE coast of Koh Torinla (Figure 2.3), an entire section of fringing reef and the extensive community of dendronepthya corals that covered Yellow Rock, a submerged pinnacle between the islands, had been completely scoured out. Almost no evidence of fragmented or dead coral colonies remained, just scoured and contoured coral sand and bare rock in areas as deep as 30m (Appendix 1, Figures A2.2-4). The only other location with a similar degree of damage was near Chong Khad headquarters (Figures 2.4a-c). In this area, surge had scoured patch reefs and hundreds of coral boulders had been transported in both directions through the channel (Figure 4d).

Koh Surin's fringing reefs have relatively few massive gorgonian seafans and soft corals compared to other areas in the Andaman Sea, but some colonies had sustained tissue damage, fragmentation or basal severing (Appendix 1, Figures A2.5a,b). Transportation of large woody debris across reef surfaces (Appendix 1, Figure A2.5c) was also observed on census dives. Soft coral damage and woody debris were both highly localized effects and were not quantified in sampling.

Very limited points of recent coral bleaching were present on some sites. However, it was unclear whether this was directly caused by the tsunami or by the few Crown-of-Thorns starfish observed within the park (Appendix 1, Figure A2.6). For this reason, coral bleaching was not included as a tsunami effect in analyses. Tsunami siltation (Appendix 1, Figure A2.7) has also not been considered as surveys were completed over two months after the tsunami, and, in some areas, it was not possible to positively identify silt as having been tsunami transported.

Effects that could be confidently attributed to the tsunami (shown in Appendix 1, Figures A2.8a-g) included fragmentation of coral colonies, overturning of basally-severed colonies, breakage of standing colonies, recent coral tissue death, recently exposed reef framework where corals had been removed or complete removal of reef framework, piling and movement of coral rubble and down-slope tumbling. Large vertical tracts of scoured reef were observed from the upper to lower reef slope along Ao Tao reef, forming channels down which broken or dislodged colonies had been transported and piled at the reef base. This type of effect was not observed on other reefs within the park.

Fragmentation of coral colonies was the most frequently observed tsunami effect (Table 2.4). There were few colonies observed that were fractured or had tissue damage yet were still standing. It seemed that the majority of affected hard coral colonies had been completely removed from the reef framework and fragmented as they were transported across or down the reef during the tsunami disturbance.

Overall, 10.26% (median with 15.12% inter-quartile range) of sampled fringing reefs showed one or more of the above categories of tsunami effect on hard coral. A consistently high variability in quantified tsunami effects within and among reefs (Table 2.5) corresponds to the patchiness observed on dives where some areas were drastically changed while adjacent areas remained virtually as they had been prior to the tsunami.

Table 2.3 – Pre- and Post-tsunami observations of 10 sampled reefs of Koh Surin

Reef	Pre-tsunami observations	Post-tsunami census observations
AS	Low complexity reef; some bleaching/COT	Some sedimentation and fragmentation of ACB
AJ	Complex; almost no fish	Two gorgonians with basal severage; minimal fragmentation of colonies
MY	Low complexity; deep corals degraded (anchoring?)	Few recent effects; large colony of *Millepora spp*. fragmented; extensive degradation of deep corals including soft corals and siltation (likely associated with anchorage effects)
ATN	Steep, complex; many fish	Vertical scoured tracts w/ piling at reef base; some garbage on reef; extensive down-slope transportation & associated damage; some large woody debris; some siltation (tsunami?)
KS	Patchy reef; dendronepthya & sand; patches of abundant zoanthid colonies on coral skeletons	Few recent effects; ghost fishing net tangled in coral colony
AP	Complex; some fish	Some recent effects;
ATS	Steep complex reef; many fish	Vertical tracts of scoured reef w/ piling at reef base; extensive down-slope transportation & associated mechanical damage; some large woody debris and siltation (tsunami?)
KTE	Low complexity; anchor/blast fishing scar patches	Few recent effects;
KTNE	Complex reef; anchor/blast fishing scar patches	Completely landscaped coral sand; very little rubble evident; large boulders showing up to 1m changes in sediment level
MN	Low complexity reef; coral degradation	Extensive siltation observed (origin uncertain); degraded corals

Table 2.4. Summary of overall proportional tsunami effects on hard coral within Koh Surin

Effect type	Mean proportion	std. dev.	Median proportion	i.q.r.
fragmentation	.1295	.2157	.0468	.1385
overturning	.0022	.0085	.0000	.0000
recent breakage	.0001	.0007	.0000	.0000
recently killed coral	.0052	.0150	.0000	.0016
recently exposed substrate	.0509	.2164	.0000	.0000
piling/movement of rubble	.0162	.0356	.0000	.0206
downslope tumbling	.0064	.0194	.0000	.0012

Table 2.5. Summary of proportional tsunami effect on hard coral at 10 reef sites within Koh Surin

Reef	Mean proportion	std. dev.	Median proportion	i.q.r.
AS	.0340	.0406	.0230	.0529
AJ	.1002	.0602	.1127	.1264
MY	.0364	.0385	.0198	.0654
ATN	.2172	.2204	.1601	.2782
KS	.0868	.0630	.0826	.1283
AP	.1325	.0896	.1136	.1185
ATS	.2109	.2363	.0651	.3332
KTE	.1751	.0911	.1817	.1560
KTNE	.9880	.0198	.9992	.0314
MN	.1072	.0702	.0897	.1080

2.3.2 Reef profile

In the following sections, untransformed tsunami effect proportions have been graphically represented. Parametric significance tests have been carried out on normalized (ln-transformed) data for groups with highly skewed distributions, and, where other parametric assumptions could not be met, non-parametric methods were employed. Extreme values and outliers are accounted for by all quadrats at KTNE (cases 73-80 on boxplots; 95-100% affected by the tsunami), two quadrats at ATN (27,30; 69% and 35% affected) and three at ATS (49-51; 67%, 38 and 37% affected). ATN and ATS were both the steepest sites within the park on which highly patchy tsunami effects were observed.

The influence of reef profile on the tsunami disturbance was examined by looking at the extent of reef flat area, the maximum depth to which reefs extended, and the steepness of the reef slope. The extent of reef flat area above sites did not seem to affect the relative proportion of tsunami affected area on the reef slope (Figure 2.5). No difference in mean effects was detected (t = -0.255, p = 0.799).

There seemed to be a slightly greater effect on sites which were deeper (Figure 2.6). This was not an important factor influencing the observed differences in tsunami effects throughout the islands, however, as normalized effects between these three groups were not significantly different (F = 1.569, p = 0.215).

Although there was no linear relationship between normalized tsunami effect and increasing reef slope (Pearson's R = 0.038, p = 0.744), Figure 2.7 shows high variability at 40º and a possible increasing effect on slopes above 45º steep. When sites below 45º (N=70) and sites above 45º (N=10) were compared, steeper sites were significantly more affected than other sites (t = -2.083, p = 0.041; without KTNE, t = -1.938, p=0.057).

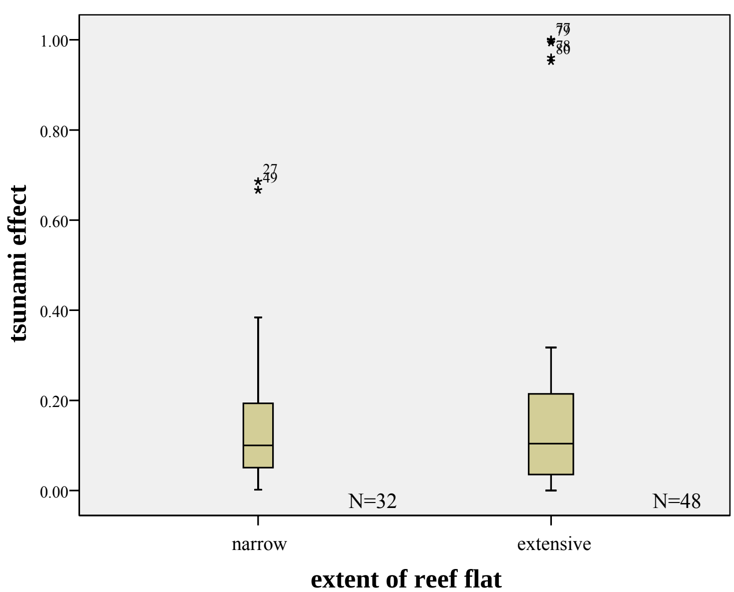


Figure 2.5. Proportional tsunami effect between sites with narrow and extensive reef flats

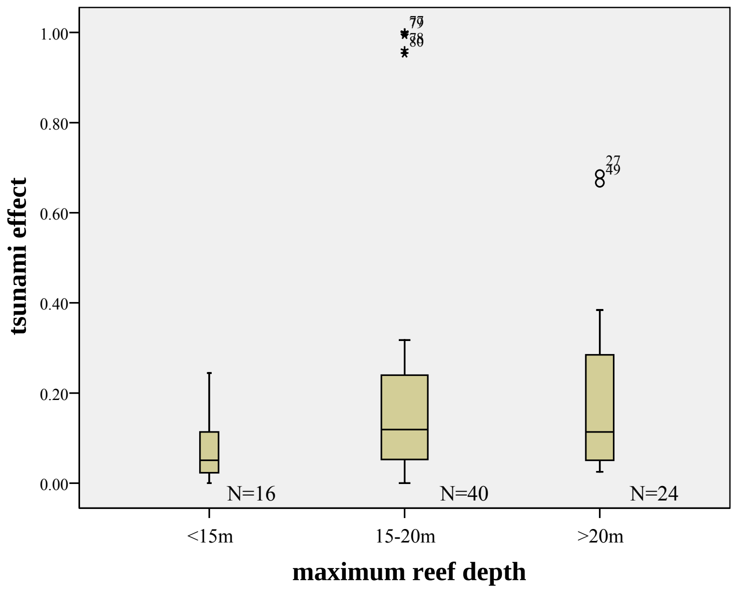


Figure 2.6. Proportional tsunami effect among sites by maximum depth of reef

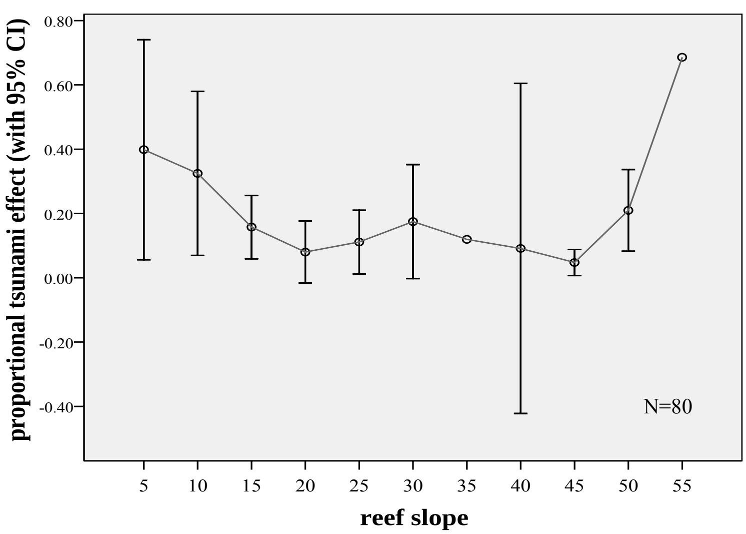


Figure 2.7. Proportional tsunami effect for sites with varying reef steepness

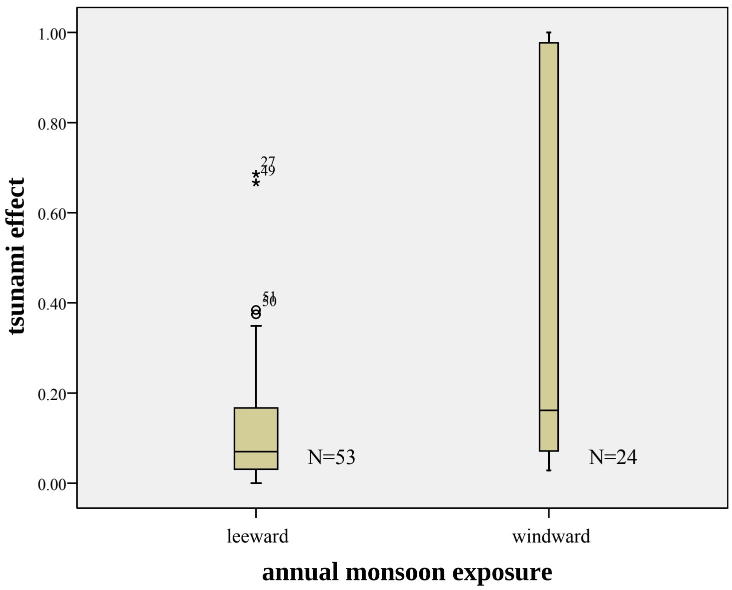


Figure 2.8- Proportional tsunami effect between sites with and without exposure to dominant annual SW monsoon winds

Table 2.6. Between-subjects tests for multivariate GLM of reef morphologies lower vs. upper reef slope

morphology	F	sig.
substrate	.008	.071
rubble	.001	.802
old dead coral	.004	.469
new dead coral	.021	.487
branching	.012	.147
boulder-like	.000	.774
submassive	.000	.759
plate-like	.000	.431
digitate	.003	.187
encrusting	.003	.149
free-living	.000	.075
soft coral	.000	.140

Table 2.7. Pre-tsunami proportion of reef morphologies throughout Koh Surin (N=18)

morphology	mean	std. dev.	median	i.q.r.
substrate	.05	.051	.03	.061
rubble	.09	.111	.06	.070
old dead coral	.18	.084	.16	.111
new dead coral	.01	.013	.00	.006
branching	.31	.199	.32	.266
boulder-like	.09	.075	.08	.128
submassive	.08	.066	.07	.109
plate-like	.07	.069	.05	.122
digitate	.02	.041	.01	.001
encrusting	.05	.039	.04	.081
free-living	.01	.010	.01	.001
soft coral	.00	.009	.00	.003

2.3.3 Reef morphology

Few well-developed reefs exist in locations with high exposure to annual SW monsoon winds; however, higher variation in effect was observed among those few exposed sites compared with leeward sites (Figure 2.8). This variation was largely due to response at KTNE. Without KTNE considered, there was no significant difference detected in tsunami response based on monsoon exposure (with KTNE, $t = -3.540$, $p = 0.001$; without KTNE, $t = -1.384$, $p = 0.173$).

A difference between the morphological composition of lower and upper reef slopes for all observed morphologies throughout Koh Surin was not detected at the scale of measurement (Pillai's Trace $F = 3.212$, $p = 0.103$). Between-subjects tests revealed a larger difference in proportional cover of substrate and boulder-like as well as digitate, encrusting, free-living and soft coral morphologies than other morphologies; however, none of these differences were statistically significant, so depth stratification was deemed unnecessary for further analyses (Table 2.6).

Summary statistics for the proportion of morphologies in 2004 line transects indicate a high amount of spatial variation among samples (Table 2.7). Only common morphologies (mean cover of at least 5% on sampled reefs) were considered while looking at a potential morphological differentiation in tsunami disturbance response since the remaining morphologies were rarely encountered in sampling and likely did not affect overall response. At Koh Surin, common morphologies include substrate, rubble, old dead coral, branching morphologies, boulder-like morphologies, submassive morphologies and plate-like morphologies.

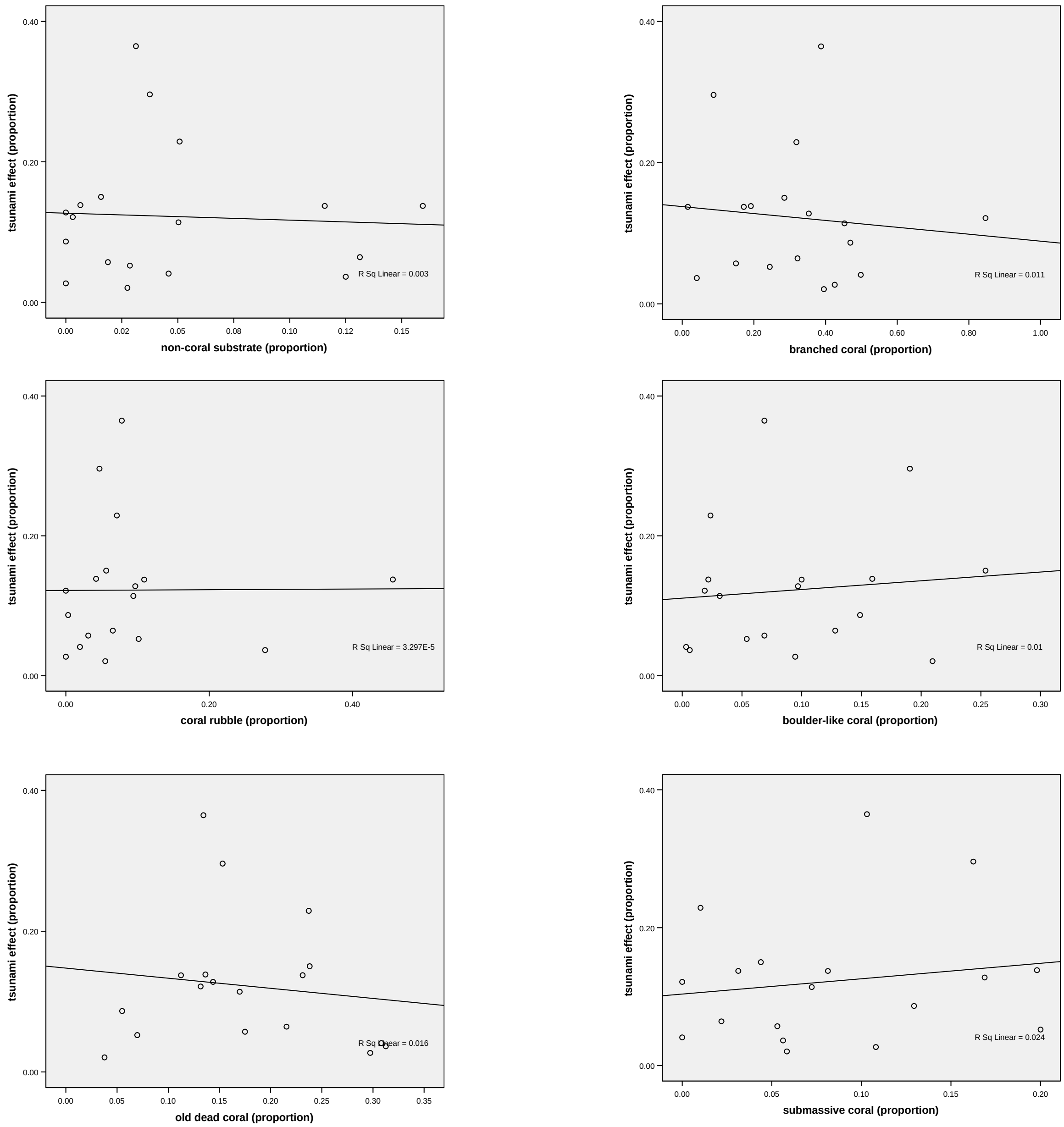
Scatterplots did not reveal any obvious relationships between tsunami effect and any type of colony morphology (Figure 2.9 – note: tsunami effect was averaged by site and depth for comparison with 2004 samples). Pearson's correlations were all insignificant (Table 2.8), even when more general cover categories were examined (e.g. Pearson's R for hard coral cover = 0.067, p = 0.791), so further predictive analyses were not carried out.

Table 2.8. Pearson's correlations matrix for proportional tsunami effect and dominant pre-tsunami morphologies

		tsunami effect	substrate	rubble	old dead coral	branching	boulder-like	submassive	platey
substrate	R	-.054	1	.761**	.341	-.528*	-.317	-.398	-.385
	sig	.832		.000	.166	.024	.199	.102	.115
	N	18	18	18	18	18	18	18	18
rubble	R	.006	.761**	1	.263	-.602**	-.351	-.141	-.282
	sig	.982	.000		.292	.008	.153	.577	.257
	N	18	18	18	18	18	18	18	18
old dead coral	R	-.128	.341	.263	1	-.174	-.373	-.477*	-.620**
	sig	.612	.166	.292		.489	.127	.045	.006
	N	18	18	18	18	18	18	18	18
branching	R	-.104	-.528*	-.602**	-.174	1	-.127	-.272	-.246
	sig	.683	.024	.008	.489		.614	.275	.324
	N	18	18	18	18	18	18	18	18
boulder-like	R	.100	-.317	-.351	-.373	-.127	1	.335	.307
	sig	.694	.199	.153	.127	.614		.174	.216
	N	18	18	18	18	18	18	18	18
submassive	R	.156	-.398	-.141	-.477*	-.272	.335	1	.500*
	sig	.536	.102	.577	.045	.275	.174		.035
	N	18	18	18	18	18	18	18	18
platey	R	.184	-.385	-.282	-.620**	-.246	.307	.500*	1
	sig	.465	.115	.257	.006	.324	.216	.035	
	N	18	18	18	18	18	18	18	18

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).



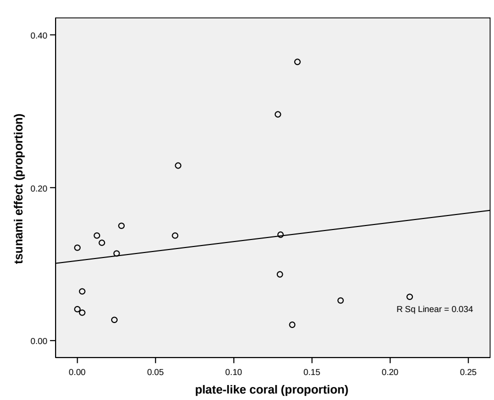


Figure 2.9-Effect by dominant morphologies

2.3.4. Reef depth

There did not appear to be substantial difference in tsunami effect based on height of the overlying water column at sites (Figure 2.10). A paired t-test comparing lower and upper reef slope quadrats was not statistically significant ($t = 1.258$, $p = 0.217$), even with outliers and extreme value cases removed.

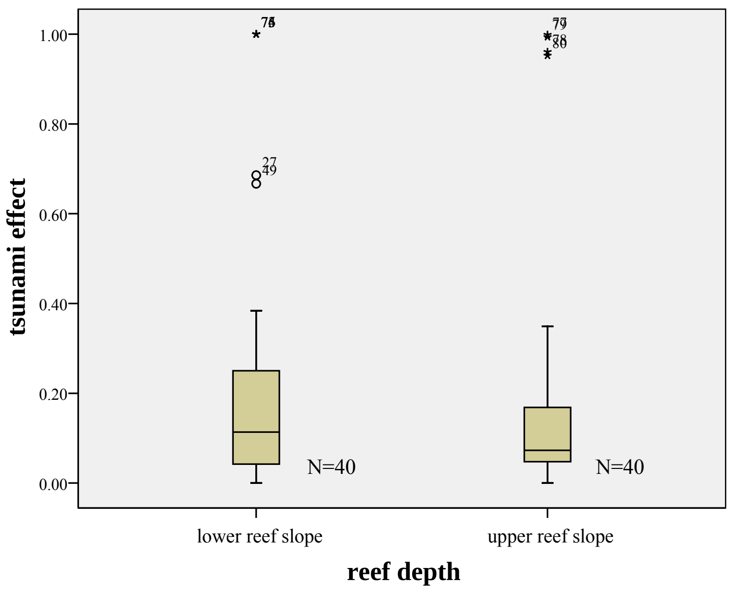


Figure 2.10. Proportional tsunami effect at the lower and upper reef slope at 10 reefs within Koh Surin

2.3.5. Reef location

As described in Table 2.3, there was a high amount of variation in tsunami effects among reef sites. Effects have been compared in the south and north region of the park, in sheltered bays and open locations, based on proximity to channel constrictions, based on differences in reef aspect and based on diurnal current flow strength. Southern reef sites seemed to have sustained higher variation in tsunami effect magnitude than northern sites (Figure 2.11.). A statistically significant difference in effect was detected between groups (independent samples t-test: $t = 3.435$, $p = 0.001$) even without considering observations at KTNE ($t = 2.245$, $p = 0.028$).

Sites that were located within bays seemed to be less affected by the tsunami than sites located outside bays (Figure 2.12). The significant difference between groups ($t = 3.161$, $p = 0.002$) was not detected if extreme value and outlier cases were not considered ($t = 1.65$, $p = 0.101$).

Sites located close to channels received a significantly greater effect than sites in open locations (Figure 2.13, $t = 4.540$, $p < 0.001$). High variation in effects for constricted sites was accounted for by the extreme effects at KTNE. Extreme values for open sites (Figure 2.13) are due to quadrats located on steep reefs (ATN/ATS). Channel constrictions seemed to be an important factor differentiating sites by tsunami effect since, without the extreme effects at KTNE included, there was still a statistically significant higher effect on sites near channels than on sites without nearby channels ($t = 2.063$, $p = 0.043$).

When effects were compared on sites by aspect a high amount of variation was seen in NE facing sites due to samples at KTNE (Figure 2.14). It appeared that west-facing sites (MN) were less affected by the tsunami, but differences were not statistically significant (Kruskall-Wallace test for untransformed effect: $\chi^2 = 8.095$, sig. 0.088).

There seemed to be a larger effect on sites with strong diurnal current flow regimes than sites with low flow regimes (Figure 2.15). This difference was statistically significant for normalized effects ($t = -3.161$, $p = 0.002$). Without KTNE, this difference was not significant ($t = -1.665$, $p = 0.101$)

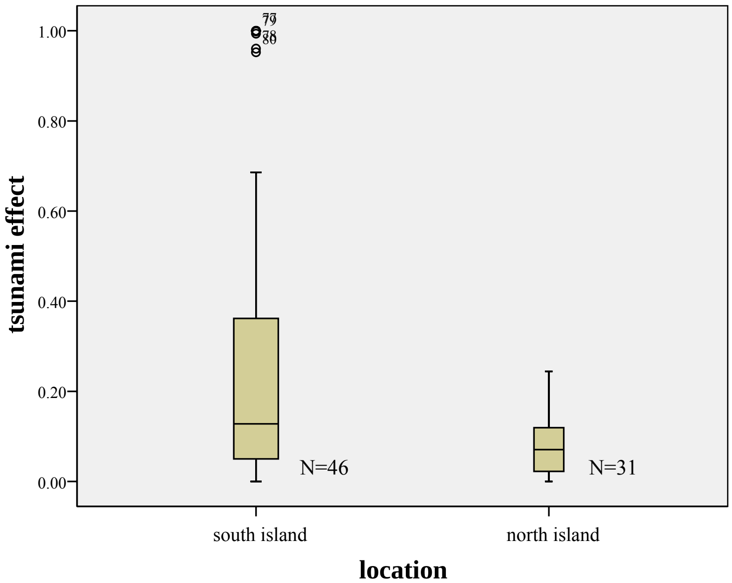


Figure 2.11. Proportional tsunami effect between southern and northern regions of Koh Surin

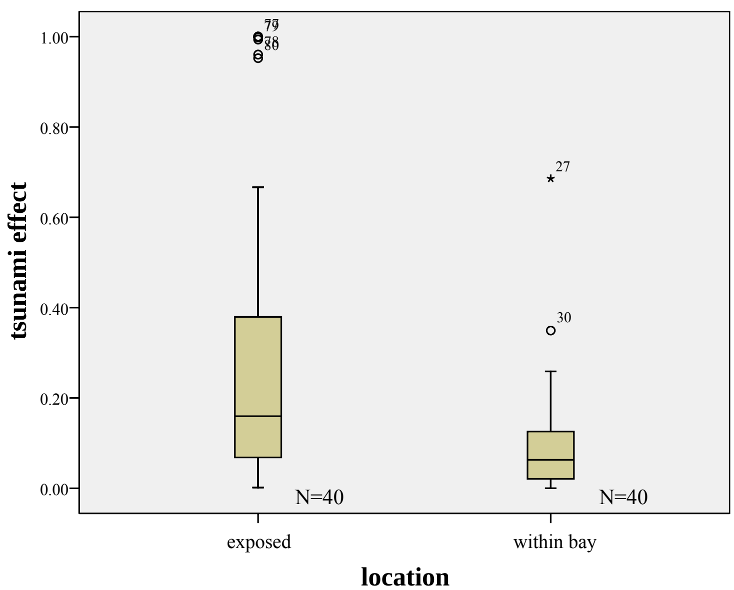


Figure 2.12. Proportional tsunami effect between sites within and outside protected bays

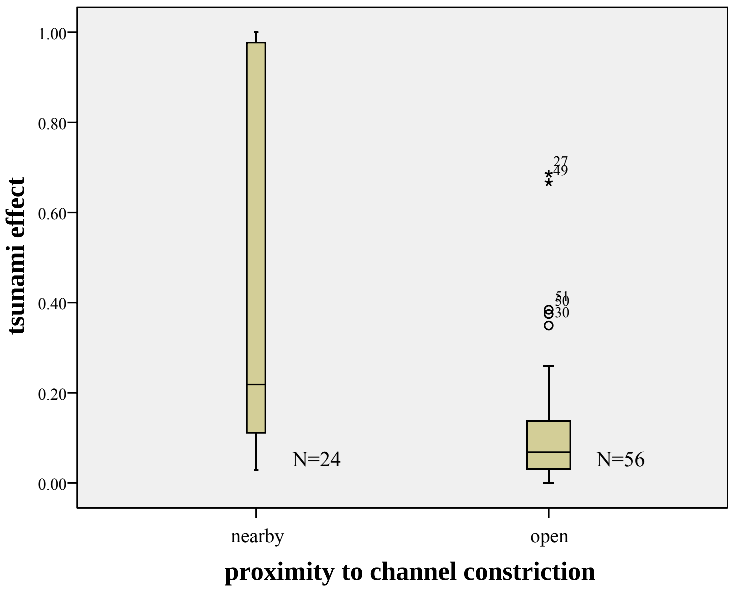


Figure 2.13. Proportional tsunami effect between sites in open and constricted locations

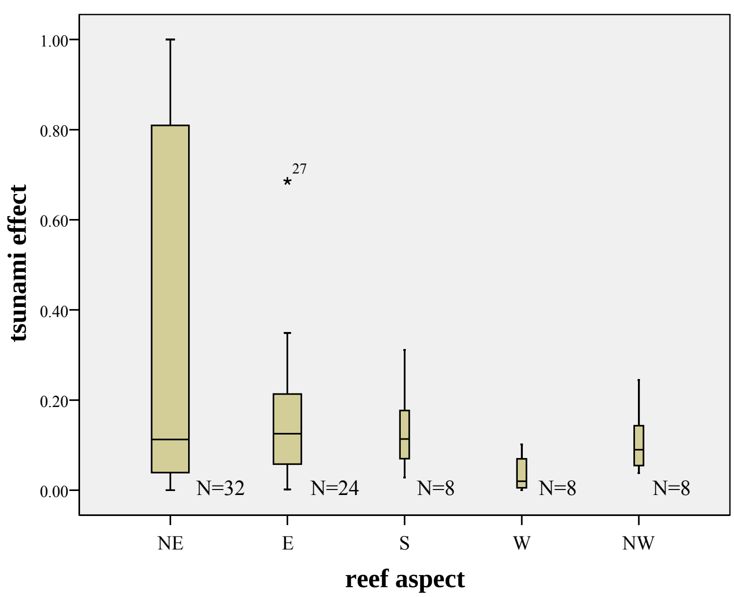


Figure 2.14. Proportional tsunami effect among sites by site aspect

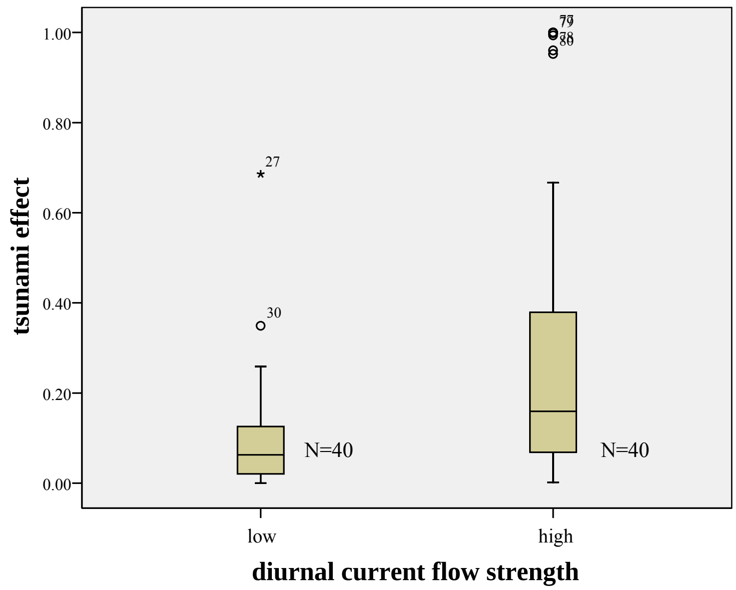


Figure 2.15. Proportional tsunami effect between sites with low and high strength current flow regimes

2.3.6. Relative influence of reef and site attributes

The constructed main effects GLM estimated the proportional tsunami effect within quadrats as a function of the location within the park, monsoon (SW) exposure, location within or outside a bay, proximity to channel constriction, and reef slope being greater or less than 45°. Because current flow strength was highly correlated with site exposure and proximity to channel constrictions (respectively, Pearson's R = -1.000 and 0.603, $p < 0.001$), this attribute was not included in the model.

When all cases were considered, the estimated model was statistically significant ($F = 8.663$, $p < 0.001$, N=80), accounting for 42.6% (R^2) of the variation in tsunami effect throughout the islands (Table 2.9). Based on this model, proximity to a narrow channel was able to explain the most variation in tsunami effect (Table 2.10; $t = 3.269$, $p = 0.001$). Reef slope, followed by location within or outside a bay, location in the park and monsoon exposure (in decreasing order of importance), were not able to explain a statistically significant amount of the variation in tsunami effects. However, the distribution of residuals was heteroscedastic (Levene's F = 2.033, p = 0.043). Residual plots showed 8 substantial outliers for the dependent variable, accounted for by extremely affected quadrats at KTNE.

Table 2.9. Tests of between subjects effects for tsunami response GLM including all cases

Dependent Variable: ln(effect)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	60.753[a]	6	10.125	8.663	.000	.426
Intercept	20.969	1	20.969	17.939	.000	.204
location in park	.299	1	.299	.256	.614	.004
monsoon exposure	.681	1	.681	.583	.448	.008
within/outside bay	.220	1	.220	.188	.666	.003
slope >/< 45 degrees	3.727	1	3.727	3.189	.078	.044
proximity to channel	20.150	2	10.075	8.619	.000	.198
Error	81.820	70	1.169			
Total	557.083	77				
Corrected Total	142.573	76				

a. R Squared = .426 (Adjusted R Squared = .377)

Table 2.10. Parameter estimations for tsunami effects GLM including all cases

Dependent Variable: ln(effect)

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-1.992	.531	-3.750	.000	-3.052	-.933	.167
location in park	.184	.363	.506	.614	-.541	.909	.004
monsoon exposure	-.268	.351	-.763	.448	-.968	.432	.008
within/outside bay	.145	.334	.434	.666	-.521	.811	.003
slope >/< 45 degrees	-.778	.435	-1.786	.078	-1.646	.091	.044
proximity to channel	2.429	.669	3.629	.001	1.094	3.764	.158

The GLM was re-estimated, excluding cases at KTNE. This reduced heteroscedasticity of residuals (Levene's F = 0.691, p = 0.714). However, this second model was not statistically significant (Table 2.11; F = 2.032, p = 0.086), only accounting for 13.9% (R^2) of the variation in tsunami effects. The removal of cases at KTNE altered the importance of factors (Table 2.12) and none of the factors were statistically significant, including proximity to a narrow channel (t = 0.872, p = 0.386).

Table 2.11. Tests of between subjects effects for tsunami effects GLM excluding cases at KTNE

Dependent Variable: ln(effect)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	13.197[a]	5	2.639	2.032	.086	.139
Intercept	72.364	1	72.364	55.721	.000	.469
island	.299	1	.299	.231	.633	.004
monsoon	.681	1	.681	.524	.472	.008
protection	.220	1	.220	.169	.682	.003
slopegrp	3.727	1	3.727	2.870	.095	.044
channel	.988	1	.988	.761	.386	.012
Error	81.818	63	1.299			
Total	557.079	69				
Corrected Total	95.014	68				

a. R Squared = .139 (Adjusted R Squared = .071)

Table 2.12. Parameter estimations for tsunami effects GLM excluding cases at KTNE

Dependent Variable: ln(effect)

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Partial Eta Squared
Intercept	-1.992	.560	-3.557	.001	-3.112	-.873	.167
location in park	.184	.383	.480	.633	-.582	.950	.004
monsoon exposure	-.268	.370	-.724	.472	-1.007	.471	.008
within/outside bay	.145	.352	.412	.682	-.558	.848	.003
slope >/< 45 degrees	-.778	.459	-1.694	.095	-1.695	.140	.044
proximity to channel	.461	.528	.872	.386	-.595	1.516	.012

2.4 Discussion

Until the tsunami, levels of natural disturbance to corals within Koh Surin had been minimal since the region 1998 warm water event (Worachananant et al. 2007). During December 2004 census dives, old scars from blast fishing and/or anchoring were observed at Koh Torinla, off Hin Kong rock, and off the SE point of Surin Tai, but no recent mechanical disturbance attributable to human or storm activity was observed on any reefs. There were low levels of coral tissue scarring from parrotfish grazing, but these scar patterns were distinct from other types of disturbance.

Mechanical tsunami effects at Koh Surin were mainly due to massive tsunami-generated surge and the secondary effects of terrestrial and reef-originated debris being dragged across the reef surface by the tsunami waves and associated surge. Breaking waves probably did not cause damage on the reef slope due to the relatively steep bathymetry off fringing reefs in this area. The type of damage on Koh Surin's reefs was very similar to tropical storm effects and seemed consistent with tsunami effects on reefs throughout the Indian Ocean (see ICRI 2005; Worachananant et al. 2007). The high localization and patchiness of this damage was also consistent with other areas affected by the tsunami (Brown 2005; Worachananant et al. 2007). Without numerical modeling of the tsunami in this area, it is difficult to explain this variability. However, by comparing the magnitude of effects among different locations, some important factors that shaped this disturbance on coral reefs at Koh Surin can be identified.

In this study, tsunami response was compared to differences in characteristics related to reef composition, profile and geographical location. These characteristics were then assessed in relation to each other for their ability to explain the spatial variability in tsunami effects throughout Koh Surin. Larger tsunami effects occurred on reefs with a reef slope of at least 45°, on sites exposed to the annual SW monsoon, on southern sites within the park, on sites with dynamic diurnal current flows, on sites in unprotected locations, and on sites located in close proximity to channel constrictions. Seafloor bathymetry was found to be highly influential since, of the above factors, proximity to channel constrictions was able to explain the most variability in tsunami effects. Reef steepness, SW exposure (monsoon exposure), location within the north or south region of the park, and location within or outside bays (in decreasing order of importance) were less influential. In the following sections, these findings will be discussed as they pertain to a priori expectations based on related research in coral reef disturbance ecology and tsunami dynamics.

2.4.1 Reef composition and the tsunami disturbance

Research has shown that certain colony morphologies exhibit more resistance to hydrodynamic disturbance than others (Hughes 1987; Marshall 2000; Madin 2005; Storlazzi et al. 2005). Reefs that are exposed to chronic storm disturbance develop with low-profile forms that create less drag (Riegl & Riegl 1996). Branching forms, for example, will be bushier on disturbed reefs and taller on undisturbed reefs. There has also been a documented differential response to disturbance among morphologies, where some are more susceptible to changes in flow than others. Erect and branching morphologies, for example, are pre-disposed to fragmentation while massive coral boulders rarely break. Areas with a high proportion of coral rubble will also be more likely to experience secondary mechanical effects from the movement of rubble than reefs with solid substrate.

Rogers (1993) suggested that the effect of hydrodynamic stress on coral reefs is a function of the dominant species and its response to high velocity flow. Therefore, relationships between the proportions of different coral morphologies and the extent of tsunami damage on sites were expected. Although they did not compare individual morphologies to tsunami effects, Coral Cay Conservation reported a significant positive relationship between tsunami effects and hard coral cover on reefs at Koh Surin (CCC 2005). Worachananant et al. (2007) assume that certain morphologies at Koh Surin were more resistant and resilient to mechanical tsunami effects, although they have little empirical evidence in support of this assumption. In contrast, differential response to the tsunami based on hard coral cover, or any variation in coral composition on reefs at all, was not quantitatively detected in this study.

There are some possible explanations for this. It could simply be that there was no relationship between pre-tsunami morphological composition of sites and the distribution of tsunami damage at Koh Surin; or that a relationship exists, but at a different scale than that sampled. The first of these possibilities is unlikely since there is substantial variation in skeletal strength among different colony morphologies (Madin 2005). It is hard to believe that there would be no variation in morphological resistance to flow – at least at some scale. It is quite likely that a morphological response to the tsunami would have been evident at the scales examined in this study on reefs located further from the epicenter. The hydrodynamic disturbance that was generated by the Sumatran earthquake traveled around the entire globe; Koh Surin was only about an hour from the source. At this proximity, it could be that differences in resistance among coral morphologies were overwhelmed by the scale of this disturbance.

At a coarser scale, the profile of reefs, except possibly slope steepness, did not seem to explain the distribution of tsunami effects observed in this study either. Deeper reefs did not appear to create higher run-up and greater tsunami effects. Similarly, any buffering or magnifying effect of primary or secondary mechanical disturbance along the reef slope by the reef flat above was not perceptible. Furthermore, monsoon-exposed reefs seemed to respond at least as much to the hydrodynamic force of the tsunami as reefs that were not adapted to prevailing monsoon storms. As seen with the lack of differential response by individual colony morphologies, disturbance magnitude and measurement level may limit the possibility of meaningful comparisons.

Although the probability that reef steepness could explain variation in tsunami response throughout the park was statistically low ($p = 0.078$ at $\alpha = 0.05$), there is some evidence to believe that steepness may still be ecologically significant. In 1993, Dollar and Tribble documented narrow vertical tracts down steep reefs after hurricanes in French Polynesia due to avalanching of shallow colonies down-slope. Within Koh Surin, Ao Tao reef is the steepest of all fringing reefs within the park, and this was the only reef where similar tracts of scoured reef framework were observed during census and survey dives. These tracts extended from the reef crest to the lower reef slope, where large tumbled coral boulders (*Porities sp.*) and fragmented coral colonies were piled. These higher proportional effects on steep reefs were, therefore, probably a function of this unique effect type, rather than tsunami wave magnification linked to reef bathymetry.

Like all tsunami effects, scoured tracts were patchy. These tracts were not well represented by random sampling and only two quadrats at ATN and ATS fell on them. These happened to be at the lower reef slope, even though tracts ran down the entire slope. This was a random sampling effect, and not support for a depth effect.

2.4.2. Depth of the overlying water column and the tsunami disturbance

Past studies of tropical storm disturbance on coral reefs show differences in effects depending on the height of overlying water on reefs, where shallow sites are typically more influenced than deep sites by hydrodynamic stress (even over a range as shallow as 7m – see Woodley et al. 1981). In general, greater shallow than deep effects were expected by the scientific community after the tsunami (ICRI 2005). Brown (2005) and Worachananant et al. (2007) concluded that the depth of overlying water influenced the severity of tsunami effects on coral reefs throughout the Andaman Sea based on the post-tsunami surveys of Thailand's Department of Marine and Coastal Resources (DMCR). However, their conclusion appears to be drawn from qualitative observations and not from quantitative analysis. In contrast, there was no detected difference in tsunami effect magnitude on deep and shallow areas of reefs based on quantitative comparisons in this study.

That tsunami disturbance may have similar magnitude at deep and shallow areas of the reef could be explained by distinguishing between some hydrodynamic properties of tropical storm disturbance and the Indian Ocean Tsunami waves. Tropical storm wave wavelengths can reach well over 20m in height with dominant periods between 10-20 seconds (NOAA 2006). In deep water, these wind-generated waves carry energy close to the surface, and there is an exponential decay of energy with depth. Thus, even with large wave heights, energy flux is actually quite limited for these waves (Yeh et al. 1994). In typical tropical storms, it is the shallower regions from the reef crest and above that are battered as waves break every few seconds throughout the storm, which may last for several days. Furthermore, the direction of this disturbance is usually sustained, transporting broken fragments toward shore and up reefs on storm-exposed sites.

The Indian Ocean tsunami, on the other hand, was seafloor-generated, engaging the entire water column, and reaching wave heights of 15.5m, wavelengths of 100-600km and periods from 20-50 minutes (Kowalik et al. 2005). The bathymetrical composition of coastlines has a large influence on the form of the waves (Yeh 1994; Matsuyama 1999). In general, as a wave approaches the coast, it will be slowed as water depth decreases. This means that wave period will decrease, increasing wave amplitude as a function of slope and local bathymetry. Thus, as the tsunami waves approached the islands, considerable force would have been carried throughout the water column. This explains the unexpected deep effects that were also observed at the nearby Similan Islands (Figure 2.2, personal observation), where drastic scouring occurred at depths of over 30m (Appendix 1, Figure A2.9).

During the tsunami event, coral colonies within the park must have been subjected to several minutes of substantial hydrodynamic force associated with both seaward and landward flow as tsunami waves approached, followed by shifting surge. Under this type of disturbance, secondary mechanical disturbance from reef and terrestrial debris would have also affected reefs at all depths. Although higher than average effects sampled along the lower reef slope at north and south Ao Tao (ATN and ATS) potentially indicated greater deep effects, this variability is probably a function of the random sampling effects related to reef steepness that have been discussed previously.

2.4.3 Reef location and the tsunami disturbance

Geographical location, mainly linked to bathymetry, seemed to be influential in the spatial distribution of tsunami effects throughout the park. Relatively large effects were detected at southern sites, those sites not located in bays, and sites with dynamic diurnal current flow. The greatest force of the tsunami disturbance within the park seems to have occurred in, and adjacent to, narrow channels. It is unclear whether reef aspect influenced tsunami effects.

Although there was no difference in tsunami response among all reef aspects, sites that were SW-facing (those exposed to monsoon storms) were more affected than unexposed sites. Since a SW approach has been assumed based on in situ observations (see also Worachananant et al. 2004) and based on global-scale numerical modeling of the tsunami (Kowalik et al. 2005; Titov et al. 2005), this would seem to support the expectation that sites exposed to the direction of tsunami approach were more affected than other sites as suggested by Brown (2005). It should be noted, though, that SW-aspect was relatively unimportant in explaining the variability in effects throughout the park. It should also be emphasized that the direction of approach of the tsunami toward Koh Surin is uncertain. In situ observations only exist for two sites, and fine-scale modeling of the tsunami in this region has not been undertaken to date. It is entirely possible (although unlikely) that the approach was from another direction or even multi-directional.

The interpretation of the difference detected in effects between southern and northern sites also depends upon the direction of tsunami approach. It is possible that, if the tsunami approached from a southern direction, the northern islands may have been sheltered from some disturbance by islands to the south. However, tsunami hydrodynamics at coastal boundaries are highly complex and will not be possible to infer without fine-scale numerical modeling of the tsunami at Koh Surin.

Unlike during storms, there is not necessarily sheltering on sites ‘leeward’ to tsunami approach since tsunami waves can travel entirely around islands (Yeh et al. 1994). In 1992, when tsunami waves split to travel around Babi Island, for example, they rejoined on the leeward side of this circular island and resulted in higher runup than on shores facing the tsunami’s approach (Yeh et al. 1994). Furthermore, complex interactions with convoluted coastlines, like those throughout Koh Surin, may lead to wave magnification, not attenuation, with distance along the shore. In fact, wave magnification of tsunami energy with distance was documented along the coasts of India (Narayan et al. 2005) and Thailand (Choi et al. 2006). The highly changeable currents felt underwater at Ao Suthep during the tsunami suggest complicated deflection and reflection at smaller scales as well.

Numerical tsunami modeling has shown that bathymetrical constrictions leading into certain bays and through channels usually create focusing and magnification of wave amplitude and associated hydrodynamic forces (Yeh et al. 1994). It did not appear, however, that wave magnification occurred as tsunami surge entered protected bays and traveled across gently shallowing fringing reef toward shore at Koh Surin. In fact, sites that were located in bays were generally less affected than sites in open areas, possibly due to sheltering. It is unclear whether sites with dynamic current flow were actually more affected than sites with less dynamic flow because current flow strength was highly correlated with location within or outside bays and proximity to channel constrictions. Regardless, this is likely more a question of bathymetry than anything else as the bathymetrical properties that influence current flow would also affect tsunami flow.

The relative importance of whether sites were in close proximity to narrow channels became statistically evident when observations at NE Koh Torinla (KTNE) were not considered in the model estimation. Although model assumptions could be met without KTNE data, the explanatory power of the model and its statistical significance were diminished.

The fundamental importance of channel bathymetry in the tsunami event has been supported by the observations of Worachananant et al (2007) who also noted severe effects in the narrow channel between Surin Tai and Nua and by personal observations of similar patterns of tsunami effects associated with channels in other locations throughout the Andaman Sea.

Thus, while several factors may have shaped the tsunami disturbance to coral reefs, seafloor bathymetry and, likely, reef slope, were the most influential of factors leading to the observed spatial variability in effects.

2.4.4. Summary

Differences in tsunami effect magnitude among reefs at Koh Surin has been attributed to the depth of overlying water on reefs, site exposure to the tsunami's approach, and seafloor bathymetry (Brown 2005; Worachananant et al. 2007). Quantitative analysis of tsunami effects surveyed in this study supports the importance of seafloor bathymetry, and *possibly* exposure, on the spatial variability of tsunami effects observed throughout Koh Surin. Reef slope steepness seems to be another important factor as reefs over 45º experienced unique avalanching effects. However, depth of overlying water on reefs does not appear to be significantly influential.

Until December 26, 2004, understanding of large-scale hydrodynamic disturbance to coral reefs was based on observations after tropical storms. The Indian Ocean tsunami provided a novel opportunity to study the influence of a massive hydrodynamic disturbance on coral reefs. Most discrepancies between expectations of tsunami effects and observed effects at Koh Surin can be explained by the difference between the scale of tsunami wave and tropical storm wave disturbance.

Tropical storms create waves with short return times, high wave-breaking force across the reef crest, and dominantly move landward. Tsunami waves, on the other hand, have long return times, create drawn-out lateral hydrodynamic force throughout the water column, and this force moves both seaward and landward. With such large scale and sustained disturbance, coarser-scale geographical variations among sites were highly influential in creating the spatial variability in tsunami effects observed at Koh Surin. At the scale of this study, these factors seem to have overwhelmed fine-scale differences in response related to reef composition and profile. An exception to this was on steeper reefs where avalanching colonies created distinct and variable patterns of secondary disturbance effects.

It is possible that a depth effect was not detected on reefs at Koh Surin because the islands have a relatively shallow fringing reef system (the maximum reef depth observed was 23m). However, this is unlikely since substantial forces must have been responsible for the scouring that was observed at depths of up to 30m at Koh Surin and the nearby Similan Islands. These deep effects, like other severe effects observed at Koh Surin, occurred in close proximity to bathymetrical constrictions within narrow channels. This is consistent with the conclusions of Choi et al. (2006), who attributed most variation in tsunami wave magnification (as measured by run-up heights) along the coastline of the Indian Ocean to variations in bathymetry.

This research was heavily constrained by time and site logistics. Analyses were kept simple due to small sample size. Because data collection was highly opportunistic, there was some inconsistency in methods of sampling 2004 and 2005 data. However, this is an observational study and focus has been placed on relative comparisons.

This study has contributed some understanding of how the tsunami affected reefs at Koh Surin, but, as a case study, the conclusions of this research cannot be generalized to other areas, and understanding the general response of coral reefs to tsunami disturbance requires more research. Future research of this nature should account for the highly spatial nature of this type of disturbance, and of coral reefs in general, by undertaking studies at multiple scales and with large samples. Wherever possible, oceanographic modeling should be incorporated into ecological studies of hydrodynamic disturbance effects on coral reefs. In the long-term, the ability of heavily affected reefs to recover from this disturbance will be a function of the ecological, social, economic and political factors that determine resilience over time. Thus, studies of recovery will require an integrated understanding of coral reef systems over time.

2.5 Conclusion

Certain coral reefs along the Thai Andaman coast were substantially affected by the 2004 Indian Ocean tsunami, and Mu Koh Surin had some of the most heavily affected reefs in Thailand. Overall, the type of damage sustained on fringing reefs among these islands was consistent with that observed elsewhere. The highly spatial nature of the event was striking – effects appeared to be extremely localized all along the Andaman coast.

Despite the dramatic effects of the tsunami in certain locations, the importance of the tsunami as a mechanism of change on reefs must be kept in perspective. In this paper, tsunami effects have been compared to those associated with tropical storms because both events create large-scale hydrodynamic disturbance on reefs. However, most tsunami affected areas are projected to recover in 5-10 years (Brown 2005), whereas tropical storms, with a high incidence of recurrence, can have long-term consequences in terms of reef modification (Rogers 1992; Dollar and Tribble 1993; Connell et al. 1997; Gardner et al. 2005).

The tsunami was a very acute, but short-term, disturbance that is unlikely to recur here in the near future. Because of this, and the generally good condition and rapid growth rates of corals in this area, recovery on fringing reefs should occur faster and more completely than it would in an area with a history of chronic disturbance (Connell 1997). Indeed, on most sites after four months, there was an overall low level of detectable coral tissue death, up to three centimeters of apical growth on fractured branching *Acropora* colonies, and evidence of coral tissue regeneration. It is only at the most heavily affected areas, like KTNE, where the tsunami may have pushed systems beyond their functional limitations, and possibly toward new non-coral regimes as seen on some heavily-disturbed coral reefs on the Great Barrier Reef and in the Caribbean (Hughes 1994; Bellwood et al. 2004). However, sites where tsunami effects may be irreversible are few.

Thus, in agreement with Baird et al. (2005), Brown (2005) and Worachananant (2007), tsunami effects alone will probably not have significant ecological consequences on most Andaman Sea reefs in Thailand. Global patterns of coral reef decline began over a century ago and are fundamentally attributed to more significant chronic pressures like over-fishing, coastal development and pollution (Pandolfi et al. 2003). In combination with rising seawater temperatures and increasing frequency of extreme weather events linked to climate change, chronic stresses are likely to place a much more significant degree of stress on reefs worldwide than an isolated event like the tsunami.

This lack of *ecological* significance, however, does not imply that the event was not significant. As discussed in Chapter 1, historical ties between coral reefs and adjacent coastal societies demand that the two cannot be viewed in isolation. The physical effects on coral reefs that resulted from the tsunami had large implications for many communities, and the response of these communities had implications for adjacent coral reefs. In the following chapter, the real and perceived effects of the tsunami on one adjacent coastal community, the diving community in Phuket, will be examined.

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CHAPTER 3: Response of the SCUBA diving industry in Phuket, Thailand, to effects of the 2004 Indian Ocean tsunami[1]

3.1 Introduction

3.1.1 Conserving coral reefs of the Thai Andaman Sea

The Andaman Sea lies within the East Indies Triangle, which straddles a relatively small region of the Indo-Pacific Ocean, but contains the world's highest marine biodiversity (Allen & Werner 2002). It is an area of evolutionary importance, as the possible source for the assemblage and maintenance of most coral reef species throughout the entire Indo-Pacific (Bellwood et al. 2005; Briggs 2005).

Coral reefs have been utilized by communities along the Andaman coast throughout their histories and have provided sustenance, coastal protection, employment, recreational opportunities and they are of cultural significance. Although reefs are naturally dynamic ecosystems, rapidly increasing changes are being observed throughout the tropics (Bellwood et al. 2004). There is a huge amount of pressure on these systems due to rapid growth of coastal populations combined with advancing technologies that improve harvesting and facilitate other uses of coral reefs.

Following the ratification of the Convention on Biodiversity in 1992, conservation has become an issue of global concern. Of late, attention has been increasingly devoted to the state of the oceans as scientists continue to uncover the escalating rate of degradation that is occurring (Bellwood et al. 2004). Coral reefs are of particular concern due to their key role as engines of productivity and storehouses of biodiversity (Pandolfi et al. 2003; Bellwood et al. 2005; Hughes et al. 2005).

Thailand has recognized the value of its coral reefs and over 50% of its reefs have

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[1] As Main & Dearden 2007 (paper based within this chapter)

been protected through designation as marine national parks, totaling over 26 parks (Chettamart & Emphandu 2002). However, the degree of protection offered by this designation varies greatly. In some parks, there are few, if any, restrictions on extractive activities such as fishing (Lunn & Dearden 2005). Even where restrictions exist, they are seldom enforced, and active management for conservation is the exception rather than the rule.

Two major underlying problems have contributed to the ineffectiveness of these tropical MPAs: the failure of coral reef science to address the type of questions that are relevant at the functional level (Risk 1999; Bellwood et al. 2004); and a lack of capacity to implement conservation management (McClanahan et al. 2006). For the past several decades, the literature in coral reef conservation has mainly been produced by specialized ecologists and it is dominantly biocentric. As this body of literature has grown, understanding of reef ecology has progressed but so has the global degradation of coral reefs.

Reefs are highly dynamic systems defined by complex processes. As the majority of coral reefs occur in proximity to populated coastlines, anthropogenic as well as ecological stressors contribute to this dynamic and cannot easily be separated. Thus, while the work of specialists provides a solid foundation for reef conservation, this knowledge alone is not sufficient for conservation. Interrupting the trajectory of reef decline requires an integrated social and ecological approach in which anthropogenic drivers can be viewed as integral to coral reef systems (Bellwood et al. 2004; Hughes et al. 2005). The current shift in the field toward a social-ecological paradigm for coral reef conservation (see chapter 1) may enhance the relevance of research for conservation, but capacity for effective management of MPAs remains a concern in most tropical countries.

In cases where resources for MPAs are lacking, those designed to incorporate community values and involvement and those with alternate sources of income have been found to be more effective than 'top-down' managed MPAs (Russ & Alcala 1999; Gjersten 2005; McClanahan et al. 2006). However, especially in the poorer countries that have most of the world's tropical coral reefs, the incentives for locals to protect resources *for tomorrow* are much less tangible than the intense competition over scarce resources provided by reefs *for today*. Incentives are thus high to maximize personal consumption over the short term at the long-term expense of reef health and resource sustainability. This struggle is in accord with Hardin's 1968 "Tragedy of the Commons".

One way to address this issue is to provide tangible reasons for communities to support long-term conservation. This is an underlying principle of ecotourism - protection of species and habitats should benefit local people more than destruction of species and habitats (Hvenegard & Dearden 1998). These benefits mainly take the form of economic benefits derived from visiting ecotourists. SCUBA diving ecotourism has this potential to assist reef conservation efforts since diving is dependent on the quality of the marine environment (Tabata 1989; Bennett 2002; Dearden et al. 2006).

3.1.2 Phuket's diving industry

Over the past few decades, divers have increasingly flocked to tropical destinations for warm waters and spectacular underwater life. Thus, the recreational diving industry has expanded rapidly in many tropical areas (Hawkins & Roberts 1992; Harriot et al. 1997; Van Treeck & Schuhmacher 1998; Musa 2002; Dearden et al. 2006).

The island of Phuket, in Thailand, contributes about one-third of the country's tourism revenue (TAT 2006). Although recent estimates are not available, in 2000, over $150 million per year in direct benefits was estimated to be pumped into the local economy by diving tourism alone (Bennett 2002). This provides substantial incentive to maintain and enhance the main resource base for this industry, the coral reefs.

Phuket, on the Andaman coast (Figure 3.1), is Thailand's main centre for diving. In 1979, Phuket's SCUBA diving industry was comprised of four small dive companies run by expatriates from the west, a few fishing boats that took divers out for daytrips to local reefs and a single air compressor (Bennett 2002). For the next few years, these companies and a few others catered to a limited number of specialized clientele, remaining well within any environmental capacities for SCUBA diving use. As SCUBA diving became a more popular recreational activity, along with exponential growth in tourism and coastal development in Thailand over the next 20 years, the dive industry expanded rapidly. Bennett (2002) estimated that there were over 85 companies based in Phuket in 2000, booking and running day and live-aboard dive trips to several island groups throughout the Andaman Sea.

With this many companies by 2000, the market had grown into one that increasingly relied upon the high turnover of inexperienced divers (Dearden et al. 2006). The drawback to this can be understood in the context of the ecotourism evolution model proposed by Duffus & Dearden (1990). In this model (Figure 3.2), small, specialized ecotourism markets become increasingly oriented towards attracting high volumes of generalist ecotourists as, over time, sites exceed their environmental capacities for use and lose the values that attract a specialized clientele. In terms of diving, this is a problem since poor technique can cause divers to damage coral (Harriot et al. 1997; Hawkins & Roberts 1997, 2005; Rouphael & Inglis 2001; Barker & Roberts 2004) and high volumes of diving activity can substantially degrade reefs (Hawkins et al. 2005; Rinkevich 2005). Thus, as described by Duffus and Dearden (1990), a feedback loop is generated, in which degradation is further exacerbated and more specialists go elsewhere in search of alternate pristine sites.

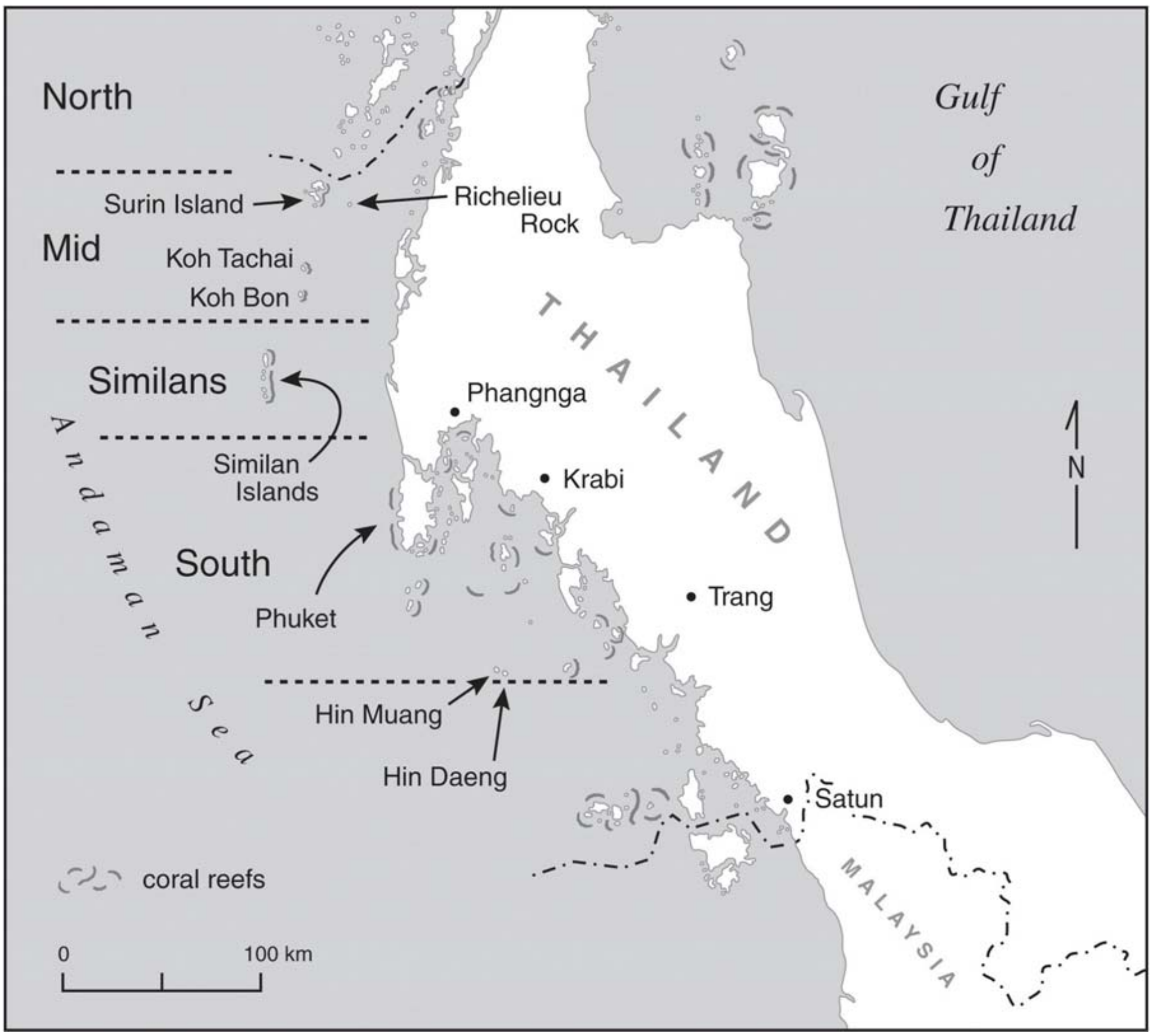

Figure 3.1 - Main diving areas near Phuket

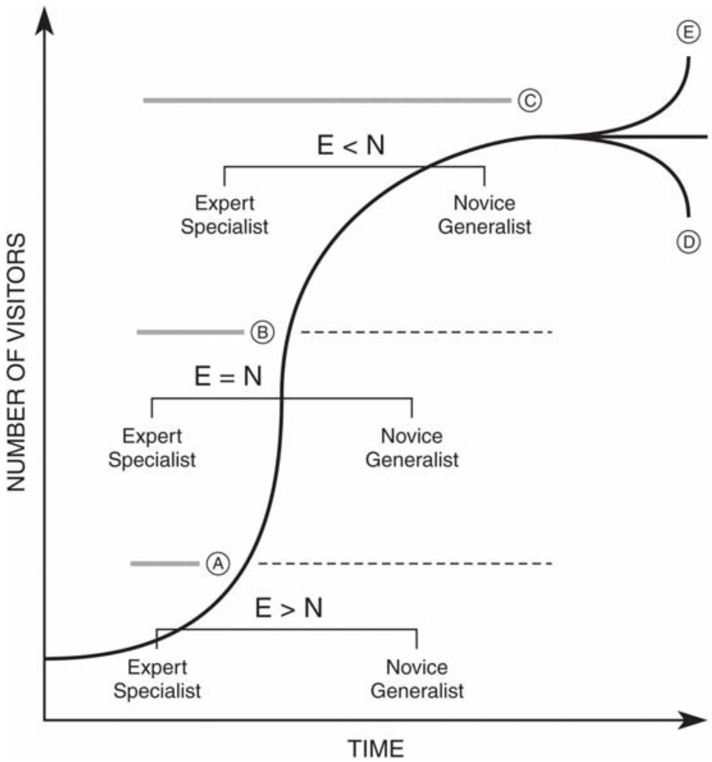

Figure 3.2. The relationship of user specialization and site evolution in a nature-based tourism industry (adapted from Duffus & Dearden's 1990 model). E represents the proportion of expert specialist tourists and N represents the proportion of novice generalists at a given stage of the continuum. At stage 'A', the industry is dominated by low numbers of expert specialists. With time, the industry will pass through stage 'B' where there are equal numbers of expert specialists and novice generalists toward stage 'C' – at which point, the sustainability of the industry begins to decline. After this stage, the industry can either crash (stage 'D') or continue to expand (stage 'E').

The sustainability of the diving industry in Phuket has been questioned by Bennett et al. (2003), and this problem of sustainability is illustrated by the marketing focus of the industry. Most companies in Phuket use whale sharks as a focal image of their advertising. Even the Tourism Authority of Thailand has designed national advertising campaigns using whale shark imagery. However, since the late 1990s, only a handful of whale shark sightings have occurred (Theberge & Dearden 2006). Continuing to market non-deliverable trip attributes obviously encourages divers, whose trip expectations are not met, to seek alternative destinations.

Studying the structure of the diving industry over time has been challenging because it is so dynamic. Companies are constantly forming, dissolving, dividing, relocating, being renamed, acquiring new staff and boats, upgrading, downsizing and so on. Furthermore, individual companies can be complex, as they may be owned by other non-diving companies or have several offices – which may be in different cities or have different names.

Although official policies in this area that influence dive practice exist, in reality the private sector is the *de facto* manager of the activity. Diving companies must be registered, but no government body actually oversees the industry. There is a policy and management vacuum that is reflected in a lack of basic safety and environmental operating standards. Members of the industry relate frequent (almost yearly) boat sinkings or accidents at dive sites reflecting poor practice and/or insuffient basic safety equipment (Dearden et al. 2006). It is a common sight to see live-aboard dive boats miles offshore with no life raft or tender. Concerns over these issues led to the formation of the Dive Operators Club of Thailand (DOCT) in 2000.

At the time of this study, the DOCT was comprised of about 56 companies, mainly based in Phuket, but also Krabi, Khao Lak and Bangkok. It evolved out of the recognition that unity and cooperation were necessary to achieve a sustainable diving industry, with a strong political voice for conserving the marine resources it depends upon. The DOCT mandate is to represent its members politically and to promote the best interests of the diving industry, including marine conservation (DOCT 2005). The DOCT is, essentially, an attempt to take control of and self-regulate the diving industry.

With the variety of dive company types in Phuket – and fierce competition amongst them – conflict within the industry is inevitable. As the industry has grown there has been an overwhelming absence of coordination and organization among companies. This did not change with the formation of the DOCT, for many reasons, including voluntary membership and the fact that the DOCT cannot create enforceable regulations. Furthermore, the DOCT itself lacks stability – since the tsunami, it dissolved for several months and has only recently been reinstated. With this instability and no practical ability to reach and coordinate all constituents, creating and implementing a cohesive plan for the future direction of the diving industry has not been possible thus far.

At the beginning of the 2004 high season, local dive guides commonly saw up to 12 large diveboats and several smaller boats at one time at popular dive sites and divers frequently complained of underwater confusion due to crowding on sites (Bennett 2002). Under this kind of pressure, many sites had already been degraded to very poor conditions by 2004. The unplanned and unchecked growth of diving tourism has come at the expense of both the marine environment and the quality of the diving experience (Davis & Tisdell 1996). Until Dec. 26, 2004, it would have taken an unprecedented effort to reverse these trends.

3.1.3 The 2004 Indian Ocean Tsunami

The massive submarine earthquake of magnitude M_w 9.2 off the NW Sumatran coast on December 26, 2004 generated tsunami waves that spread across the Indian Ocean and were detected all over the world (Titov et al. 2005). This event devastated coastal regions throughout the Indian Ocean and created major destruction in Sumatra, Sri Lanka, along the SE coast of India and the west coast of Thailand. Estimates suggest that from 156,000 to 178,000 lives were lost in this region and anywhere from 26,500 to 142,000 are missing and presumed dead (Liu et al. 2005). The global reach of impacts and response to this disaster was facilitated by international tourism so that many countries far from the earthquake epicenter lost citizens stimulating the largest international relief and aid effort in modern history (Rabinovich et al. in press).

The tsunami drastically affected both natural and human systems. The response of both, in turn, illustrated the importance of understanding social-ecological ties and had implications for society and conservation of the marine environment. Fishing was disrupted, temporarily reducing take and secondary forms of disturbance related to the industry; freshwater systems were rendered saline, limiting water resources for coastal communities; and aquaculture facilities were swept away, releasing nutrients and chemicals and introducing new species into surrounding environments. This case study will examine some direct and indirect tsunami impacts on the diving industry in Phuket and implications of the diving industry's response to this event for future conservation of Thailand's Andaman Sea.

The specific research questions addressed are:

i. What was the impact of the tsunami on scuba diving tour companies in Phuket?

ii. How did diving companies respond to tsunami effects?

iii. How did recreational divers perceive dive site conditions following the tsunami?

The next section outlines the study area. This is followed by a description of the survey methods and results. These results are then discussed in terms of their implications for the future of Phuket's diving industry and applied marine conservation in Thailand.

3.2 Methods

3.2.1 Study area

Located along the Andaman Sea coast of Thailand, Phuket is a popular international destination for divers. It is the base for the majority of Thai dive tour companies that operate day and live-aboard trips in the surrounding Andaman Sea (Figure 3.1). Four types of dive tour companies exist in Phuket – operators that run daytrips, operators that run live-aboard trips, operators that run day and live-aboard trips and booking agents. Companies may either own or charter boats and, depending on their size, either have a permanent staff of divemasters and instructors or hire private contractors. Some companies offer instruction at various levels, and, with almost no exception, tourist dive trips are guided by a certified divemaster or instructor.

Research was conducted during Phuket's 2004/5 high season for diving, which typically runs from late October to late April, after which the annual SW monsoon brings stormy and unpredictable weather to the area. This study involved two parts: SCUBA diving tour operator interviews and post-dive questionnaires for recreational divers.

3.2.2 Sampling methods and data analysis

A list of all SCUBA companies believed to exist in Phuket prior to the Dec. 26, 2004 tsunami was compiled based on DOCT records, other diving industry members in Phuket and personal observation. From this list, a complete census of all companies running or booking dive trips in the Andaman Sea was attempted during the period of April 1-20, 2005. Appointments for interviews with English-speaking owners or managers were made by phone, email, referrals and walk-ins. Interviews were conducted using a structured 19 question questionnaire (Appendix 2, A3.1), with interview times ranging from 20-60 minutes. The interview included questions regarding company characteristics, tsunami effects and post-tsunami recovery, participation in rescue, restoration and cleanup activities and comments on the status of the industry and its role in marine conservation. Of 65 companies with physical presence in Phuket, 35 were interviewed, including 6 daytrip, 9 live-aboard, 11 daytrip/live-aboard and 9 booking agent companies. Simple descriptive statistics have been employed to summarize results of these interviews.

In the second part of this study, a short questionnaire on diver perceptions of tsunami effects was developed to be somewhat consistent with earlier work of Bennett (2002) in Phuket regarding diver expectations and values and for comparison with DOCT tsunami damage surveys (DOCT 2005; Appendix 3). During a two week pilot study, trial questionnaires were opportunistically administered in the field to 25 recreational divers and completed during live-aboard trips. Questionnaires were modified for clarity based on responses and feedback from these divers. In February, 2005, ten companies with boats were selected by convenience and asked to participate in distributing questionnaires to all clients at the end of their dive trip aboard the boat. Due to time constraints, random stratified selection was not feasible, but an effort was made to approach companies that ranged from small to large (based on number of staff and shop size). Seven of these ten companies agreed to participate. Divemasters for each company were contacted and given detailed verbal and written instructions for distribution. Questionnaires (Appendix 2, A3.2) mainly included closed questions regarding diver and dive trip details, diving experience level, expectations for, and observations of, tsunami effects on the marine environment at dive sites, as well as importance and satisfaction rankings for dive trips and various dive site attributes. Seven hundred questionnaires were distributed, and between late February through to mid-April, 2005, 124 useable questionnaires were returned. Responses have been summarized using simple descriptive statistics and Chi-square tests for comparisons.

At the end of the 2005/6 diving season, a short follow-up questionnaire (Appendix 2, A3.3) was distributed. All companies that had participated in earlier surveys and could be contacted were given these questionnaires by hand and responses were collected on site, mailed or emailed to the author. Of the 35 companies initially interviewed, 14 responded.

3.3. Results

3.3.1. Structural changes to Phuket's diving industry

In 2000, Bennett (2002) documented the presence of 85 dive companies in Phuket. However, after extensive searching, only 65 dive tour operators and trip booking agents (62% and 38%, respectively) had physical presence in Phuket just prior to the tsunami in 2004. During intensive searches between April 1-20, 2005, 16 companies were found which had drastically downsized their operations and 7 had shut down indefinitely, leaving 42 fully operational post-tsunami companies (Figure 3.3). The majority (77%) of interviewed companies had been established prior to 2000. Of the two companies most recently established (in 2004), one had shut down after the tsunami and the other was effectively non-operational for the remainder of the season.

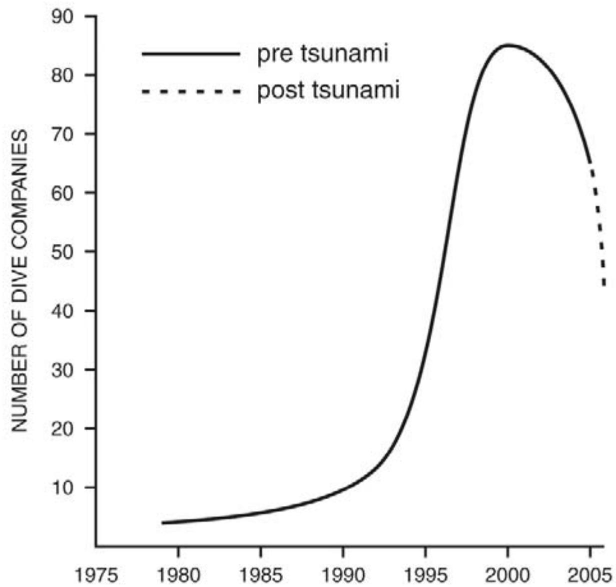

Figure 3.3 - Number of dive companies in Phuket over time to 2005 (based on Bennett 2002)

3.3.2. Tsunami impacts on members of the diving industry

Most waterfront dive shops on the west coast of Phuket were destroyed by the tsunami, and several dive shops just back from shore suffered some form of water damage. No dive boats were reported to be severely damaged, since most were out of harbour on trips or anchored in well-protected bays. Nineteen of 35 companies had property damage or equipment loss ranging from US $1,800 to $640,000. This high variability reflects the variability in assets held by diving companies in Phuket, mainly depending upon the number and size of waterfront shops owned by each company. Respondents who had resources invested in one or more boats did not seem to be more affected than respondents who did not own a boat. The vast majority of all companies had negligible insurance coverage and claimed they had received minimal, if any, assistance from the Thai government.

Most dive companies were not directly affected by tsunami damage to dive sites and did not change dive trip itineraries. A small number of heavily-dived sites around Koh Similan Islands #4, #7 and #9, as well as moderately-dived sites around Koh Surin, were not dived for the remainder of the season to avoid having clients see tsunami damage on reefs. Koh Surin reefs were some of the most heavily tsunami-affected reefs in Thailand and, of the three live-aboard companies known to run trips to Koh Surin, two completely avoided the area after the tsunami. Some daytrip companies were affected by the complete loss of infrastructure after the tsunami on the Phi Phi Islands, south of Phuket (see Figure 3.1). For most of January, Phi Phi and its popular dive sites were closed, but upon reopening to tourists, companies resumed their pre-tsunami trip itineraries.

The 2004/5 high season had started promisingly and most companies were fully booked in December, with very high expectations for the rest of the diving season. Following the tsunami, almost all companies were dramatically affected by loss of diving tourism. There were dramatic decreases in inquiries and many trip cancellations. By April 20, 2005, only three interviewed companies were on par with their average high season revenue, while seven did not know when, if ever, their company would recover from lost revenue.

The overall decline in dive tourism in Phuket following the tsunami was substantial. Compared to previous equivalent periods, there was a mean of 63.6 ± 40.5% fewer diving days for dive companies that were interviewed (diving day = a day when one company has divers on the water). A total of 4631 diving days (dd) were lost by Phuket's dive tour operators because of cancelled day and live-aboard trips (1271dd), companies ceasing to operate some or all of their boats (1120dd) and complete or temporary closure of 20 dive companies (2240dd).

There was high variability in the number of diving days lost by different companies. Companies that did not suffer large declines in business attributed this to good reputation and rapport with customers, as well as the ability to assure customers that diving conditions were unchanged and Phuket's infrastructure intact. Also, several companies had binding contracts with customers, so diving trips that may otherwise have been cancelled, ran at the expense of these companies. In January and February, it was common to see two divers on live-aboard trips that would normally take at least 18 divers.

3.3.3. Post-tsunami response

Of the 35 diving companies interviewed, 32 participated in post-tsunami rescue, cleanup and restoration activities, and several staff volunteered independently of their companies. Immediate response involved sending boats and crew to help with first aid, rescue and emergency evacuation of tourists and locals from Phi Phi Island and along Phuket's west coast. A few days after the event, dive guides from Phuket were in the water with researchers from Bangkok universities, facilitating and participating in preliminary reef damage assessments. Most companies joined in subsequent DOCT-organized and independent beach and reef cleanup projects around Phuket, Phi Phi, Khao Lak, the Similans and Koh Surin. Many companies also organized and paid for volunteer recreational divers from Bangkok and abroad to participate. Booking agents that sold dive gear joined in these efforts by donating equipment to damaged shops and offering discounts to divers directly involved in the tsunami and subsequent cleanups.

Throughout the remaining season, several companies donated their boats and staff for government-affiliated assessment and post-tsunami restoration projects. In these efforts, local knowledge of dive guides was a substantial resource for scientists from distant universities and organizations that were not as familiar with specific dive site conditions. As an example, in April, 2005, Sea-King Divers and Marine Project donated their boats and staff to facilitate a gorgonian seafan restoration project at the Similan Islands. This was a joint government and university initiative with the purpose of restoring seafans that had been dislodged and damaged during the tsunami. Restoration team members included university professors from Thailand and Japan, scientists from Phuket Marine Biological Station, volunteer biologists from abroad and dive professionals from Phuket. The trip was preceded by a series of meetings with all groups to determine optimal strategies for attempting to reattach tsunami-dislodged massive gorgonian seafans to the seafloor. A key factor in the success of this project was the ability to plan during these preliminary stages based on the intimate knowledge of site characteristics and diving conditions contributed by local dive professionals who were diving on these reefs daily.

Participation in post-tsunami relief was not restricted to ocean-based efforts. Many owners and managers of dive companies organized and distributed aid from foreign contacts and past customers to damaged communities. The staff of Raya Divers, for example, was active in Khao Lak and on Phi Phi Island in first aid response and body recovery, as well as in body identification later on in the season. The Junk made deliveries of food and supplies to the Moken village at the Surin Islands part of their dive trip schedule. Sea-King Divers organized donations from abroad to buy school supplies for a local community that was being rebuilt. Ocean Rover made weekly trips up the coast to bring supplies to coastal communities and channeled post-tsunami donations into a scholarship fund for the education of tsunami-orphaned children.

3.3.4. Dive operator concerns

In the open-ended portion of interviews, two concerns dominated: concern over the current lack of organization and regulation of the diving industry; and frustration that the industry has been overlooked by the government and scientists as a stakeholder in matters related to the sea.

Few operators were concerned that the tsunami would have a negative and long-term effect on dive sites or the quality of the trip that they could offer to customers. Interestingly, 22 of 35 operators felt that, overall, the tsunami had more positive than negative outcomes for the marine environment. Some key positive outcomes included less diving, fishing and boat pressure on reefs, and heightened public awareness of the importance of the marine environment for Thailand. Industry members also noted that this was the first time they had seen widespread cooperation among diving companies and collaboration with scientists and the government.

3.3.5. Recreational diver damage expectations

When asked to rate expected versus perceived damage by ‘no expectations,’ ‘much less,’ ‘less,’ ‘more’ and ‘much more than expected,’ few respondents saw more tsunami effects than they expected prior to their diving trip. Ninety-seven percent found less or much less coral damage, 93% saw less garbage on dive sites and 91% found less terrestrial damage than expected. There were no detected relationships between damage expectations and diver experience level (number of logged dives, number of recent dives, certification level, number of countries dived and past diving experience), trip type (month of response, daytrip or live-aboard, planned or unexpected diving, tsunami influence on trip planning), or personal attributes (country of origin and sex).

3.3.6. Underwater perceptions

Between Dec.27, 2005 and Jan.10, 2005, professional divers in the DOCT assessed popular dive sites for tsunami effects. Using a scale modified from ICRI (International Coral Reef Initiative) recommendations (ICRI/ISRS 2005), damage was estimated as the proportion of each site affected by the tsunami, ranging from none (0%), slight (1-35%), moderate (36-75%) to heavy (76-100%). The results of these assessments were compiled in an unpublished report (DOCT 2005) on the status of 59 sites. Recreational divers were asked to estimate damage on the same sites.

Over the period of this study, 124 recreational divers made 1193 damage estimations on 40 sites assessed by the DOCT (DOCT 2005; Appendix 3). Only 3 of 14 sites with moderate to heavy damage were purposely avoided by all surveyed companies after the tsunami: one at Similan Island #9 (Snapper Alley), and two at Koh Surin (North Torinla and Yellow Rock). Several sites rated with moderate to heavy damage by the DOCT were still dived by participating dive tour companies after the tsunami. Recreational divers in this study did not perceive damage on most of the sites with any tsunami damage identified by local professional divers in December and January (Figure

3.4). On 31 DOCT-assessed slight to heavily damaged sites, over 85% of recreational divers perceived no damage.

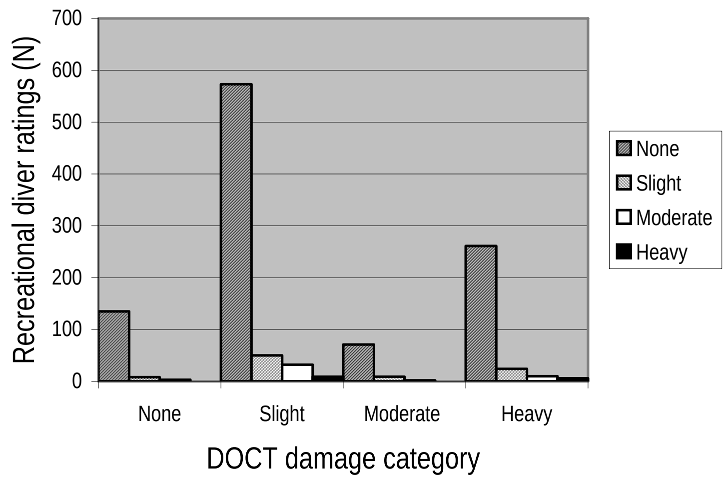

Figure 3.4 - Recreational diver ratings of tsunami impacted sites assessed by the DOCT

Table 3.1 – Recreational diver tsunami damage perception for diver and dive trip characteristics

Characteristic	Group	N	% divers perceiving damage	Chi-square p-value (df=1)
Sex	Male Female	63 39	57% 54%	0.75
Country of origin	Thailand Other	12 93	67% 55%	0.44
Certification level	Open water Specialized	57 33	54% 58%	0.77
Logged dives	<100 100+	44 53	59% 53%	0.54
Dives in past year	<25 25+	39 57	51% 56%	0.64
Thailand diving experience	None 1+ prior trips	58 50	50% 64%	0.14
Number of countries dived	1 2+	12 85	58% 54%	0.78
Nature of trip	Planned diving Unplanned diving	92 14	50% 58%	0.59
Month of response	Feb/March April	73 35	59% 51%	0.46
Tsunami effect on trip plans	Unaffected Affected	85 21	71% 54%	0.15

There were no statistically significant relationships detected between diver characteristics and the perception of any underwater tsunami effects (Table 3.1). However, divers with previous diving experience in Thailand and divers whose travel plans were affected by the tsunami may have been slightly more likely to perceive tsunami effects than those divers without previous experience diving in Thailand and divers whose plans were not affected by the tsunami (Table 3.1).

3.3.7. Diver values

When divers were asked to rank eight dive site attributes for the importance of each to the quality of the diving experience, low crowding at dive sites was ranked moderately to very important by 82% of all respondents (Figure 3.4). The presence of large exciting species was important for 76% of respondents and the presence of small rare species was important for 62%.

A few potentially important differences were detected in the ranked importance of specific dive site attributes for the quality of the diving experience between different types of divers (Appendix 4). The opportunity to take underwater photographs seemed to be more important for divers who had logged at least 100 dives (N=51) versus those with less than 100 dives (N=56; χ^2 p = 0.003). The educational aspect of the diving experience was ranked highly important for more female divers (N=36) than male divers (N=73; χ^2 p = 0.047). Low levels of dive site crowding were more important for female (N=40) versus male (N=73) divers (χ^2 p = 0.013), divers with at least 100 dives (N=55) versus divers with less than 100 dives (N=51; χ^2 p = 0.011), and for divers with at least 25 dives in the past year (N=60) versus divers with less than 25 dives in the past year (N=46; χ^2 p

= 0.003). Dive site crowding levels may also have been more important for divers who had experience diving in more than one country than divers who had only ever been diving in Thailand (χ^2 p = 0.062). Finally, more divers with at least 100 dives (N=50) versus divers with less than 100 dives (N=53) ranked the remote and exotic nature of dive destinations as important for a dive trip experience (χ^2 p = 0.039).

Although there was no statistically significant difference between groups, the presence of large, exciting species may have been more important for divers who had only ever been diving in Thailand, and not elsewhere (χ^2 p = 0.093), and for divers who decided to go on a diving trip after arriving in the country as opposed to those whose main priority for coming to Thailand was diving (χ^2 p = 0.051). Additionally, divers with at least 100 dives may have placed higher importance on the pristine condition of dive sites than divers with less than 100 dives (χ^2 p = 0.077).

Post-diving satisfaction rankings (Figure 3.5) revealed high satisfaction with overall dive trip experience (89% of all respondents were at least 80% satisfied). However, there were low levels of satisfaction for certain aspects of the diving experience. Only 66% of divers who ranked the pristine quality of dive sites as important (N=97) were satisfied with this attribute. Forty-five percent of divers who ranked the presence of large exciting species during dives as important (N=91) were satisfied. For those divers who ranked dive site crowding as important (N=99), just 43% were satisfied. Most divers were satisfied with the variety and abundance of species (87% were at least 80% satisfied, N=117), the presence of small, rare species (84% were satisfied, N=91), the opportunity to learn about the marine environment (91% were satisfied, N=76), and the remote and exotic nature of their diving experience (80% were satisfied, N=69). For those divers who placed high importance on the opportunity to take underwater photos (N=46), 78% were satisfied.

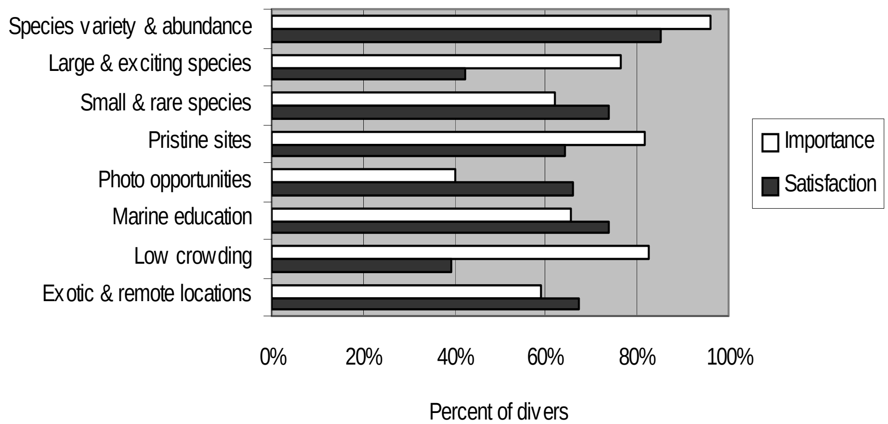

Figure 3.5 - Divers who ranked 8 dive site attributes as moderately to very important and those who were moderately to very satisfied with these attributes

Table 3.2 – Recreational divers who were at least 80% satisfied with their dive trip experience in Phuket

Characteristic	**Group**	**N**	**% divers over 80% satisfied**	**Chi-square p-value (df=1)**
Sex	Male Female	76 40	89% 90%	0.93
Country of origin	Thailand Other	14 104	71% 92%	**0.02**
Certification level	Open water Specialized	68 33	91% 88%	0.60
Logged dives	<100 100+	53 56	91% 91%	0.93
Dives in past year	<25 25+	49 59	92% 92%	0.95
Thailand diving experience	None 1+ prior trips	68 55	92% 85%	0.32
Number of countries dived	1 2+	16 93	88% 92%	0.50
Nature of trip	Planned diving Unplanned diving	120 18	75% 89%	0.94
Month of response	Feb/March April	74 49	92% 84%	0.16
Tsunami effect on trip plans	Unaffected Affected	97 24	86% 100%	**0.05**

There were few differences between diver types in terms of overall dive experience satisfaction levels (Table 3.2). Fewer divers who were from Thailand were at least 80% satisfied, compared to those divers who were from other countries. It also seems that divers whose trip plans were influenced by the tsunami disaster in Thailand were more satisfied overall than divers whose plans were not affected. There were no detected differences in satisfaction level between divers with different experience levels in terms of number of logged and recent dives, certification level and those with prior diving experience in Thailand or experience diving in other countries.

3.3.8. Phuket's diving industry in 2005/6

Of 14 follow-up survey respondents, 12 commented on changes in occupancy on day and live-aboard diving trips since the 2004/5 Andaman high season. Ten companies experienced changes in trip occupancy. Half of the companies had recovered to pre-tsunami or higher levels and the remaining half reported a loss of tourist clientele since the tsunami. However, seven of these 10 companies have consistently had fewer bookings for their live-aboard trips.

For individual dive operators, the impact of the tsunami on dive site quality remained an insignificant concern. Only one of 14 companies had changed its trip itinerary (this was the only company that ran trips to Koh Surin and dove the previously popular site, Yellow Rock), and five companies were still avoiding specific sites in Koh Similan as reported for the 2004/5 season. Overall, there seemed to be little permanent change within these companies since the tsunami although two had decreased staff volume and/or diversified their tour operations.

Changes in the structure of Phuket's diving industry that were observed in 2004/5 did not seem to have had long-term effects. Locating the companies that had participated in 2004/5 surveys for follow-up was challenging, as expected, as several of these had likely moved locations, changed staff or closed down. Only one respondent believed that there had been a decline in the number of dive tour companies since the tsunami; the majority of operators thought that the number of companies had increased to pre-tsunami levels. The volume of closures in 2004/5 seemed to have been compensated for by the industry's consistently high turnover of new companies. No respondents had observed changes in the management of the diving industry that they felt could be attributed to tsunami effects. High competition combined with a lack of collaboration and communication among dive companies were still of great concern for all operators.

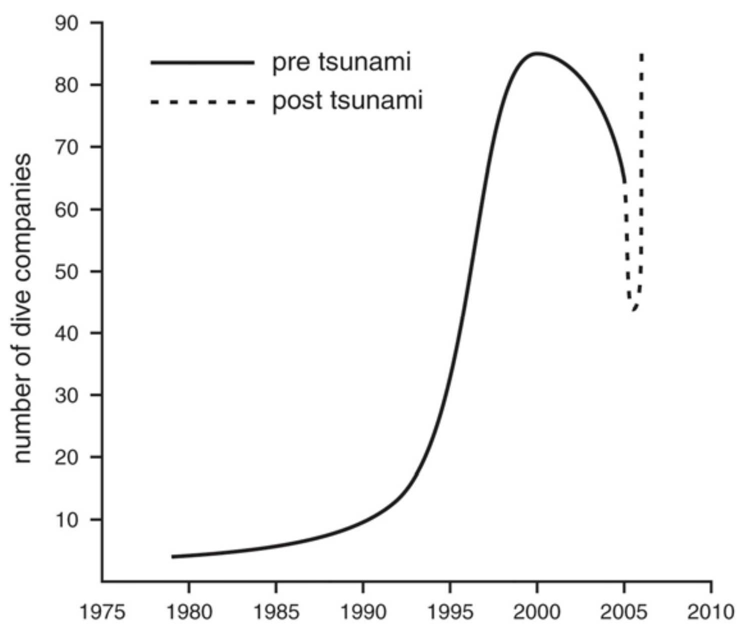

Figure 3.6. Number of Phuket diving companies over time to 2006

Five of 13 respondents felt that communication between the industry and the Thai government and universities had improved as a result of post-tsunami collaborative initiatives. A positive future for the diving industry was envisioned by most operators, and they felt that the tsunami had influenced the improvement of local safety standards and awareness of marine conservation among divers. There was some concern over the low prices offered by competing companies as they could drive down industry standards, but this seemed to be balanced by the continued ability of Phuket (largely due to these competitive prices) to draw a large clientele of divers interested in SCUBA instruction at all levels. Three operators, however, viewed this direction as unsustainable and stated an urgent need to focus on important issues for conservation of the Andaman Sea.

The effects of the 2004 Indian Ocean tsunami followed by social and ecological responses to the event have several general implications for marine conservation in Thailand. First, linkages between Phuket's diving industry and the marine environment that were brought to light by this event illustrate the importance of managing coral reefs as linked social and ecological systems. Second, the high variation in tsunami effects indicates a need for management that can operate at a scale that is site-specific. Finally, the tsunami revealed the ability of Phuket's diving industry to recognize incentives for, and contribute substantially toward, conservation of the marine resources to which diving is fundamentally tied.

3.4. Discussion

3.4.1. Understanding social and ecological linkages

The true effect of natural disturbance on a coral reef arises from a combination of effects due to the disturbance itself, internal and external stressors to the system, and the history of the reef (Adger et al. 2005; Bellwood et al. 2004). Thus, a singular discipline perspective of disturbance is not sufficient to understand its influence on linked systems. The tsunami was a physical process that affected ecological and social systems, and these effects were strongly influenced by each other. To understand the implications of the tsunami for Thailand's coral reefs, a geographical perspective that links both physical and social understanding is necessary.

Physical tsunami damage on coral reefs overall was much lower than initially expected. Rogers (2005) suggested that this may be because Andaman Sea reefs have high resilience to disturbance due to chronic exposure to storms during the SW monsoon, combined with naturally rapid rates of coral growth. Areas under such disturbance tend to develop wave-adapted coral communities that are resistant to hydrodynamic stress (Rogers 1992). Although differential resistance to the tsunami disturbance among coral morphologies was not detected in an ecological survey of corals within Mu Koh Surin Marine National Park at the time of this study (Chapter 2), it is likely that adaptive resistance occurred at certain scales. High growth rates of corals, on the other hand, were evident even one month after the tsunami when damaged corals showed signs of tissue regeneration. By April, fast-growing *Acropora* corals had up to 3cm of new apical growth at skeletal fractures.

Thus, chronic exposure to disturbance, high growth rates and the short duration of the tsunami (Liddle & Kay 1987; Connell 1997; Rogers 2005) may have mitigated the extent of long-term physical damage to most coral reefs in Thailand. Even at Koh Surin, with some of the most tsunami damaged reefs in Thailand, no more than 10% of total coral cover within the park was estimated to have been lost (CCC 2005, chapter 2).

The physical effect of the tsunami on the marine environment did not affect diving tourism in Thailand as much as the *social perception of tsunami damage* did. The dramatic portrayal of the tsunami by media created much concern amongst tourists over the extent of devastation in Thailand. Concerns for divers were heightened by projections such as in *The Bangkok Post* on December 28, 2004, quoting a coral reef researcher out of Bangkok who had not yet been in the water after the tsunami: 'Coral reefs also victims of waves; diving paradise ruined.'

There was a massive reduction in diving tourism (and all types of tourism) in the region during the high tourist season following the tsunami as divers responded to media sensationalism over the event. In reality, the vast majority of divers who came to Thailand after the tsunami – as well as scientists who conducted post-tsunami surveys – found substantially less damage under water and on land than they had anticipated given media and the scale of the event.

There were some 'positive' outcomes of this publicity for the marine environment, however. The loss of diving tourism temporarily meant less pressure on heavily exploited marine resources. This respite could have been beneficial for recovery and repair of marine fauna since diving activity can create considerable stress on coral reefs at high intensities (Hawkins & Roberts 1997, 2005; Rouphael & Inglis 2001; Barker & Roberts 2004).

This decline in tourism also gave the diving industry time to organize and run reef clean-up and restoration initiatives and there was more public involvement in marine conservation initiatives than ever before. The public's desire to participate in these initiatives seems to reflect Dearden et al.'s (2007) suggestion that divers are much more likely to contribute to resource conservation if they can perceive a need to conserve the resource. As a side-effect of 'negative' media hype, local and foreign divers were keen to contribute toward conservation in efforts to repair the substantial damage they assumed Thailand's coral reefs had sustained.

Benefits of increased involvement were not straightforward. Several of these cleanups were described by participants as 'underwater zoos' since there was typically high crowding on sites, and most divers did not receive proper training prior to restoration activities – actually *causing* coral damage in some cases. This disorder reflects an insufficiency in the management of diving activity in Thailand overall which will be discussed in the next section.

Determining the value of these initiatives for marine conservation, however, would require an integrated assessment of the associated social and ecological values. Broadly, the natural resilience of Andaman Sea reefs was evident as most reefs showed signs of recovery within a few months of the tsunami; thus, although some damage was incurred to corals, it may be that this damage is not significant when weighed against the future implications of the fact that people, who would otherwise not have been, were involved and thinking about the ocean.

3.4.2. Site-specific regulation for conservation

One of the most common and striking observations after the tsunami had hit Thailand was the consistently high amount of spatial differentiation in terrestrial and marine damage all along the Andaman coast. A remarkable spatial variability in tsunami damage was evident on coral reefs within Mu Koh Surin Marine National Park, for example, where highly localized portions of completely destroyed reef lay directly adjacent to imperceptibly affected reef (Chapter 2). In the same way that understanding why this is so requires complex and detailed understanding of the biophysical structure of the coastline at site-specific scales, effectively managing such spatially heterogeneous systems requires a similarly site-specific understanding (Rogers 1992; Pandolfi 2002; Chapter 2).

The challenge of effectively implementing site-specific management is considerable since – especially in a developing country like Thailand – it is not realistic to assume government can (or will) commit the required resources to enforce policy at fine scales. For this reason, a mechanism for reef conservation has been proposed in which other sectors actually take the lead in reef conservation on the ground (Dearden et al. 2006; Main & Dearden 2007). In this scenario (to be discussed further in the following section), applied reef conservation would be substantially incentive-driven, capitalizing on the dependence of the diving industry on coral reef condition, ultimately in order to maintain good opportunities for diving tourism.

Where post-tsunami diving may lead to further reef degradation, one option for management is to enforce site closures to diving activity. This has occurred in the past on degraded sites in Thailand (at the time of this study, closures at the Similan Islands were in effect to facilitate reef recovery). However, enforcing site closures can be a costly process due to the resources required for enforcement. Although the variability in tsunami effects within and among reef sites calls for site-specific management for recovery on those sites that were heavily affected, based on the results of this study, allocating government resources to the closure of sites is likely unnecessary.

Just as a ‘disaster tourism’ industry temporarily developed in places like the Phi Phi Islands (Figure 3.1), in which boats took tourists from the mainland for daytrips to see the destruction caused by the tsunami (personal observation), some divers were curious to see tsunami damage to coral reefs. Most of the diving industry, however, did not encourage ‘disaster diving,’ and reported their preferential avoidance of the few entirely destroyed Andaman Sea dive sites. The low damage estimations of recreational divers on all sites confirmed this avoidance of certain heavily damaged sites after the tsunami. However, these low damage estimations are of more interest than just as evidence for the above.

Surveys showed that most recreational divers did not notice tsunami damage, even on sites where dive professionals found heavy damage. There are three potential explanations for this: that sites had completely recovered from the time of the DOCT report; that recreational divers did not notice damage; or that recreational divers did not actually dive on specific locations with tsunami damage.

Based on extensive diving throughout the period of this study, the first possibility cannot account for the lack of damage perception. By April, even with high rates of recovery and although tsunami damage was sometimes difficult to distinguish from other types of damage, there were still obvious signs of tsunami effects – especially on sites with heavy damage (Chapter 2; Worachananant et al. 2007). The second possibility, that recreational divers were diving on tsunami damaged sites, but did not notice tsunami effects, may partially account for the low damage perception rates, especially since certain divers may have been less likely to perceive damage than others. It is the final possibility; however, that merits some discussion.

The nature of underwater tsunami damage throughout the Andaman Sea was so localized that adjacent dive sites were affected very differently in certain locations (Chapter 2). This was also true within sites. For example, at East of Eden along the east coast of one of the Similan Islands (Figure 3.1), the entire south end of the site was devastated and hardly any corals were left standing. In the shallower regions of the site to the north, corals remained intact and tsunami effects were hardly noticeable. Thus, since divers usually only travel within 100m from their point of descent depending on current (Hawkins et al. 1999), and since most sites, like East of Eden, are considerably larger than this, a dive guide would conceivably have fairly effective control over where divers travel within dive sites.

Since dive operators were still diving areas that had been rated with slight to heavy tsunami damage without recreational divers perceiving any tsunami effects in most cases, it is likely that dive guides were voluntarily (and effectively) restricting activity within sites to avoid certain locations. Two important implications for dive industry management and marine conservation can be drawn from this conclusion. First, special restrictions for diving activity on damaged sites to promote recovery (as suggested by Worachananant et al. 2007) are probably not necessary - the industry is already self-managing in this respect. Second, it affirms that site-specific management – usually not feasible at the government level – is possible if driven by those in industry who naturally operate at the scale of sites. These two implications lead to the following discussion of the prospective utility of the diving industry to help Thailand surmount some difficult issues in the application of marine conservation.

3.4.3. Incentive-driven conservation

One of the largest obstacles to applied conservation – especially in the tropics – is a consistent lack of resources for implementation (Lapham & Livermore 2003). These resources include finances, knowledge and manpower to apply management prescriptions. During the aftermath of the tsunami, however, an alternative source of resources for marine conservation in Thailand was revealed - Phuket's diving industry. The industry's response to the event showed both its potential for sustainable self-management and the substantial resources it has to contribute toward conservation applications.

In the same way that some locals felt that the tsunami had physically "cleaned out" the Andaman Sea, it temporarily did the same for Phuket's diving industry. The aftermath of this large-scale natural disaster was a time when the industry could have capitalized on a changing climate in order to engineer a more desirable future for itself. The tsunami temporarily reduced the number of companies and the volume of diving tourism in Phuket, likely leaving more stable and well established companies. This is noteworthy since companies that operate long-term should necessarily be more invested in the long-term health of marine resources upon which they depend than would more transient companies.

Barring some other mechanism for change, it takes a monumental and coordinated shift in thinking and behaviour to reverse unsustainable trajectories of development. Throughout history, this kind of change within communities has rarely been accomplished without some substantial external drivers (Diamond 2005). What the tsunami did for Phuket's diving industry was to physically push what had developed into an oversaturated market with no regulatory controls (Bennett 2002) back down to earlier stages of development. As summarized in Figure 3.2, Duffus and Dearden's (1990) earlier stages of development in the evolution of a nature-based tourism industry are characterized by a lower volume and more specialized market than the oversaturated generalist market which develops over time. From a conservation perspective, the early stages of development are desirable since highly specialized divers have more resources to contribute to local economies (Bennett 2002), they may have less individual impact on coral reefs (Zakai & Chadwick-Furman 2002), and their higher requirements for low crowding and dive site quality (Bennett 2002; Dearden et al. 2006) encourage diving practices that are sustainable in the long-term.

In theory, in the aftermath of the tsunami, the fewer and more committed diving companies in Phuket had an opportunity to influence the future of the industry. This large-scale natural disaster provided a brief chance for these companies to decide whether to allow their industry to regain its past unsustainable state or to decide to rally and lead the way toward a more sustainable future. Beyond the few members of the industry who directly stated a desire to follow the latter course, the actions of most remaining members – especially in post-tsunami marine conservation initiatives, indicated the same. What was lacking was a plan for management and the leadership to implement it.

While government involvement in marine conservation is essential for broad-scale management, governments rarely commit sufficient resources to be effective at relevant scales (Lapham & Livermore 2003). These economic constraints can be alleviated by utilizing the dependence of marine-based tourism industries on the quality of marine resources. The way this works is that for industries to protect long-term profit, the marine resources that draw tourist dollars must simultaneously receive protection.

This study shows that Phuket's diving industry has potential for implementing incentive-driven conservation. First, the industry's awareness of its vested interest in the long-term health of Thailand's oceans was emphasized by loss of tourist revenue due to [perceived] environmental damage. Second, the effects of the tsunami initiated communication and cooperation among previously politically-divided groups – potentially paving the way for necessary future collaboration. Third, the industry's response to the tsunami exhibited its ability to mobilize quickly and provide important resources for marine conservation initiatives.

Since the quality of the diving experience is primarily based upon the quality of the marine environment in which it takes place (Tabata 1989; Musa 2002), the diving industry is fundamentally dependent upon the good condition of the Andaman Sea and its coral reefs. After the tsunami, this was evident by the extreme concern regarding underwater damage to reefs. Several companies voluntarily assessed and reported on damage at popular dive sites and made reef cleanups a high priority in the initial tsunami aftermath. Many of these companies also had the opportunity to educate and mobilize a large base of locals and foreign divers to become involved in these efforts. While the reasons behind these efforts may have been economic – rather than environmental – the outcome is the same: a voluntary stewardship of the marine environment.

Along with this coordination came enhanced communication and cooperation for the diving industry on different levels. Prior to the tsunami, there was little communication amongst dive companies in Phuket and between the industry and scientists and the government. After the tsunami, many companies ran joint trips and referred customers to each other to maximize efficiency of their operations. Since industry members played large roles in coastal rescue and relief efforts, they spent considerable amounts of time working alongside local communities. They also worked with government employees and scientists on a number of assessment and restoration projects. The tsunami catalyzed these groups to work together with clear and shared objectives, and created potential for a more communicative and less competitive future.

The diving industry's response to the tsunami also revealed the availability of its resources for contributing to the social-ecological resilience of Thailand's oceans. Almost immediately after the tsunami, the diving industry was able to mobilize and offer its equipment, skilled staff and knowledge of the marine environment in response to the event. Companies provided boats, staff and diving equipment. Dive guides provided valuable skills and revealed an intimate knowledge of the local marine environment. Throughout the remainder of the season, the diving industry ran frequent reef restoration projects and several companies organized volunteer divers to participate in them. The tsunami revealed not only the diving industry's considerable resources for marine conservation but also a motivation to apply them for this purpose.

3.4.4. Current status of Phuket's diving industry

Follow-up surveys in 2005 indicated that the changes discussed above were mostly short-lived. Responses affirm that the ecological consequences of the tsunami on coral reefs are likely to be minor, as discussed in chapter 2. The structure of the industry in terms of number and type of SCUBA diving tour companies after a year had passed closely resembled that of the industry before the tsunami. This suggests that Phuket's diving industry may not have reached its saturation point (stage 'C', Figure 3.2) and does not support recent projections of industry decline (Main & Dearden 2007) based on the observed reduction in the number of diving companies in Phuket - especially after the tsunami, but also between 2000 and 2004 (Dearden et al. 2007). Assuming that earlier versions of the industry fit within the nature-based tourism evolution model (Duffus & Dearden 1990), it is possible that the diving industry is still evolving within stage 'B' (Figure 3.2) or that Phuket's diving industry has begun to evolve along another evolutionary trajectory (stage 'E', Figure 3.2).

Thus far, the tsunami has not seemed to have had many long-term consequences for diving companies in Phuket. The diving companies that suffered the least from lost tourism were those with a solid reputation and good client relationships, those with a high level of adaptability and those companies with alternate sources of income. This event encouraged certain forward-thinking companies to promote their own resilience by diversifying away from just one type of clientele and one resource base (Dearden et al. 2007).

Another change that seemed to have long-term potential was the improvement in communication between the industry and university and/or government groups. Before the tsunami, there were almost no cooperative efforts among these groups for conservation and the diving industry was usually overlooked as a stakeholder in marine related issues (Bennett 2002). At the very least, post-tsunami collaborative efforts have revealed that the diving industry has considerable *and readily available* resources for marine initiatives.

Although an opportunity for change was created by this disaster, the diving industry was not capable of utilizing it at the time. A major reason for this was a lack of effective leadership in directing the industry. The DOCT was initially founded to provide this leadership, but issues within the organization prevent it from carrying out its mandate. In recent years, the organization has been as unstable as the industry itself, disbanding during the 2004/5 high season and reforming only recently in 2006.

Some difficulties associated with the DOCT relate to its structure. The president and committee who manage the organization are selected from the community of dive operators – these people may have, and more importantly, are *perceived* by others to have, vested interests. They also typically cannot be expected to have time to balance DOCT duties with running their diving companies during high tourist seasons when management is most critical. These difficulties are not insurmountable and an appropriate reconfiguration could greatly enhance the ability of the organization to see that the diving industry's natural strengths contribute toward conservation.

3.4.5. Future directions

With appropriate leadership and vision, a successful path toward a sustainable diving industry that contributes to conservation is attainable. This must be based on understanding the tourists who ultimately provide the resources and incentives for conservation. To move toward market and environmental sustainability without compromising the positive experience of visitors, it is essential to understand which dive site features are valued by which tourists and how actual conditions compare with expectations.

Although the sample of recreational divers surveyed in this study cannot be assumed to be representative across all of Phuket, results may inform current understanding based on past research. Phuket seems to be meeting expectations related to the presence of small, rare species on dive sites, the opportunity provided on dive trips to learn about the marine environment and the opportunity to experience remote dive sites. Divers in Phuket seem to place high value on low levels of crowding, the presence of large, exciting species on sites and the pristine nature of sites (in agreement with the results of Bennett 2002). There was a large degree of discrepancy between these values and satisfaction levels.

Differences in the physical and perceptive capabilities are evident amongst different types of divers (Bennett 2002; Dearden et al. 2006; Topelko 2007). As found by Inglis et al. (1999) and Bennett (2002), divers with more experience typically have higher requirements for dive site conditions than divers who have not spent much time underwater. In Phuket, specialized divers (who are typically highly experienced) have been found to be particularly sensitive to site crowding and require more pristine site conditions with specific features than unspecialized divers (Bennett 2002; Dearden et al. 2006). This difference arises partly from having a reference point based on past diving experience, but also, it is a function of diving ability. In general, new divers are less likely to notice details of their surroundings as they must learn to manage themselves and their equipment under water (Dearden et al., 2006). The higher requirements of divers with experience may be justification for developing site-specific restrictions in certain areas based on levels of diving experience.

The fact that crowding was not satisfactory for all divers at the time of this study is somewhat surprising since there were a lot less divers on the water after the tsunami than during a typical high season. At Richelieu Rock, a challenging dive site and one of the most highly-regarded dive sites in Thailand (Strickland & Williams, 2000), it was not uncommon to see up to 12 dive boats at one time before the tsunami carrying divers of all levels (The Junk, personal communication). After the tsunami, there were regularly no more than five boats anchored off the pinnacle and often just one (personal observation).

It is possible that dissatisfaction with crowding levels during this study may be due to adjusted expectations for low crowding because of the tsunami. Regardless, as Bennet (2002) found, crowding levels that existed before the tsunami must not have been acceptable for most divers. This is further justification to regulate the number of divers at specific sites with restrictions such as by experience level as suggested above – especially on those challenging and highly valued sites like Richelieu Rock (Dearden et al. 2006).

Dissatisfaction related to crowding was matched by a general disappointment in the amount of large exciting species present at dive sites (also found by Bennett 2002). Several divers commented at seeing fewer sharks than hoped for – specifically, whale sharks. This is of interest because at least 70% of the diving companies interviewed advertised whale sharks as a focal image on their websites and/or advertising pamphlets. It should be noted that over this study period (in keeping with the past few seasons – see Theberge 2002), from early December to late April, there were only a handful of whale shark sightings on trips in this area.

Without meeting key expectations for the majority of divers who come to Phuket, the diving industry will not be able to sustain itself over time. Marketing trip attributes that cannot be delivered will undoubtedly reduce the likelihood that divers will return to Phuket – further deteriorating the industry's reputation and accelerating its decline (Dearden et al. 2006).

Satisfaction with the presence of small and rare species on trips may suggest one possible direction for improving the current status of the industry: by focusing marketing away from transient species like whale sharks to species such as pipefish or anglerfish that exhibit site fidelity, the industry would be focusing on a draw that is reliable. Furthermore, since divers with more experience highly value the opportunity to take photographs, building high trip expectations around these small and rare (and also highly photogenic) species should draw more photographers.

As well as being able to satisfy trip expectations, moving away from a 'whale shark marketing strategy' and building high trip expectations around small and rare (and also photogenic) species should draw more specialized divers like photographers. This could potentially reduce the need for companies to rely on high turnover of masses of inexperienced divers since more experienced specialized clientele are willing to spend more money per trip than new divers (Bennett 2002). In summary, as outlined by Dearden et al. (2006), benefits of drawing more specialized divers include higher yields per diver, enhancement of Phuket's SCUBA diving reputation, and possibly, less impact on the marine environment than might occur with high volumes of less experienced divers (Hawkins et al. 1999; Zakai & Chadwick-Furman 2002).

3.5. Conclusion

In agreement with the previous work of Bennett (2002) and Dearden et al. (2004, 2006), the response of divers in the Andaman Sea during the 2004/5 diving season suggested what a more sustainable diving industry could look like in Phuket. Until now, there had never been a catalyst to induce a climate of change to encourage the industry to work cohesively toward shared goals for sustainability.

It appears if there will be any long-term effects of the tsunami on Phuket's diving industry these will be less physical than perceptual. Although the industry has essentially regained market over-saturation and the lack of management that existed before the tsunami, the effect of the tsunami on this community illustrated how opportunity to drive change can follow on the heels of a large-scale natural disaster – provided the mechanisms to sustain change are in place. In this case, the diving industry's response to the event highlighted its dependence on the marine environment and illustrated the considerable financial, equipment and knowledge-based resources that exist within diving companies. This could have implications for marine conservation in Thailand.

The concluding chapter of this thesis will emphasize how this research relates to the necessity of managing coral reefs for conservation as integrated systems. The way in which the tsunami particularly illustrated social-ecological linkages and potential for incentive-driven means for conservation will be discussed. Main findings of this research will then be highlighted and followed by recommendations for Phuket's diving industry to move toward sustainability and leadership in conservation of Thailand's coral reefs.

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CHAPTER 4: Koh Surin's coral reefs, Phuket's diving industry, and the tsunami

4.1. Introduction

Global consensus over the decline of coral reefs is confirmed by rapidly disappearing living coral cover, widespread bleaching and loss of coral reef function throughout the tropics (Pandolfi et al. 2003; Wilkinson 2004; Bellwood et al. 2004). Conservation-related coral reef research has been conducted for decades, but these efforts have not addressed causality appropriately to mitigate anthropogenic causes of reef decline (Pandolfi et al. 2003; Hughes et al. 2005). Scientists are now calling for a reunification of scientific effort to shift inquiry from a biocentric to human-inclusive paradigm (Birkeland 2004; Adger et al. 2005; Hughes et al. 2005; Rinkevich 2005).

The idea behind this paradigm shift is not to replace biologically-driven inquiry, but, rather, to reframe and broaden understanding in order to address issues relevant to conservation management. This involves understanding how different sources of stress interact and influence reef function in social and ecological terms and at different scales. Redefining reefs as social and ecological systems within the context of space reflects a fundamentally geographical approach to conservation.

A disjuncture between reef science and management has prevented implementation of truly adaptive management on most coral reefs even within MPAs. It is crucial that scientists, who can interpret the response of coral reef systems to conservation efforts, be involved in the design and implementation of adaptive management strategies. The key concern is whether the impetus of reef scientists to carry out adaptive solutions for conservation will be able to catch up to the rapid rate of global coral reef decline.

In Thailand, reef monitoring first began in 1986 under the ASEAN-Australia Living Coastal Resources project (Wilkinson 2004). Although this area is known to lie within the world's highest region for coral reef biodiversity (SE Asia accounts for over 75% of global coral reef biodiversity – see Wilkinson 2004), effective management is undermined by soft legislation and lack of communication and organization. In 2004, it was reported that only 18% of the MPAs that cover 50% of Thailand's coral reefs had "good management" (Wilkinson 2004, p254).

Mu Koh Surin Marine National Park is among these MPAs assessed with good management. Officially, the park has consistent ecological and socio-economic monitoring, a park database, zoning plans have been developed, and GIS has been employed to map the area for management purposes (Wilkinson 2004, CCC 2005, Worachananant et al. 2007).

These are good initiatives. However, even here, the use of existing tools and knowledge to implement conservation is compromised by lack of staff for regulation (especially in the off-season), lack of financial resources for conservation projects, and a lack of communication among research groups, the park and marine-based industries that use the area. In reality, there is little evidence "good management" on the ground.

One way to overcome implementation challenges is to promote a greater role for the private sector in conservation efforts. Benefits for conservation derived from encouraging the tourism industry to use reef resources sustainably have been demonstrated at the islands of Palau, Philippines, and Bonaire, Netherlands Antilles.

As related by Birkeland (1997), the island government of Palau recognized tourism as an alternative to the highly destructive export fishing industry that had grown in the area. As catch began to decline, Palau realized that export fishing was competing with a far more sustainable and highly profitable use of its coral reefs. In 1994, the export of fishes caught at Palau was made illegal during the spawning season in order to encourage tourism and subsistence fishing economies. By protecting its fish stocks, Palau was able to support a non-extractive, service-based use of its coral resources: Marine-based tourism. This industry has been able to sustain the livelihoods of far more people, with far greater potential over the long-term and substantially less environmental impact than an export fishery.

Bonaire Marine National Park has also encouraged a marine-based tourism industry and owes its management success to contributions of that industry. In the first ten years after its designation in 1979, Bonaire was little more than a ‘paper park,’ with few resources and almost no management of diving, its main industry at the time. By the early 1990s, the expanding diving industry was compromising Bonaire’s coral reefs through increasing tourist visitation. To address this threat, managers implemented a user fee to create resources for operations. Along with grants and donations, the user fee has since enabled Bonaire to become entirely self-financing (De Meyer date unknown). This has ensured that the necessary resources are available for active enforcement of Bonaire’s recreational zoning and comprehensive management plan for conservation.

Underlying these successes is the understanding that, regardless of ultimate motivations, marine-based tourism industries rely on maintaining the quality of the marine environment. A healthy economy is necessary for the development and support of new policies and business owners can have substantial leverage within their communities. Although marine-based tourism activity can have negative consequences for the environment (see chapter 3), it is less exploitative than many other reef-dependent activities, such as fishing.

As exemplified by Palau and Bonaire, and as suggested by the work of Bennett (2002), Dearden et al. (2004) and this thesis research, supporting sustainable marine-based tourism on reefs may not only be beneficial, but necessary, for conservation. It is not a coincidence that 'paper parks' are plentiful in the tropics. This abundance is due to a consistent lack of resources and coordination to effectively implement management by traditional means. The reality is that most governments are not willing to make the investment of resources that effective conservation would require.

In Thailand, utilizing the existing resources of the diving industry has several benefits for MPA management. First, it may reduce the government staff and resources required for effective regulation and enforcement since the industry has the ability to mainly self-manage and can provide a continuous 'watch' on the water. Second, the industry can supply parks with a considerable source of financial revenue for management (including the cost of monitoring, research, and education), and knowledge revenue, as diving companies have the most intimate familiarity with the resources they utilize daily. Finally, giving the industry a larger role in reef management will encourage self-identification as an invested stakeholder and steward of Thailand's coral reefs.

This project was developed in response to the immediate effects of the 2004 Indian Ocean tsunami observed at Mu Koh Surin Marine National Park and within the adjacent coastal communities of SW Thailand. In the aftermath of large-scale natural disasters, like the tsunami, that ties between ecology and society can become clearly revealed.

The questions driving research for this thesis evolved from the awareness that a social as well as ecological examination of tsunami effects was necessary to understand the implications of the event for marine conservation. This project was an attempt to examine the gap between conservation theory and application.

4.2. Summary of main results and conclusions

4.2.1. Koh Surin's fringing reefs and the tsunami

- The tsunami disturbance on coral reefs was highly variable at several spatial scales.
- Mechanical damage to coral colonies by the tsunami disturbance was similar to damage observed on reefs after severe tropical storms.

  Similar effects included skeletal fragmentation, basal severance, overturning, down-slope tumbling, tissue damage, scouring, bleaching and smothering with silt (Bries et al. 2004; ICRI 2005).
- Mechanical forces occurred as lateral flows and secondary disturbance.

  It seemed that surge and the transportation of tsunami-generated debris across the reef slope created the observed mechanical effects to reefs. Wave-breaking probably did not influence the upper reef slope.
- The greatest effects on hard coral seemed to occur in the southern region of the park, outside of protected bays, in areas with dynamic diurnal current flow, on SW-exposed reefs, in close proximity to narrow channels and on reefs greater than 45° steep.

Sites located in the northern region of the park may have received some sheltering from the southern islands. However, it was probably not southern location, as much as the steepness and proximity to a narrow channel, which accounted for the greater response of reefs in the south. Sheltering by headlands may have protected bays from this disturbance. Larger effects at sites with characteristically high diurnal current strengths were probably strongly related to bathymetrical characteristics of these sites that influence flow. The greater effect on SW-exposed reefs may suggest a greater response on reefs in direct exposure to tsunami approach – IF the waves reached the islands from the SW. The higher magnitude of effects on steep reefs was due to an avalanching effect of dislodged colonies, creating vertical tracts of scoured reef framework. This effect was not present on other reefs. Overall, the greatest wave magnification appears to have occurred due to constricting bathymetry through channels at Koh Surin.

- Seafloor bathymetry, specifically constrictions associated with narrow channels, outweighed all other factors in explaining the spatial variability in tsunami effects.

    This finding is consistent with understanding of tsunami dynamics (Yeh 1994; Matsuyama et al.1999) and observations of effects observed along the coastline of the Indian Ocean where variations in tsunami effects have been attributed mainly to seafloor bathymetry (Narayan et al. 2005; Choi et al. 2006).

- There was no detected difference in tsunami disturbance between deep and shallow areas of reefs.

    With the exception of piling of dislodged colonies and fragments at the base of steep reefs, response was consistent across the entire slope from reef crest to base.

This finding is inconsistent with expectations for tsunami effects as well as the conclusions of post-tsunami DMCR surveys (Brown 2005), but can potentially be explained by tsunami wave properties.

- Long-term consequences of the tsunami disturbance for most coral reefs are not anticipated.

Due to the short duration of the event, and its unlikely recurrence, substantial long-term changes on most coral reefs will probably not occur. Chronic stressors like over-fishing, pollution and increasing frequencies of tropical storms are far more likely to create long-term change than this tsunami event.

- The ecological significance of this event is probably not high.

Quick recovery is expected due to the low level of other sources of disturbance in the area, combined with the good condition and fast growth rate of corals in the area (Brown 2005; Worchananant et al. 2007). Heavily affected sites are few, have strong current flow and are spatially proximal to good potential sources for recruitment. Very few areas may not regain pre-tsunami conditions in the near future due to substantial loss of reef framework.

4.2.2. Phuket's diving industry and the tsunami

- The *perception* of physical effects had a greater impact on the diving industry than the actual tsunami.

Although shoreline damage was considerable in certain areas, very few injuries to staff and damage to property was reported by diving companies. The initial devastation in Thailand as portrayed by the media was focused on the most severely affected tourist areas. The diving industry was affected by this as well as by rumours of coral reef destruction. In Phuket, even the most heavily affected shorelines were rapidly rebuilt and infrastructure restored within a month. In almost all areas along the beach-front, tsunami damage was imperceptible and coral reef damage was found to be minimal during post-tsunami surveys (Brown 2005; CCC 2005). With no international media follow-up to these initial reports, perceptions of widespread destruction remained throughout the high tourist season, and the resulting loss of tourist revenue had larger consequences for the diving industry, and all supporting industries, than the physical impact of the tsunami itself.

- The tsunami event had some positive implications for reef conservation including a reduction in diving associated pressures on reefs, increased awareness of marine-related matters, increased participation in conservation efforts and the facilitation of collaboration among public, industry, university and government groups.

  The decline in diving tourism in Phuket after the tsunami reduced the volume, and associated pressures, of diving on Andaman Sea sites. The event raised the profile of the marine environment by illustrating Thailand's social and economic dependence on the sea. It created awareness of the necessity for conservation by stimulating many locals and foreign tourists to become involved in conservation initiatives for the first time. It also brought to light and facilitated communication of the common conservation-related goals of the diving industry, university and government groups for the first time. This may promote long-term collaboration among these groups.

- The industry is aware of its dependence on the [perceived] quality of the marine environment.

  The loss of tourism revenue due to perceptions of damage to coral reefs was linked to the importance that tourists place on the quality of the marine environment (as found by Bennett 2002). Most companies referred to the threats to coral reef condition in the Andaman Sea and involvement in ongoing conservation projects during interviews. Furthermore, participation in cleanup and restoration projects, as well as the time spent addressing tourist concerns regarding reef damage after the tsunami, indicates a high level of concern for maintaining the Andaman Sea's reputation for the quality of its coral reefs.

- Diving companies are able to manage diving pressure at the scale of sites.

  Even while diving on severely affected sites, most recreational divers did not notice tsunami effects. This is likely due to the spatial variability in effects on sites which enabled dive guides to avoid heavily damaged areas. Since all tourists are required to dive with a guide, Phuket's diving industry thus has the ability to manage diving pressure at the scale of sites. This is an essential requirement for effective conservation on spatially variable coral reefs, and it has proven nearly impossible for governments with limited resources to manage this.

- Most diving companies are able – and willing – to quickly mobilize their considerable resources in response to the social and ecological needs of their community.

  In contrast to government response which must run through bureaucratic channels for approval, the diving industry was able to mobilize itself for immediate response to the tsunami disaster. This involved the mobilization of vast resources including money, equipment, manpower, and knowledge. As influential members of the community, several of Phuket's dive company owners were able to organize and conduct successful rescue, rehabilitation and restoration efforts on land and on the ocean.

- The underwater perceptions of recreational divers indicated the need for dive site management and justified site restrictions based on diver characteristics.

  As communicated by divers in 2000 (Bennett 2002), diving tourists visiting Phuket are still not satisfied with levels of site crowding. Even after the tsunami, with volumes of divers substantially reduced, levels of crowding at certain sites were still a concern. As found by Bennett (2002) and Dearden et al. (2006), divers with more experience and with higher dive site requirements for satisfaction have greater ability to perceive dive site conditions and have lower tolerance for high crowding on sites. This provides some justification for looking at options to restrict the volume of inexperienced divers on challenging and pristine sites in order to increase satisfaction levels for experienced divers.

- Phuket's marketing strategy is contributing to the decline of the industry and reducing its potential for sustainability.

  Over 70% of dive companies use the whaleshark as a focal marketing species, despite the steady decline in frequency of encounters. Despite the industry's awareness of its lack of sustainability and a communicated desire to alter this, companies continue to gear marketing towards the 'whaleshark tourist.' This marketing strategy seems to draw unspecialized divers looking for cheap and exciting vacations (Bennett 2002). Without being able to satisfy these divers by producing large and exciting species on dive trips (Theberge & Dearden 2006), the industry must depend on a high turnover and volume of 'whaleshark tourists.'

- Most diving companies are aware that they are operating within an unsustainable industry.

  The vast majority of operators commented on the saturation of the diving industry and struggles related to poor communication and cooperation among companies. Several operators voiced concern at the level of competition within the industry that was driving down prices and causing companies to compromise in the areas of safety and quality of trips. Concern was also evident for the lack of some regulatory body to develop and enforce safety and management regulations. Several dive operators recognized the changes brought about by the tsunami as an opportunity for the diving industry to alter its future. However, the absence of a clear and unified plan for management was evident as the industry was not able to capitalize on tsunami-induced change. As Bennett concluded in 2002, the industry is steadily becoming more unsustainable.

4.3. Recommendations

4.3.1. Managing for recovery and conservation at Koh Surin

Since Koh Surin has an effective reef monitoring program, few resources should be required for monitoring and facilitating the recovery of tsunami-impacted sites. Some suggestions for promoting reef recovery within the park include:

- Continued reef monitoring.

University and government research groups have been studying and consistently monitoring coral reefs within the park. Park staff trained in SCUBA diving should continue to support, and become increasingly involved in, these projects. There should be emphasis placed on the interpretation and communication of results of monitoring so that it can contribute to adaptive management of Koh Surin's reefs.

- The definition of targets and indicators for tsunami recovery.

  Monitoring tsunami recovery of corals should be integrated into existing research and monitoring efforts within the park. This will require defining recovery targets and appropriate indicators to assess the rate of recovery.

- Resource allocation to management of good coral spawning sites.

  Resources should be focused on the management of intact sites that will support the growing amount of marine-based activity within the park, rather than allocated to reef restoration efforts. In locations that are unlikely to recover quickly, a restoration strategy, such as the use of ReefBalls (see www.reefball.org) would be required to surmount the challenges of high velocity current flow, but this is costly. Good sources for larvae exist within the park and recruitment may be naturally successful over time in some areas.

- Enforcement of park zoning.

  The option of zoning certain areas within the park has been suggested (Dearden et al. 2004; Worachananant 2004, 2007). Since diving activity is the main recreational activity within the park, a zoning plan should be developed to specifically regulate diving. The work of Bennett (2002), on the profile and perceptions of divers visiting Phuket, provides compelling support for developing site restrictions based on diver experience level (see Dearden et al. 2006). The possibility of coordinating enforcement for this type of zoning with the diving industry should be explored. However, substantial resources should not be allocated to development of a zoning plan without first assessing the feasibility of the park to implement such a plan.

- Addressing the issue of illegal fishing.

  The structural complexity and good condition of Koh Surin's coral reefs should support a high biomass and diversity of fishes. However, there is a noticeable lack of large carnivorous fish, such as groupers and sharks, within the park. Several dive guides commented that they have seen a recent decline in large fish at Koh Surin. There are many possible reasons for this but the most likely explanations are linked to overfishing. Enforcement of the park's no-take policy is minimal – there are anecdotal reports of park staff fishing for sharks, a blind eye is turned to 'subsistence' fishing by the Moken, and there is considerable political pressure not to disrupt the commercial fishing industry. Heavy fishing pressure just outside the park's boundaries, combined with illegal fishing within the park (especially in the low tourist season when park staff is reduced) is a considerable and challenging problem.

4.3.2. Managing for the sustainability of Phuket's diving industry

The lack of sustainability of Phuket's diving industry detected in 2000 by Bennett (2002) does not seem to have diminished. However, most dive operators are aware of this and recognize the need to make changes within the industry. Some important recommendations for facilitating these changes are:

- Regulation of the diving industry

  Regardless of anything else, the diving industry cannot continue to operate without some form of regulation. At present, this is not just a question of economic sustainability, but the far more pressing issue of ensuring the safety of tourists and members of the industry. Regulation could potentially be managed within the diving industry, but will likely require an external 'watchdog' and some government support. Since the industry is already saturated with companies, a temporary restriction on the establishment of new dive companies may be reasonable. The Thai government must also begin to view the diving industry as a stakeholder and valuable contributor in decision-making processes pertaining to the resources on which they depend.

- Leadership within the industry

  Although some top-down government-level regulation will be required to manage diving activity, stimulating change within the diving industry will require strong internal leadership. The continued ineffectiveness of the DOCT suggests that dive operators may not be the appropriate candidates for this position due to industry politics. This role will be challenging for many reasons, but could potentially be filled through a university or NGO.

- Applied research that contributes to management

  Re-directing Phuket's diving industry toward sustainability will be an adaptive process. It will be important to identify a desirable market and base the development of a marketing strategy on the needs of this market. Scientists should be involved in all stages of this process by designing research that provides feedback on the industry's profile and the response of the industry to management.

4.3.3. Fostering incentives for conservation through Phuket's diving industry

The diving industry clearly perceives existing incentives to support efforts to conserve its marine resources. Whether the industry's support for conservation can be maintained over time in the face of constant pressure to focus on short-term profit, and whether the industry will continue to participate and possibly assume a leadership role in conservation, remains to be seen. Critical elements that could turn the tables are whether the industry can make sustainable internal changes and acquire external guidance and support for creating tangible incentives for conservation. Some suggestions to foster incentive-driven conservation include:

- Clarity in park management

  The level of communication between the diving industry and government regarding park policy must be improved. One example of why this is necessary involves park user fees. At this time, both the Koh Similan and Koh Surin collect user fees. However, there is no clear indication for industry and the public as to how this revenue is spent and many companies look for ways to avoid paying. As exemplified by self-financing parks like Bonaire (BMP 1999), dive companies and tourists are much more willing to pay user fees if they can be clearly seen to contribute to park operations and conservation (see also Bennet 2002).

- Educational guidance from parks

  Most diving companies (especially on live-aboard trips) offer pre-dive briefings. These can range in environmental educational value for divers. Since most marine parks in Thailand have certified divers on staff, they should be involved in the development of a standardized briefing protocol which covers park guidelines and site-specific environmental education.

- Direct payment for environmental leadership

  Payment for environmental leadership can be directly applied for the purpose of conservation in the form of government subsidies for companies (although, governments may not be willing to provide these). Direct payment can also come in other forms. With an industry as media-dependent as the diving industry, publicity can be directly translated into financial terms. The development of high profile awards for environmental leadership may be one method for encouraging forward-thinking direct incentives for conservation-focused involvement.

- Regulatory incentives

  If government involvement reaches such a level that government regulation of the industry can influence participation in conservation, this could be one way to discourage unwanted behaviour. However, this requires government resources which are usually scarce.

4.4. Suggestions for future research in Thailand

Regarding tsunami effects on coral reefs at Koh Surin, future research should be designed to account for the high amount of spatial variability on coral reefs by ensuring a large sample size and inquiry at multiple scales. Until the tsunami can be modeled for this area, future research on physical tsunami effects at Koh Surin should focus on the long-term recovery of affected reefs. This will require determining the causes of stress on reefs, defining appropriate diagnostic indicators that respond to these stressors and developing research programs that fit within a framework of adaptive management. It is essential that conservation scientists become involved in the management of Koh Surin's coral reefs.

Future work with Phuket's diving industry should be highly applied and should build upon knowledge of diver perceptions in that area (Bennet 2002, Dearden et al. 2006). It will be important to address the issue of capacity-building for sustainability of the industry. Scientists should be involved in developing a management plan for the industry and for diving activity within the Andaman Sea. An essential component of this will be to address the implementation of principles of incentive-driven conservation through Phuket's diving industry.

4.5. The broader picture

In the short-term, climate change and increasing coastal population pressure on coral reefs, coupled with anthropogenic stresses, will likely cause continued reef degradation; certain ecological regimes will be irreversibly altered, with severe social consequences. Although largely caused by humans, the effects of stressors like climate change that occur at such a large scale cannot be managed by humans. What can be managed by humans, in theory, is *human behaviour*. The hope in coral reef conservation lies in reef scientists and managers realizing this and focusing on problems that occur at manageable scales. As discussed, this will require identification of stresses on coral reefs, linkage of these stresses to causality, and adaptive management of anthropogenic pressures to alleviate stress and encourage social-ecological resilience.

Throughout human history, where widespread changes in resource use behaviour have occurred, they were stimulated by a common perception of environmental crisis (Diamond 2005). The scientific community has reached consensus regarding the coral reef crisis, and communities that depend on coral reefs are also rapidly becoming aware of this. The response of Phuket's diving industry to the tsunami disaster encourages belief in a real potential for this awareness. The industry illustrated not only its awareness of its dependency on the marine environment, but also its capacity to quickly mobilize and work with scientists to facilitate – and even drive – conservation on the ground. If we prove able to manage the anthropogenic stresses on coral reefs, then the total stress that has led to degradation may be reduced enough to be absorbed by the natural resilience of the social and ecological components of coral reef systems. In the long term, human-caused destruction of the world's coral reefs may not be inevitable.

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APPENDIX 1 – Images of tsunami damage at Koh Surin

Fig.A2.1- 9m^2 sampling quadrat

Fig.A2.2- Tsunami-scoured channel between South Surin Island and Koh Torinla

Fig.A2.3- Scoured rocky pinnacle between South Surin Island and Koh Torinla (extensive soft coral coverage prior to tsunami)

Fig.A2.4- Sediment level change after tsunami

Fig.A2.5a- Ripped gorgonian sea-fan colony

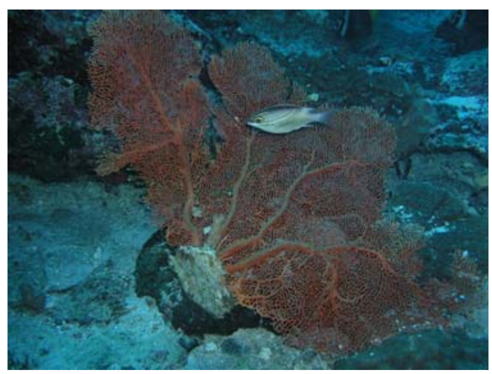


Fig.A2.5b- Basally severed gorgonian sea-fan colony with fish

Fig.A2.5c- Terrestrial woody debris at Ao Tao reef

Fig.A2.6- Crown-of-thorns predation on *Acropora hyacinthus*

Fig.A2.7- Sediment-covered *Acropora* fragments

Fig.A2.8a- Fragmentation of *Acropora nobilis*

Fig.A2.8b- Basally-severed and overturned *A. hyacinthus*

Fig.A2.8c. Fragmented standing *Tubastraea micrantha*

Fig.A2.8d- Down-slope tumbling of massive Faviidae colonies (note tissue abrasion)

Fig.A2.8e- Base of KTNE reef slope after reef framework was removed by the tsunami

Fig.A2.8f- Local dive guide, Johnny, holding *A. nobilis* fragment over piled tsunami rubble at Koh Torinla

Fig.A2.8g- *A. nobilis* colonies tumbled down-slope and overturned at reef base

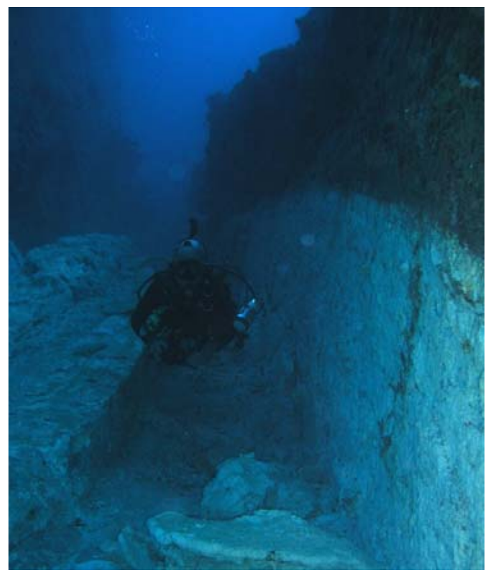


Fig.A2.9- Sediment level drop after tsunami at 30+m at Elephant Head Rock, the Similans

APPENDIX 2 – Interview template and questionnaires
A3.1. Post-tsunami Phuket dive company interview template for interviewer

Phuket dive operators post-tsunami interview questions
To be administered by interviewer

Tsunami effects

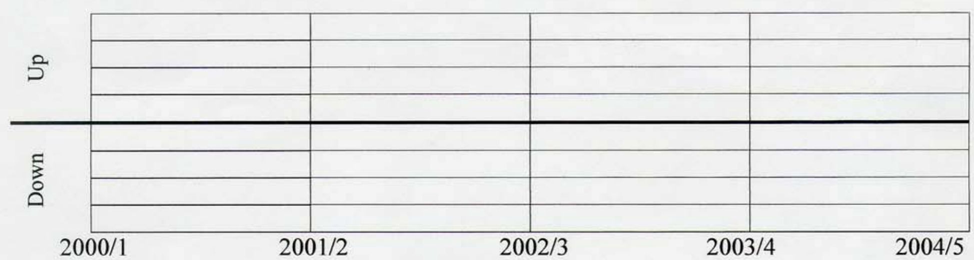
1. Did your company experience any damage or loss of property as a result of the tsunami? **Yes** **No**
If yes, please estimate the cost of this damage or loss to your company: _________ThB
What proportion of this cost has been covered by insurance? ________%

2. Were any of your staff injured or lost in the tsunami? **Yes** **No**
Please describe ____
____.

3. **Until** Dec. 26, 2004, how did revenue for this high season compare with the average of your previous 4 high seasons in the same time period?
Trend = same/increase/decrease *Amount* = slight/moderate/large/dramatic (___%)
Comments? ____
____.

4. To date, how has this high season compared to the average of your previous 4 high seasons regarding
a) inquiries: *Trend* = same/increase/decrease *Amount* = slight/moderate/large/dramatic (___%)
b) bookings: *Trend* = same/increase/decrease *Amount* = slight/moderate/large/dramatic (___%)

5. Please map changes in your company's high season revenue levels since your 2000/1 high season



6. How many diver days have you lost as a result of the tsunami? ___________.

7. How many trips have you cancelled as a result of the tsunami?
Day trips: _______% ; Multi-day trips: ________% ; Total diving days cancelled: _________.

8. Has your business changed as a result of the tsunami in terms of
a) services offered ____
____.
b) number of staff employed ____
____.
c) other ____
____.

9. Has your company offered any special promotions/discounts to generate business? **Yes** **No**
Please describe: ____.

10. Have you changed your dive trip itinerary as a result of the tsunami? **Yes** **No**
If yes, how? ____.

11. Do you think effects from the tsunami have influenced your clients' dive trip satisfaction? **Yes** **No**
If so, how? ______________________________.

Recovery

1. Did your company receive any assistance/aid in response to tsunami impacts? **Yes** **No**
If yes, what and from whom (government/private sector/NGOs)? ______________________________
______________________________.

2. Did your company participate in any relief/rescue/restoration efforts after the tsunami? **Yes** **No**
If yes, what and where? ______________________________
____
______________________________.

3. How long do you expect it will take for recovery of
a) your business (revenue)? ______________________________
______________________________.
b) Phuket's dive industry (revenue)? ______________________________
______________________________.

4. Is there anything that should be done to facilitate dive industry recovery in Phuket?
____
____
______________________________.

5. What, if any, long-term effects do you think the tsunami will have on the structure and/or management of Phuket's dive industry? ______________________________
____
______________________________.

6. Have there been any positive outcomes of the tsunami for
a) Phuket's dive industry? ______________________________
____
______________________________.
b) for Thailand? ______________________________
______________________________.

7. As Phuket recovers from the tsunami, is there anything that should be done to improve the dive industry's management or marine conservation? ______________________________
____
____
______________________________.

8. Does your company have any past/present/future involvement in any marine conservation activities in Thailand? **Yes** **No**
If yes, what? ______________________________
____
____

Further comments? ______________________________
______________________________.

A3.2. Post-tsunami recreational diver questionnaire

SCUBA DIVING THE ANDAMAN SEA:
POST-DIVE SURVEY FOR DIVER PERCEPTION OF TSUNAMI DAMAGE

MSc project for the University of Victoria, Canada,
in cooperation with Thailand National Parks and Kasetsart University, Bangkok.

Your answers will be used to examine effects of the Dec. 26, 2004 tsunami on recreational SCUBA diving and to voice concerns and needs of the recreational SCUBA diving industry in decisions pertaining to dive site management.

Today's date: __________, 2005
Boat and/or company name: ____________________
Dive guide:____________________________
Length of trip: _____ day(s)

1) Your diving trip is:
a) the main reason for your trip to Thailand
b) a planned activity as part of a longer trip
c) an unplanned activity, booked after your arrival in Thailand

2) Is this your first diving trip in Thailand? **Yes No**

3) Please rate your overall satisfaction with your diving experience in the Andaman Sea on a scale from **1 (low) to 10 (high)**: _____.
Comments? ____.

4) Has the tsunami of Dec. 26, 2004 affected your travel plans and/or itinerary? **Yes No**
If yes, how? ____
____.

5) What features of a dive are most important for you? How satisfied are you with your diving experience in the Andaman Sea? **Please rate on a scale from 1 (low) to 5 (high).**

	LEVEL OF **IMPORTANCE**					LEVEL OF **SATISFACTION**				
☐ Variety/abundance of marine species	1	2	3	4	5	1	2	3	4	5
☐ Presence of large, exciting species	1	2	3	4	5	1	2	3	4	5
☐ Presence of small, rare species	1	2	3	4	5	1	2	3	4	5
☐ Pristine and undamaged dive sites	1	2	3	4	5	1	2	3	4	5
☐ Good photo opportunities	1	2	3	4	5	1	2	3	4	5
☐ Expanding marine knowledge	1	2	3	4	5	1	2	3	4	5
☐ Sites uncrowded by other divers	1	2	3	4	5	1	2	3	4	5
☐ Remote, exotic location	1	2	3	4	5	1	2	3	4	5

6) Which of the features above do you feel have been affected by the tsunami on this dive trip. **Please check (√) box above**

7) Would you be specifically interested in seeing dive sites that have experienced high levels of tsunami damage? **Yes No**

8) Please compare your expectations of **tsunami effects** before diving with your actual experience diving the Andaman Sea? **Please check (√) the appropriate level:**

	Much less than expected	Less than expected	As expected	More than expected	Much more than expected	No expectation
Damage to corals						
Presence of fish						
Garbage/waste						
Sedimentation						
Damage to land						

Comments? ____.

9) Please list all sites dived on this trip where you noticed tsunami damage. **Circle** the estimated amount of damage you noticed (your personal opinion):
slight (1-35%), **medium** (36-75%), **heavy** (75-100%)

Site name: ☐ ____ - slight medium heavy
☐ ____ - slight medium heavy
☐ ____ - slight medium heavy
☐ ____ - slight medium heavy
☐ ____ - slight medium heavy
☐ ____ - slight medium heavy
☐ ____ - slight medium heavy
☐ ____ - slight medium heavy
☐ ____ - slight medium heavy
☐ ____ - slight medium heavy

10) Did you notice rebuilding or restoration work at any of the above sites? **Yes No**
If yes, which sites? **Please check (√) box above**
Comments? ____.

Any additional comments? ____
____
____

DIVER INFORMATION
Sex: Male Female
Age: Under 20 20-30 30-40 40-50 50-65 65+
Place of residence: city ________________, country ________________.
Diving certification level: ______________. **Year of open water certification:** ____.
 # Logged dives: __________. **# Dives in last 12 months:** __________.
Countries dived in last 5 years: ____________________________________.

Thank you for your time. If you would like to be informed of the results of this survey, please write your email address here: ________________________. **Enjoy your trip!**

A3.3. 2005/6 Follow-up dive operator questionnaire (hand delivered in Phuket by Kirsten Vandermeer for mail-in response)

Date: ___________

Company name: ________________ (for comparison, answers are anonymous)

Follow-up questions for Phuket dive operators

1. Please estimate your overall dive trip occupancy (% occupancy/total capacity) for the following Oct-Apr high season(s):

a) 2000/1-2003/4 *average* — day trips - _____%
liveaboard trips - _____%

b) 2004/5 season — day trips - _____%
liveaboard trips - _____%

c) 2005/6 season *until now* — day trips - _____%
liveaboard trips - _____%

2a) Has your company changed its dive trip itinerary following the 2004 tsunami to avoid damaged areas? **Yes** **No**
If so, which ones?

b) Dive sites? **Yes** **No**
If so, which ones?

3. Have there been any changes in the structure of your company and/or business approach as a result of your experience during and after the tsunami? **Yes** **No**
If so, what changes?

4a) Are you aware of any marine research/conservation projects that members of Phuket's diving industry have been involved in following the 2004/5 high season? **Yes** **No**
If so, what?

b) Has your company participated in any of these projects? **Yes** **No**
If so, which ones?

5. Do you think that there have been any changes since December 26, 2004 that you could attribute to the tsunami in:

a) the number of SCUBA diving companies currently operating in Phuket?

b) the management of Phuket's diving industry?

c) the amount of collaboration/communication between members of the diving industry?

d) the amount of collaboration/communication between university/government researchers and the diving industry?

5. How do you envision the future for Phuket's diving industry?

For the Andaman Sea?

Appendix 3 – Post-tsunami dive site report by DOCT members

Summary of Koh Similan /Koh Surin dive site conditions, following the tsunami of 26/12/2004, as reported by the dive crew of June Hong Chian Lee. (Combined experience of 10.000+ dives, during 7 seasons, at these locations).

During these dives the 3 dive teams and videographer endeavoured to assess different areas of individual sites, in order to collate the most comprehensive picture possible, whilst still ensuring safe and enjoyable diving for our guests. The reports we have received, for the dive sites surveyed so far, have been given a dive quality rating between 1 and 10 .

We have asked the customers on the current trip to rate the dive sites also, some of these are first timers and some are repeat customers, we feel this may help provide a more objective viewpoint. This information should be available to us upon their return.

Name divesite	Day And Time Of dive	Instructor	% of coral intact	% 0f Fish life Intact	Instr. Rating	Customer R
NE # 6, Hok Hok Nuea	31/12/2004 08:00	Mick	90	100	6	
The Channel, south # 6	31/12/2004 08:00	Jay/Kay	80	100	7	
The Channel south, # 6, Wrec	31/12/2004 08:00	Martin	90	100	7	
Fanfare Point, North # 7	31/12/2004 11:00	Mick	60	90	4	
East of Eden, east # 7	31/12/2004 11:00	Kay	80	100	8	
East of Eden, south end # 7	31/12/2004 11:00	Jay	60	85	5	
Hideaway, SE # 9	31/12/2004 14:00	Mick	5	75	2	
The Hideaway North, East # 9	02/01/2005 00:00	All	85	100	7	
Snapper Alley, South # 9	31/12/2004 14:00	Jay/Chin	5	60	2	
Christmas Point, NE # 9	03/01/2005 00:00	Kay	50	80	4	
The Pinnacles, North # 9	03/01/2005 00:00	Mick/Martin	75	90	7	
Fantasea Reef, West # 8	31/12/2004 00:00	All	100	100	10	
Donald Duck Bay	31/12/2005	Jay	90	100	6	
Ko Tachai, North Peak	28/12/2004 and 02/01/20(	Kay	40	100	4	
Ko Tachai, South Peak	28/12/2004 and 02/01/20(	All	70	90	8	
Nicobar X-Press, Ko Torinla, r	27/12/2004	All	5	60	2	
Surin Tai/Ko Torinla, Hin Doc l	28/12/2004	All	5	75	2	
Koh Torinla, East Reef	27/12/2004	All	70	100	6	
Richelieu Rock	27/12/2004	All	100	100	10	
Elephant Head, # 7/# 8	29/12/2004	All	70	100	8	
Morning Glory East # 5	29/12/2004	All	90	100	7	
Beacon Beach, East # 8	03/01/2005	All	85	100	5	
Beacon Beach South, East # 8	03/01/2005	Jay	60	100	5	
Beacon Point, SE # 8	03/01/2005	Jay	40	70	3	
Sharkfin Reef North, # 3	03/12/2005	All	95	100	7	
Coral Gardens North, # 1	03/01/2005	Mick	80	100	6	
Coral gardens South, # 1	03/01/2005	Jay/Kay	95	100	7	
Rocky Point, # 1	04/01/2005	All	75	90	7	
Rocky Point Bay, # 1	04/01/2005	All	95	100	7	
Boulder City, # 3	04/01/2005	All	95	100	7	
Ko Bon, Pinnacle	01/01/2005	All	100	100	6	
Ko Bon, West Ridge	01/01/2005	All	90	100	7	
Ko Bon, North	01/01/2005	Martin	95	100	5	

Remarks: In general, the deeper areas were affected more than the shallower areas. A lot of Divesites look worse than they are, because a thick layer of fine sand has been washed away, exposing a lot of snow white rubble from the past. With all that missing sand, of course a lot of the bottom dwelling species of marine life, like Gobies, Lizardfishes, Jawfishes, Sea Cucumbers, Starfishes, Crinoids and Nudibranchs have gone missing or simply washed/blown away. Generally the more fragile corals, specially of the species Acropora, Tubastraea, Firecorals and Gorgonian Seafans have had more or less damage, depending on the location of the Divesites.

Note to Diveguides: Try to free any corals from layers of sand by brushing or waving, in order for them to breathe and get sunlight. Try to fix any broken Seafans in an upright position so they can feed and turn over any coral that you find lying upside down, without damaging the surrounding healthy coral.

Dive Sites Report from DOCT members

Location	Dive site	Report					Report By	Remark
		Not mension	None	Slight (1-35%)	Medium(36-75%)	Heavy(76-100%)		
Island No.	Coral Garden North			20%			The Junk, dived on3/1/05	100% of fish life intact,Instr rating is 6
	Coral Garden South			5%			The Junk, dived on3/1/05	100% of fish life intact,Instr rating is 7
	Rocky Point			25%			The Junk, dived on 4/1/05	90% of fish life intact,Instr rating is 7
	Rocky Point Bay			5%			The Junk, dived on 4/1/05	100% of fish life intact,Instr rating is 7
Island No.	Shark Fin Reef		None				Colona Diving, dived on 30/12/04	
				Slight			See Beas Diving, reported on 4/1/05	
	Shark Fin Reef North			5%			The Junk,dived on3/1/05	100% of fish life intact,Instr rating is 7
	Boulder City			5%			The Junk, dived on4/1/05	100% of fish life intact,Instr rating is 7
				Slight			See Beas Diving, reported on 4/1/05	
Island No.	Honeymoon Bay(eastcoast of Isl 4)			Slight			See Beas Diving, reported on 4/1/05	
Island No5	Hideaway		None				Colona Diving, dived on 29/12/04	
	Barracuda Point		None				Colona Diving, dived on 29/12/04	
	Barracuda Point(E-coast of Isl. 5&6)			Slight			See Beas Diving, reported on 4/1/05	
	Anita's reef (morning glory) (East #5)			10%			The Junk, dived on29/12/04	100% of fish life intact,Instr rating is 7 There are some sea fans damaged. apart from that the site appears to be ok.
Island No	Koh Hok Nuea (North-East of #6)			10%			The Junk, dived on 31/12/04	100% of fish life intact, Instr. Rating is 6
	The Channel (South #6)			20%			The Junk, dived on 31/12/04	100% of fish life intact,Instr rating is 7
	The Channel (South Isl.6) wreck			10%			The Junk, dived on 31/12/04	100% of fish life intact,Instr rating is 7
Island No	Fanfare Point				40%		The Junk, dived on 31/12/04	90% of fish life intact,Instr. Rating is 4
	East of Eden			5-10% demange at the boomie to the north		(to the south is heavy damage to all of the hard coral	Colona Diving, dived on 27,28,29/12/04	Table corals can be found strewn across the sand. Towards the shallows, the soft coral garden is ok. The marine life looks to be unscathed.
	East of Eden (E-coast of Isl. 7)			Slight		South -west coast is heavy damage	Sea Bee Diving, reported on 4/4/05	
	East of Eden (East of #7)			20%			The Junk, dived on 31/12/04	100 % of fish life intact, Instr rating is 8
	East of Eden(South end# 7)				40%		The Junk, dived on 31/12/04	85% of fish life intact, Instr rating is 5
	Deep Six (N-coast of Isl. 7)					Heavy	Sea Bee Diving, reported on 4/4/05	
	Elephant Head Rock			15% demage, mainly with the swim throughs and table corals			Colona Diving, dived on 29/12/04	
					Mediun		See Beas Diving, reported on 4/1/05	
				30%			The Junk, dived on 29/12/04	100% of fish life intact; Instr rating is 8 Some larger coral heads are broken. There is a considerable amount of white rubble between boulders and some damage to sponges and soft corals, but OK
Island No.	Atlantis Wreck		None				Colona Diving, dived on 27/12/04	
	Beacon Reef		None				Colona Diving, dived on 27/12/04	
	Beacon Beach (East#8)			15%			The Junk, dived on3/1/05	100% of fish life intact,Instr rating is 5
	Beacon Beach South(East#8)				40%		The Junk, dived on3/1/05	100% of fish life intact,Instr rating is 5
	Beacon Point (SE#8)				60%		The Junk, dived on 3/1/05	70% of fish life intact,Instr rating is 3
	Eastcoast	Not mension					Sea Bee Diving, reported on 4/4/05	O.K.
	Fantasea Reef(west#8)		None				The Junk, dived on 31/12/04	100 % of fish life intact , Instr. rating now 10
	Donald Duck Bay(night dive)			10%			The Junk, dived on 31/12/04	Night dive, 100% of fish intact, Rating 6
Island No. 9	Breakfast Bend					100 % damage to all hard corals	Colona Diving, dived on 27/12/04	Probably the worst site of all dived
	Breakfast Bend					100% damage	Sea Bee Diving, reported on 4/4/05	Not O.K.
	Hideaway (S-E#9)					98% damage	The Junk, dived on 31/12/04	75% of fish life intact, Instr rating is 2
	The Hideaway North (East of Isl.9)			15%			The Junk, dived on 2/1/05	100% of fish life intact,Instr rating is 7
	Snapper Alley S.E.					100 % damage to all hard corals	Colona Diving, dived on 27/12/04	Probably the worst site of all dived
	Snapper Alley (E-coast)	Not mension					Sea Bee Diving, reported on 4/4/05	O.K.
	Snapper Alley (south of Isl.9)					95 % damage	The Junk, dived on 31/12/04	60 % of fish life intact, instructor rating 2
	Christmas Point					60% damage to the hard-soft coral and sea fans at the North-west corner	Colona Diving, dived on 27/12/04	
	Christmas Point(NE#9)				50%		The Junk, dived on 3/1/05	80% of fish life intact, Instr rating is 4
	North Point			20 % demage to hard corals			Colona Diving, dived on 29/12/04	
	North Point					Heavy but still diveable	Sea Bee Diving, reported on 4/4/05	Still O.K.
	The Pinnacles (North#9)			25%			The Junk, dived on 3/1/05	90% of fish life intact, Instr rating is 7
	North			20 % damage			The Junk, dived on 31/12/04	100% of fish life intact

Location	Dive site	Not mension	None	Slight (1-35%)	Medium(36-75%)	Heavy(76-100%)	Report By	Remark
Koh Bon	Koh Bon-Westridge			the south bay rubble can be seen			Colona Diving, dive on 28/12/04	
				10%			The Junk, dived on1/1/05	100% of fish life intact,Instr rating is 7
	North			5%			The Junk , dived on1/1/05	100% of fish life intact,Instr rating is 5
	Koh Bon						See Beas Diving, reported on 4/1/05	O.K.
	Koh Bon Pinnacle		None				The Junk, dived on 1/1/05	100% of fish intact, Instr Rating 6
							See Beas Diving, reported on 4/1/05	O.K.
Tachai	North Reef					Heavy but still diveable	See Beas Diving, reported on 4/1/05	Still O.K.
	South Reef					100% damage	See Beas Diving, reported on 4/1/05	Not O.K.
	Edge reef south-coast					100% damage	See Beas Diving, reported on 4/1/05	Not O.K.
	North Peak					60 % damage	The Junk, dived on 28/12/04 and 2/1/05	100 % of fish life intact , rating now 4 The shallow areas appear fine, but the deeper areas are showing extensive damage generally.
	South Peak			30%			The Junk, dived on 28/12/04 and 2/1/05	90 % of fish life intact , rating now 8 There is extensive damage to corals in the shallow areas. Some boulders have collapsed and deep rubble trenches are apparent. On the northern slope there is damage to hard and soft corals. Fish life is reported to be still good.
Richelieu	Richelieu	Not mension					See Beas Diving, reported on 4/1/05	O.K.
	Richelieu		None				The Junk	100 % of fish life intact , Instr rating 10 There is almost no apperent damage.
Surin	Nicobar X-Press Koh Torinla -N					95 % damage	The Junk, dived on 27/12/04	60 % of fish life intact, rating now 2 Nicobar express (North). Almost completely destroyed and considered to be no longer worth diving. Koh Torinla slope. A strech of 300 metres is ok, but still quite some demage
	Hin Dog Mai(Pinnacle between Koh Torinla and Surin Tai)					95 % damage	The Junk, dived on 27/12/04	75 % of fish life intact, rating now 2 Almost completely destroyed and considered to be no longer worth diving.
	Koh Torinla (east reef)			30%				100 % of fish life intact , Instr rating 6
Krabi	Bida Nok (West side to south)			5%			Sea King Divers, report on 10/1/05	100 % of fish life intact, Instr rating is 5
	Hin Bida		None				Sea King Divers, report on 10/1/05	Instr. Rating is 6
	Bida Nai (Souh/west to East)		None				Sea King Divers, report on 10/1/05	70 % of fish life intact, Instr rating is 5
	Koh Ha Yai (west side)		None				Sea King Divers, report on 10/1/05	
	Koh Ha North		None				Sea King Divers, report on 10/1/05	Instr. Rating is 7 , 80 % of fish life intact
	Koh Ha Klang (night dive)		None				Sea King Divers, report on 10/1/05	Instr. Rating is 7
	Hin Muang			5%			Sea King Divers, report on 10/1/05	Instr. Rating is 9
	Hin Deang			5%			Sea King Divers, report on 10/1/05	Instr. Rating is 8
Phuket	Shark Point (1-3)			5%			Sea King Divers, report on 10/1/05	Instr. Rating is 7

Remarks: In general, the deeper areas were affected more than the shallower areas. A lot of Divesites look worse than they are, because a thick layer of fine sand has been washed away, exposing a lot of snow white rubble from the past. With all that missing sand, of course a lot of the bottom dwelling species of marine life, like Gobies, Lizardfishes, Jawfishes, Sea Cucumbers, Starfishes, Crinoids and Nudibranchs have gone missing or simply washed/blown away. Generally the more fragile corals, specially of the species Acropora, Tubastraea, Firecorals and Gorgonian Seafans have had more or less damage, depending on the location of the Divesites.

APPENDIX 4 – Importance of dive site attributes for recreational divers

Table A4.1. Recreational divers ranking high variety and abundance of marine species 4-5 on a 5-point scale of importance for dive trip satisfaction (1=lowest importance, 5=highest)

Characteristic	Group	N	% divers who place high importance on attribute	Chi-square p-value (df=1)
Sex	Male Female	76 40	95% 100%	0.14
Country of origin	Thailand Other	14 105	100% 95%	0.40
Certification level	Open water Specialized	68 34	96% 97%	0.72
Logged dives	<100 100+	53 56	96% 96%	0.96
Dives in past year	<25 25+	49 60	100% 93%	0.07
Thailand diving experience	None 1+ prior trips	67 56	97% 95%	0.51
Number of countries dived	1 2+	16 94	100% 96%	0.40
Nature of trip	Planned diving Unplanned diving	101 19	95% 100%	0.32
Month of response	Feb/March April	74 49	95% 98%	0.36
Tsunami effect on trip plans	Unaffected Affected	24 97	96% 96%	0.99

TableA4.2. Recreational divers ranking the presence of large and exciting species as 4-5 on a 5-point scale of importance for dive trip satisfaction (1 = lowest importance, 5= highest)

Characteristic	Group	N	% divers who place high importance on attribute	Chi-square p-value (df=1)
Sex	Male Female	75 40	76% 75%	0.91
Country of origin	Thailand Other	14 104	79% 77%	0.89
Certification level	Open water Specialized	67 34	75% 74%	0.91
Logged dives	<100 100+	52 56	81% 70%	0.18
Dives in past year	<25 25+	48 60	83% 72%	0.15
Thailand diving experience	None 1+ prior trips	67 55	81% 71%	0.21
Number of countries dived	1 2+	15 94	93% 73%	0.09
Nature of trip	Planned diving Unplanned diving	101 18	73% 94%	0.05
Month of response	Feb/March April	74 48	73% 81%	0.29
Tsunami effect on trip plans	Unaffected Affected	96 24	77% 71%	0.52

Table A4.3. Recreational divers ranking the presence of small and rare species on dive sites 4-5 on a 5-point scale of importance for dive trip satisfaction (1=lowest importance, 5=highest)

Characteristic	Group	N	% divers who place high importance on attribute	Chi-square p-value (df=1)
Sex	Male Female	73 40	62% 65%	0.72
Country of origin	Thailand Other	13 102	85% 60%	0.08
Certification level	Open water Specialized	66 33	59% 64%	0.66
Logged dives	<100 100+	50 55	58% 71%	0.17
Dives in past year	<25 25+	45 60	67% 58%	0.38
Thailand diving experience	None 1+ prior trips	66 53	61% 64%	0.69
Number of countries dived	1 2+	15 92	67% 61%	0.67
Nature of trip	Planned diving Unplanned diving	99 17	62% 71%	0.48
Month of response	Feb/March April	72 47	61% 64%	0.77
Tsunami effect on trip plans	Unaffected Affected	94 24	67% 42%	**0.02**

Table A4.4. Recreational divers ranking the importance of the pristine condition of dive sites 4-5 on a 5-point scale of importance for dive trip satisfaction (1=lowest importance, 5=highest)

Characteristic	Group	N	% divers who place high importance on attribute	Chi-square p-value (df=1)
Sex	Male Female	74 40	81% 85%	0.60
Country of origin	Thailand Other	14 103	79% 84%	0.58
Certification level	Open water Specialized	67 34	82% 88%	0.42
Logged dives	<100 100+	51 56	76% 89%	0.08
Dives in past year	<25 25+	47 60	81% 87%	0.41
Thailand diving experience	None 1+ prior trips	67 54	82% 81%	0.91
Number of countries dived	1 2+	15 93	80% 85%	0.63
Nature of trip	Planned diving Unplanned diving	101 17	81% 94%	0.19
Month of response	Feb/March April	74 47	80% 85%	0.46
Tsunami effect on trip plans	Unaffected Affected	95 24	81% 83%	0.80

Table A4.5. Recreational divers ranking the opportunity to take underwater photos 4-5 on a 5-point scale of importance for dive trip satisfaction (1=lowest importance, 5=highest)

Characteristic	**Group**	**N**	**% divers who place high importance on attribute**	**Chi-square p-value (df=1)**
Sex	Male Female	72 35	46% 31%	0.16
Country of origin	Thailand Other	14 103	57% 39%	0.19
Certification level	Open water Specialized	67 34	34% 45%	0.31
Logged dives	<100 100+	51 56	23% 53%	**0.00**
Dives in past year	<25 25+	47 60	33% 44%	0.25
Thailand diving experience	None 1+ prior trips	67 54	39% 42%	0.81
Number of countries dived	1 2+	15 93	33% 38%	0.71
Nature of trip	Planned diving Unplanned diving	101 17	43% 33%	0.45
Month of response	Feb/March April	74 47	38% 44%	0.47
Tsunami effect on trip plans	Unaffected Affected	95 24	44% 30%	0.25

TableA4.6.Recreational divers ranking the opportunity to learn about the marine environment 4-5 on a 5-point scale of importance for trip satisfaction (1=lowest importance, 5=highest)

Characteristic	**Group**	**N**	**% divers who place high importance on attribute**	**Chi-square p-value (df=1)**
Sex	Male Female	73 36	62% 81%	**0.05**
Country of origin	Thailand Other	14 98	79% 66%	0.36
Certification level	Open water Specialized	64 32	67% 72%	0.64
Logged dives	<100 100+	49 53	82% 70%	0.63
Dives in past year	<25 25+	43 59	65% 66%	0.92
Thailand diving experience	None 1+ prior trips	63 53	67% 64%	0.78
Number of countries dived	1 2+	14 89	57% 67%	0.45
Nature of trip	Planned diving Unplanned diving	97 16	65% 75%	0.43
Month of response	Feb/March April	71 45	63% 69%	0.54
Tsunami effect on trip plans	Unaffected Affected	91 23	64% 70%	0.60

Table A4.7. Recreational divers ranking low levels of dive site crowding 4-5 on a 5-point scale of importance for dive trip satisfaction (1=lowest importance, 5=highest)

Characteristic	**Group**	**N**	**% divers who place high importance on attribute**	**Chi-square p-value (df=1)**
Sex	Male Female	73 40	77% 95%	**0.01**
Country of origin	Thailand Other	14 102	71% 84%	0.23
Certification level	Open water Specialized	67 34	82% 82%	0.97
Logged dives	<100 100+	51 55	75% 93%	**0.01**
Dives in past year	<25 25+	46 60	74% 95%	**0.00**
Thailand diving experience	None 1+ prior trips	66 54	82% 83%	0.83
Number of countries dived	1 2+	15 93	67% 86%	0.06
Nature of trip	Planned diving Unplanned diving	100 17	82% 88%	0.53
Month of response	Feb/March April	73 47	82% 83%	0.91
Tsunami effect on trip plans	Unaffected Affected	94 24	82% 83%	0.87

TableA4.8. Recreational divers ranking remote and exotic location as 4-5 on a 5-point scale of importance for dive trip satisfaction (1=lowest importance, 5=highest)

Characteristic	**Group**	**N**	**% divers who place high importance on attribute**	**Chi-square p-value (df=1)**
Sex	Male Female	72 38	61% 55%	0.55
Country of origin	Thailand Other	12 101	75% 59%	0.30
Certification level	Open water Specialized	65 33	60% 67%	0.53
Logged dives	<100 100+	50 53	53% 72%	**0.04**
Dives in past year	<25 25+	46 58	57% 64%	0.45
Thailand diving experience	None 1+ prior trips	64 53	58% 60%	0.78
Number of countries dived	1 2+	15 91	60% 60%	0.97
Nature of trip	Planned diving Unplanned diving	96 18	63% 50%	0.32
Month of response	Feb/March April	69 48	68% 46%	**0.02**
Tsunami effect on trip plans	Unaffected Affected	92 23	59% 57%	0.85