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Dissertação de Mestrado

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Orientadores:

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Prof. James True – Prince of Songkhla University

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"The bridging of science to policy development, management and conservation is critical if there is to be a legacy of vital reefs left for future generations to enjoy" (Richmond and Wolanski, 2011).

"Strengthening climate resilience is a smart investment in a safer, more prosperous future."

(UN Secretary-General Ban Ki-moon at Climate Summit, 2014)

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Resumo

Este trabalho surge no âmbito do Mestrado em Ecologia e Gestão do Ambiente para o qual foi realizado um estágio de cinco meses na ilha de Koh Tao, Tailândia, visando o estudo da resiliência, sua avaliação e aplicação nas estratégias de gestão dos recifes de coral de Koh Tao.

Os recifes de coral são dos ecossistemas mais ricos e produtivos da Terra. Providenciam benefícios de ecossistema a 500 milhões de pessoas que deles dependem para alimentação, protecção costeira e rendimentos do turismo e das quais 30 milhões são completamente dependentes dos recifes para a sua subsistência.

Os impactos humanos sobre os recifes de coral estão a aumentar, na medida em que estes estão ameaçados globalmente, sendo um terço das espécies de coral classificado de "imediatamente ameaçado de extinção". Aliado aos impactos humanos de desenvolvimento costeiro insustentável, à sobrepesca e à pesca destrutiva, as alterações climáticas à escala global contribuem para o agravamento destas pressões locais, levando a cada vez mais eventos de branqueamento de corais. Este fenómeno tem vindo a ser cada vez mais preocupante, com maior frequência e intensidade, prevendo-se um agravamento do mesmo nas próximas décadas, acompanhado por um aumento da população que vive nas zonas costeiras. Para garantir o nosso bem-estar futuro é necessária uma gestão sustentável dos recursos marinhos tendo em consideração a complexidade dos ecossistemas, tal como as relações destes com as populações humanas. Devido à importância da capacidade dos recifes em resistir aos impactos ambientais e recuperar destas perturbações, a resiliência tem sido um princípio fundamental na conservação e gestão dos mesmos. Através de ferramentas de gestão é possível identificar áreas de maior resiliência que devem ser incluídas em redes de áreas marinhas protegidas, que beneficiam outras áreas mais vulneráveis, identificando também quais as ameaças ecológicas mais proeminentes localmente, de modo a poderem fazer-se planos estratégicos de gestão do território.

No sudoeste asiático, por volta de 95% dos recifes estão sob ameaça, sendo esta uma das áreas mais expostas às alterações climáticas. Particularmente no golfo da Tailândia, dois episódios distintos de branqueamento de coral foram observados em 1998 e 2010, com efeitos bastante acentuados nalgumas áreas sujeitas a sedimentação, eutrofização da água e stress térmico.

Na Tailândia, a gestão dos recifes assenta em leis e regulamentações que se aplicam a todas as áreas de recife e medidas adicionais aplicáveis apenas a áreas protegidas. A ilha de Koh Tao é conhecida pelo seu intenso desenvolvimento turístico, especialmente relacionado com a actividade de mergulho recreativo. Ainda que Koh Tao seja uma pequena ilha com 21 km^2, existem cerca de 50 escolas de mergulho que são responsáveis por um terço das certificações anuais mundiais da PADI (Associação Profissional de Instrutores de Mergulho). De acordo com as classificações da UNEP (Programa do Ambiente das Nações

Unidas), os recifes de coral de Koh Tao enfrentam níveis altos de ameaça provenientes de actividades recreativas, bem como níveis médios de ameaça provenientes da pesca e de outras actividades ligadas ao desenvolvimento local. Em Koh Tao, o Plano de Desenvolvimento Turístico de 1995 não foi implementado com sucesso, tendo sido classificado o desenvolvimento turístico como não tendo regulamentação efectiva e carecendo a ilha de uma gestão ambiental efectiva.

Apesar desta ilha não se encontrar incluída num parque nacional marinho, grupos comunitários locais, promovidos por operadores de mergulho locais em conjunto com a Marinha Tailandesa, o Departamento de Recursos Marinhos e Costeiros e a Universidade do Prince de Songkla, têm vindo a desenvolver projectos que visam a conservação dos recifes de coral pela implementação de zonamento e regulamentação marítima.

Com este trabalho pretende-se adaptar o protocolo da IUCN (União Internacional pela Conservação da Natureza) para uma avaliação do grau de resiliência dos recifes à volta da ilha de Koh Tao e para uma identificação dos factores ambientais, ecológicos e humanos associados.

Foram assim recolhidos dados quantitativos e semi-quantitativos em catorze locais de mergulho, denominados “sites”, sobre várias componentes ecológicas dos recifes de coral. Os dados quantitativos dizem respeito à população de corais e à distribuição das classes de tamanho de famílias/géneros mais e menos resistentes ao stress térmico. Para a obtenção dos dados semi-quantitativos utiliza-se uma tabela de referência que qualifica o índice de resiliência dos diferentes indicadores numa escala de 1 a 5, onde 1 descreve condições prejudiciais e 5 descreve condições benéficas para os corais.

O cálculo da resiliência foi feito utilizando dois métodos: o método IUCN e aquele a que se chamou o método R^2M (“resistance”, “recovery” e “management”). Ambos são calculados a partir da média dos grupos, que por sua vez é calculada pela média dos factores de cada grupo. Ao método IUCN foram excluídos um total de 17 factores. Os “sites” são depois classificados de alta, média ou baixa resiliência e através da análise das tabelas provenientes desta classificação é possível identificar os factores que mais influenciam estes resultados.

O método IUCN apresenta mais “sites” na classificação de resiliência média que o método R^2M, o que indica que um maior número de factores avaliados faz com que as pontuações tendam para a média dos grupos. No entanto, no que diz respeito à ordem de classificação, ambos os métodos tiveram classificações de resiliência semelhantes e mostraram que os “sites” menos resilientes pertencem a zonas de maior desenvolvimento turístico.

Dos dois métodos, o R^2M é o que parece ser de mais fácil utilização e interpretação dos resultados, ficando o gestor a saber directamente através da tabela quais os “sites” em que se devem focar os esforços de gestão.

Como era de esperar, os “sites” mais resilientes (White Rock, Hin Ngam, Shark Island, Tanote e Ao Leuk) apresentaram maior número de colónias e maior proporção de famílias resistentes. A dominância de corais de géneros mais resistentes indica que os géneros mais susceptíveis (ex. *Acropora*) terão diminuído em número significativo devido a eventos prévios de branqueamento de corais e/ou por acção de impactos humanos. As colónias de maiores dimensões são pertencentes a géneros mais resistentes que apresentam crescimento lento e massivo (*Porites* e *Diploastrea*). Os géneros mais abundantes (*Porites, Pocillopora*, *Goniastrea* e *Montipora)* apresentam maiores níveis de recrutamento indicando que neste momento, serão os mais adaptados ao ambiente de Koh Tao.

Pode-se assim dizer que de uma forma geral, a resiliência dos recifes de coral em Koh Tao é média/alta. Contudo, existem medidas que podem ser tomadas com o objectivo de melhorar a capacidade de lidar com futuros eventos de branqueamento de corais, manter a biodiversidade e aumentar a resiliência destes ecossistemas.

Neste sentido, são propostas algumas recomendações que visam maximizar a conservação dos recifes de coral de Koh Tao. A primeira dessas recomendações é a de integrar na zona No-Take, “sites” com alta resiliência, que apresentam sinais de conectividade populacional (Hin Ngam, Ao Leuk e Tanote) de modo a servirem de santuário a um ecossistema saudável. Hin Wong também deverá ser considerado para inclusão em zona protegida devido à sua abundância em colónias da família Acroporidae e por apresentar resiliência média/alta. Dado o caso do aumento da área de protecção não ser possível, sugere-se delimitar uma zona No-Take com os “sites” mais resilientes (Hing Wong, Tanote, Ao Leuk, Hin Ngam, Shark Island and White Rock) e criar uma zona de segurança em torno de White Rock, incluindo Japanese Gardens, Twins e Sairee. Recomenda-se também, e especificamente para Japanese Gardens e Sairee, medidas de mitigação dos efeitos de eutrofização da água, poluição, sedimentação e danos físicos por parte de mergulhadores, de modo a aumentar a resiliência destes locais. Em toda a ilha, devem ser tomadas medidas de gestão mais efectivas ao nível de implementação, fiscalização e consciencialização das comunidades locais e dos visitantes nos âmbitos marítimo e terrestre.

Palavras-chave: resiliência, gestão, branqueamento de corais, alterações climáticas, recifes de coral, Koh Tao, Tailândia

Abstract

Human impacts on coral reefs together with global climate change are leading to an increase in frequency and magnitude of coral bleaching events, threatening these ecosystems globally. As reefs depend heavily on their capacity to resist impacts and recover from disturbances, resilience has become a fundamental principle of reef management and conservation, making the identification and incorporation of resilient coral reef areas in MPAs (Marine Protected Areas) a priority. This study provides information on the resilience level of fourteen reef sites of Koh Tao, Thailand, a developing island known for it´s intense dive tourism. Two methods were used for calculating resilience by adapting an IUCN (International Union for the Conservation of Nature) resilience assessment protocol. Data collection on general coral community and the assessment of selected resilience factors facilitated information for management decisions on zoning and help target management strategies on specific sites. Most coral reefs on the island have medium or high resilience level but measures can be taken to improve conservation strategies such as reducing nutrient input level, pollution and sedimentation, by regulating and controlling land-based development and protecting fish population dynamics. Enlarging MPA No-Take zone to include high resilience sites with probable connectivity is also suggested in order to create a refuge area and enhance overall resilience.

Key Words: resilience, management, bleaching, climate change, coral reefs, Koh Tao, Thailand

I. Introduction

I. Introduction

1.1. Coral Reefs at risk

Coral reefs are among the most biologically rich and productive ecosystems on earth (UNEP, 2006). They provide valuable ecosystem benefits to 500 million people who depend on them for food, coastal protection and income from tourism, of which 30 million are totally dependent on coral reefs for their livelihoods (Burke *et al.,* 2011; Wilkinson, 2008) Human impacts on coral reefs are increasing to the extent that reefs are threatened globally (Hughes *et al.,* 2003) and one third of all tropical corals are considered as immediately threatened with extinction using IUCN Red List criteria (Wilkinson, 2008). Sedimentation, agricultural runoff of nutrients and chemicals, poor land management, agriculture and industry, over-fishing, destructive fishing and unsustainable and destructive development of coastal areas are direct human pressures affecting coral reefs worldwide. These impacts which can often be managed at a local scale are compounded by the more recent impacts of global climate change (Hughes *et al.,* 2003). By 2030, 50% of global coral reefs are expected to experience thermal stress and coral bleaching (Burke *et al.*., 2011). This is considered the most pressing impact derived from climate change. Episodes of coral bleaching and disease have already increased greatly in frequency and magnitude over the past 30 years and disturbingly this phenomenon is foreseen to intensify in coming decades (Hughes *et al.*, 2003). Moreover, increasing carbon dioxide emissions are slowly causing the world´s oceans to become more acidic. Ocean acidification reduces coral growth rates and could reduce their ability to maintain their physical structure, through increased dissolution of aragonite exoskeleton (Burke *et al.* 2011). Other global change threats are diseases, plagues and invasive species that are increasing the vulnerability of these ecosystems. Our incapacity to deal with the problem is reflected by ineffective oceans´ governance, weak political action, increasing human poverty and poor capacity for management and lack of resources, especially in small island countries (Wilkinson, 2008).

The latest GCRMN (Global Coral Reef Monitoring Network) report from 2008 estimates that 19% of the world's reefs are effectively lost, another 15% are at a critical stage and likely to be lost within 10–20 years, and a further 20% are threatened, already experiencing 20–50% loss of corals. The remaining 46% of reefs are considered at low risk level, but nonetheless, are threatened by global climate change and ocean acidification. (Wilkinson, 2008)

The outcome statement of the 2012 United Nations Conference on Sustainable Development (Rio+20) – "The Future We Want", recognized the significant economic, social and environmental contributions of coral reefs, in particular to islands and other coastal States, as well as their significant vulnerability to impacts including climate change, ocean acidification, overfishing, destructive fishing practices and pollution.

1.2. **Management of Coral Reefs and Resilience**

By 2015, 50% of the world population will live in coastal areas (Wilkinson, 2008) and across the tropics, coastal population is expected to grow up to 1.95 billion people by 2050 (Sale *et al*., 2014), putting enormous stress on natural resources and leaving managers with an array of problems to face. To ensure our future wellbeing, marine and coastal ecosystem functions and productivity must be managed sustainably; that is, taking into account the complexity of these ecosystems, the connections among them and how people interact with them (Agardy *et al.,* 2011).

The main coral reef management instrument practiced so far, has been the creation of MPAs (Sale, 2008), a potentially great idea but with limited success (Rinkevich, 2008), since only 6% of coral reefs around the world are located in effectively managed MPAs and 73% are located outside MPAs (Burke *et al.,* 2011).

In the past few years, the focus of research has changed from basic to applied and management-directed studies (Richmond and Wolanski, 2011) and increasingly policy-makers, conservationists, scientists and the broader community are calling for management actions to restore and maintain the resilience of coral reefs to climate change (Obura and Grimsdith, 2009).

Resilience of a reef community is the ability to maintain or restore structure and function following mortality of corals (Obura and Grimsdith, 2009). Two key components of resilience are resistance, the ability of an ecological community to resist or survive a disturbance, and recovery, the rate a community takes to return to its original condition (West and Salm, 2003). As reefs depend heavily on their capacity to resist impacts and recover from disturbances (Hughes *et al.*, 2003), resilience has become a fundamental principle of reef conservation and management (Marshall and Schuttenberg, 2006). Resilient coral reef areas are in high priority for increased management attention and should be incorporated in MPAs (West and Salm, 2003; Baskett *et al*., 2010; Maynard *et al*., 2012; Keller *et al*., 2008) as to be protected from local stressors and build networks that maximize benefits in other areas that are more vulnerable to bleaching (Marshall and Schuttenberg, 2006; Sail *et al*., 2014).

1.3. **Resilience Assessment Tools**

Long-term monitoring of changes on reefs subjected to different environmental factors and human pressures is vital for understanding and prediction of reef recovery in the face of climate change (Phongsuwan *et al.,* 2013).

Assessment tools are protocols that help managers identify the most prominent threats and the drivers behind them, and what ecological changes can be expected over time. Large-scale assessments are usually carried out by national and multinational institutions whereas small-scale assessments can be community-based, but both have the same goal: to identify information needs and priorities for management in an objective and defensible way (Agardy *et al.,* 2011).

There is a need to include resilience-related criteria in MPA site selection to cope with more frequent and severe coral bleaching events (Marshall and Schuttenberg, 2006) and develop a tool that could be applicable even in low-resource countries, effectively improving coral reef management in the face of climate change (Obura and Grimsdith, 2009).

In 2009, the IUCN (International Union for Conservation of Nature) created a rapid assessment protocol including the measurement or estimation of 61 “resilience factors” that produced a ranking of the relative resilience of different sites evaluated. Studying the perceived importance, empirical evidence, and feasibility of measurement of factors promoting coral reef resilience, McClanahan *et al.* (2012) concluded that there are relatively few factors for which there is evidence of strong effects on ecosystem dynamics. This suggests that decreasing the number of factors may produce more robust and defensible results (McClanahan *et al.*, 2012). Moreover, having fewer factors to estimate or measure also increases capability to use the protocol and may increase the use of these protocols (Mayard *et al.*, 2012). In this view, a different approach is suggested by Maynard *et al.*, (2012) in which resilience factors are classified in different categories to better inform management decisions on the factors they can influence, and facilitate interpretation of results. In this process 17 resilience factors are excluded on the remark that they have limited relevance to the components of resilience. Coral reef resilience assessments have great potential as tools that can help design and implement more resilient MPA networks. However, these protocols need revision in order to create more focused and practical methodologies as well as to improve the communication and presentation of results to managers (Maynard *et al.*, 2012).

1.4. **Resilience Indicators**

In Table 1 are listed resilience factors suggested by IUCN protocol (Obura and Grimsdith, 2009) in 11 groups and their importance as drivers of resilience. Also shown in Table 1 are other references that support the relevance of each factor in measuring resilience as part of a resilience assessment tool.

Table1. Importance of resilience factors and supporting authors of factor relevance for resilience assessment.

Factor Group IUCN	Resilience Factors	Importance Obura and Grimsditch (2008), (2009)	Supporting authors of factor relevance for Resilience Assessment
Benthic	Hard Coral	A primary indicator of reef health, hard corals are the main reef-building taxonomic group on coral reefs	West and Salm, (2003)
	NIA	A primary competitor and inhibitor of corals, and indicator of nutrient/bottom-up and herbivory/top-down controls	Smith *et al.,* (2006)
	Rubble	An indicator of substratum integrity and suitability for coral recruitment and growth.	Maynard *et al.,* (2012)
Substrate and Morphology	Topographic complexity -macro	The large scale structure of a reef, provids habitats for large and higher-trophic level mobile organisms (e.g. fish)	
	Topographic complexity -micro	The surface roughness and small-crevice space on reefs affectsrecruitment of corals.	Maynard *et al.,* (2012); McClanahan *et al.,* (2012)
	Sediment texture	Sediment grain size and sorting affects benthic organisms.	
	Sediment layer	Entrapment of sediment in algal filaments/turf inhibit settlement.	
Cooling and Flushing	Wave energy/exposure	Wave energy causes vertical mixing, can reduce boundary layer effects on coral metabolism and increases oxygenation of water, enhancing coral metabolism. Exposure to weather events is expressed as wave energy to corals	
	Deep Water	Proximity to deep water enables mixing with cold water by upwelling and waves,currents and exposure.	West and Salm(2003); Maynard *et al.,* (2012); Marshall and Schuttenberg, (2006)
Shade and Screen	Physical shading	Shading of corals by reef slopes, pillars orabove-water features (hills/cliffs/ rocks) canprotect corals from stress	Maynard *et al.,* (2012); West and Salm(2003); Marshall and Schuttenberg, (2006)
	Canopy corals	Shading of understory corals by canopy corals (tables, staghorn, plates, etc) can protect corals from stress	
Extremes	Exposed low tide	Shallow corals exposed to the air at low tideexperience frequent stress, and may be moreresistant to thermal stress.	Maynard *et al.,* (2012); West and Salm(2003)
	Ponding/pooling	Restricted bodies of water heat up more due to less mixing and greater residence times, and alsoenhance metabolic stress	Maynard *et al.,* (2012)
	Survival of past bleaching	Corals that have bleached in the past but not died may be acclimatized to bleaching conditions, and have higher tolerance for repeated bleaching events	West and Salm(2003); Marshall and Schuttenberg, (2006)
Anthropogic	Nutrient Input	Nutrient enhancement or eutrophication alters many reef processes, enhancing algal and microbial growth,and metabolically stressing corals.	Smith *et al*., 2006; Maynard *et al.,* (2012); McClanahan *et al.,* (2012)
	Pollution (chemical)	Chemical pollution causes metabolic stress to reef or-ganisms, either causing mortality, or reducing their ability to withstand other stresses	Maynard *et al.,* (2012)
	Pollution(solid)	Solid wastes foul the substrate and may make it unsuit-able for coral recruitment and growth.	
	Turbidity/Sedimentation	Anthropogenically enhanced turbidity and sedimentation in general negatively affects corals, see shading/screening factor	
	Physical damage	Physical damage to the site or to corals results in mortality and/or inhibits recovery.	McClanahan *et al.,* (2012)
	Fishing pressure	Overfishing causes reef degradation by changing trophic web structures, altering top-down ecological controls and leading to phase shifts.	Hughes *et al*., (2003); ; Maynard *et al.,* (2012); McClanahan *et al.,* (2012)
	Destructive fishing	Destructive fishing causes physical damage to the site, and/or alters fish population dynamics	
	Dispersial barrier	Anthropogenic factors that enhance natural barriers or create new barriers to external seeding of larvae	West and Salm, (2003)
Management	Management Biodiversity	Management that reduces any of the above anthropogenic stressors enhances the natural ability of corals and reefs to resist bleaching and to recover.	West and Salm, (2003)
	Management Resources		
	Management Environmental Quality		
Coral Condition	Mortality recent	Coral condition tells us about the current and historic condition of coral community (past impacts and recovery to date)	x
	Coral disease		McClanahan *et al*., (2012); West and Salm, (2003)
	Mortality-old		Marshall and Schuttenberg, (2006)
	Recovery-old		
Coral Population	Recruitment	Recruitment of new corals is necessary for population recovery and injection of genetic variability	West and Salm, (2003); McClanahan *et al.,* (2012)
	Fragmentation	Asexual reproduction by fragmentation is an important strategy of propagation for many corals.	Maynard *et al.,* (2012)
	Dominant size class	The dominant size classes, by area, indicate the maturity and ecological stage of a community	West and Salm, (2003); Maynard *et al.,* (2012); McClanahan *et al.,* (2012)
	Largest corals(3)	The largest corals at a site indicate how long conditions have been suitable at the site, and the degree of environmental stability/community persistence	

Table1 (continued)

Fish Groups	Abundance and diversity of herbivores	Herbivores – exert the primary control on coral-algal dynamics and are implicated in determining phase shifts from coral to algal dominance especially in response to other pressures such as eutrophication and mass coral mortality	Hughes *et al.,* (2003); West and Salm, (2003); McClanahan *et al*., (2012)
	Scrapers	Scraping herbivores exert control on algal growth (E.g. smaller parrotfish)	
	Grazers/Browzers	Grazing herbivores exert control on epilithic turf algae (E.g. large rabbitfish, batfish, parrotfish) and browsing herbivores exert control on macroalgal (E.g. surgeonfish)	
	Piscivores	Top level predators exert top-down control on lower trophic levels of fish. They are very vulnerable to overfishing, and good indicators of the level of anthropogenic disturbance (fishing) on a reef. E.g. sharks and groupers)	x
Connectivity	Self-seeding	Recruitment of new corals appears to be more strongly driven by self-seeding	West and Salm, (2003)
	Local seeding(10km)	Larval density decreases with distance from healthy source reefs, thus inter-reef distances are important for allochthonous larval seeding	
	Distant seeding (100km)	Larval density decreases with distance from the source, thus distances between major reefs are important for allochthonous larval seeding	
	Currents	Locations within direct current flows will have enhanced capacity for external seeding of larvae, maximizing connectivity among reefs	
	Dispersial barrier	Natural dispersal barriers reduce the degree of external seeding of larvae	

1.5. **Coral Reef Management in Thailand**

In Southeast Asia, nearly 95% of reefs are threatened, and about 50% are in the high or very high threat category (Burke *et al.*, 2011). The region is classified as one of the most exposed areas to climate change presenting severe to high stress due to compound variables such as sedimentation, eutrophication and radiation stress (Maina, 2011). Particularly in the Gulf of Thailand, two distinct episodes of severe coral bleaching were observed in 1998 and 2010 (Phongsuwan *et al.*, 2013; Sutthacheep *et al.*, 2013). These bleaching events have severely affected coral reefs that in some areas have not recovered.

Coral reef management in Thailand rests on laws and regulations that apply to all coral reefs and additional measures applicable only to MPA´s. In recent years, central agencies, provincial governments and the private sectors have undertaken non-regulatory actions aimed at improving coral reef conditions through restoration, preventive measures and education (UNEP, 2007). These actions depend largely on individuals, businesses and government agencies working together to solve problems. Such voluntary efforts are called “non-regulatory measures”.

Non-regulatory measures can include education and scientific activities as well as direct management actions such as mooring buoy installation. The Department of Fisheries in Thailand has offered conservation education to reef fishermen, and cooperation among coral reef scientists in the country has been extensive. In addition, researchers have worked together to document reef conditions in Thailand through the ASEAN-Australian baseline study and the coral reefs project of the Department of Fisheries (UNEP, 2007).

1.6. **Case Study – Koh Tao**

Located in the gulf of Thailand, Koh Tao (Fig.1) is an island well-known for scuba-diving. With only 21 km^2, it has a 1.9 km^2 coral reef cover. There are more than 50 diving schools on the island and many other businesses that rely on marine tourism. Koh Tao accounts for the second highest number of annual dive certifications worldwide and is responsible for one-third of the annual registrations of PADI (Professional Association of Diving Instructors) globally (Wongthong and Harvey, 2014) making it a good case study of coral reefs subjected to intense tourism. According to UNEP - United Nations Environment Program, (2007) Koh Tao´s reefs are facing high levels of threat from recreation activities as well as natural impacts; medium level threats from fishing and development impacts; and low level threat from land-based pollution. Uncontrolled infrastructure development, rubbish overload, pressure on sewage system, coastal and soil erosion, forest clearance, marine pollution and loss of biodiversity are among the perceived negative impacts associated with dive tourism (Wongthong and Harvey, 2014). The tourism development plan of 1995 was not successfully implemented (Szuster and Dietrich, 2014), development of dive tourism on the island has been classified as unregulated and it´s environmental sustainability is yet to be managed (Wongthong and Harvey, 2014). However, although Koh Tao is not part of a marine national park, the community with the stewardship of dive operators, namely the Save Koh Tao Community Group, initiated local conservation programs. These have worked along with the Royal Thai Navy, the Department of Marine and Coastal Resources and the Prince of Songkla University to accomplish some important conservation projects and implement zoning and marine regulations. Some funding has also been received from a few energy enterprises but still little has been accomplished in addressing land based threats to reef health. If such a small island is to sustain such development pressures in the face of climate change, cooperative and effective management of ecosystems and natural resources are urgently required.

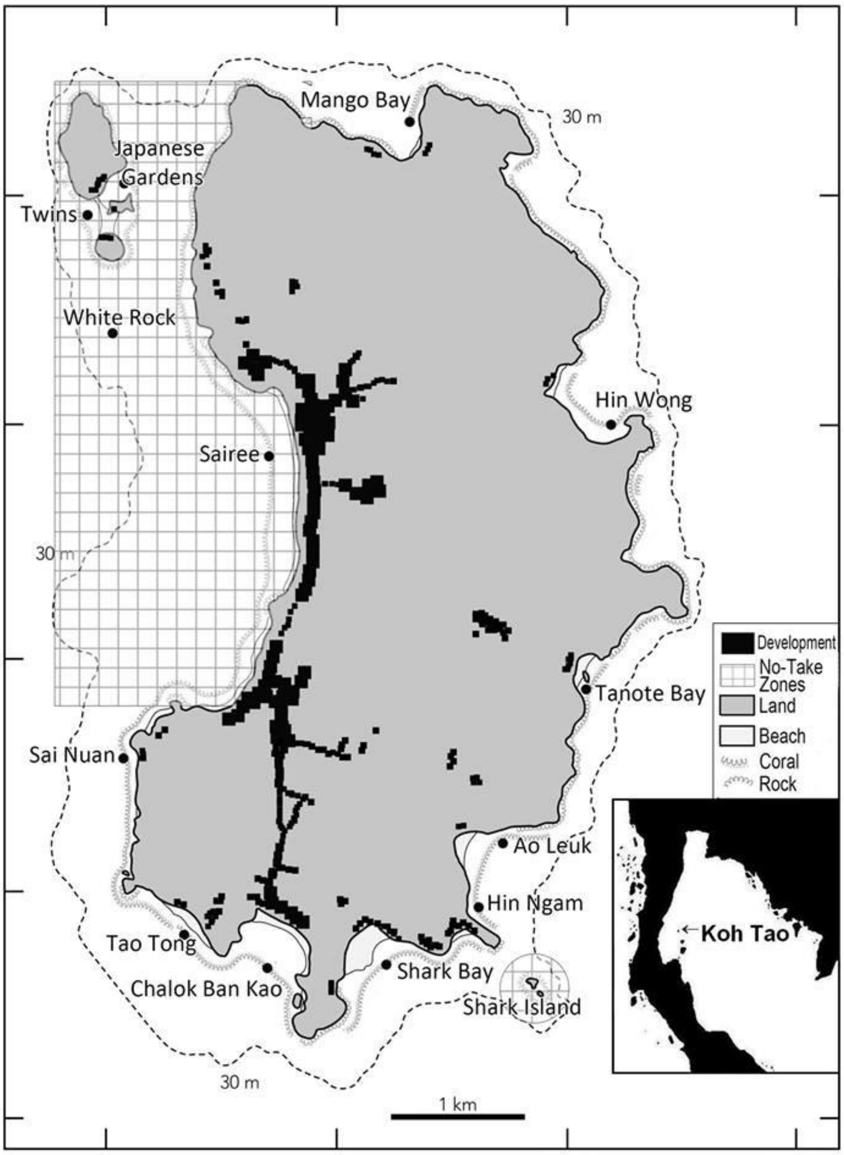

Fig.1. Koh Tao map with 14 dive sites surveyed, development areas and zoning based on Platong *et al.* 2012

1.7. **Objectives**

The following study aims to adapt the IUCN, (2009) protocol according to the specificity of the locale and resources available and to optimize the presentation of resilience assessment results, taking in consideration the latest outcomes on key resilience indicators to support coral reef management.

The main objective is to target and prioritize management and conservation efforts by:

1. Assessing the resilience of coral reefs on Koh Tao by identifying areas of high, medium and low resilience;

2. Identifying sites that have high resilience and are currently not included in (MPA) marine protected area and informing management decisions on potential re-zoning;

3. Identifying which factor groups are responsible for reducing resilience at individual sites;

4. Targeting sites of low or medium scores for management, where anthropogenic stress can be reduced in order to improve resilience;

5. Recommending site-specific and overall actions that can be taken to mitigate specific human stressors and increase resilience on Koh Tao´s reefs.

II. Material and Methods

II. Material and Methods

Data collection was performed during the time period of February to June, 2014

2.1. **Material**

In addition to standard SCUBA diving equipment, for each survey the material used is described below:

Benthic cover: 2x 50 m Transect lines, underwater slate and pencil, datasheet

Coral Population and Size Class Distribution: 2x 50 m Transect lines, underwater slate marked along its top with 5, 10 and 20 cm to help guide size estimates for small corals and fragments, pencil, datasheet, Genus guide for corals, 1m ruler/stick (3/4" PVC tube) marked at 10, 20, 40 and 80 cm to help guide size estimates for larger corals

Fish herbivore populations: Underwater slate, pencil and datasheet

Resilience indicators: Datasheet Indicator/criterion table for constant updates.

2.2. **Methods**

This assessment followed mainly the methodology recommended by the IUCN Resilience Assessment of Coral Reefs 2009.

Some alterations were made to optimize the feasibility of measurement and to make use of already existing EMP (Ecological Monitoring Program) data provided by the New Heaven Coral Reef Conservation Program (Scott 2012).

Quantitative and semi-quantitative data was collected for 14 individual sites, on several components of the reef ecosystem, to provide an overarching assessment of resilience as described below:

2.2.1. Quantitative data

<u>*Benthic cover*</u> – in situ data collected by Koh Tao Ecological Monitoring Program

For EMP substrate survey, 2x 100m point–intercept transects were used (Deep and Shallow part of reef) for each of 14 sites. For point-intercept transects every 50cm on the line is sampled.

<u>*Coral Population and Size Class Distribution*</u> – Sampling of recruitment, small corals and larger corals for selected genera was done on 4 haphazardly set 25*1 m belt transects,(2 x Deep and 2 x Shallow part of reef) for each of 14 dive sites. Twenty-one coral genera were chosen based on abundance and ecological function: *Porites, Pocillopora, Goniastrea, Montipora, Favites, Platygyra, Leptoria, Goniopora, Diploastrea, Favia, Lobophyllia, Echinopora, Tubastrea, Acropora (non-staghorn), Montastrea, Merulina, Symphylia, Galaxea, Hydnophora, Astreopora* and *Turbinaria*. Size classes are in doubling size classes (0-2.5, 2.6-5, 6-10, 11-20 cm, etc.)

In order to evaluate and compare the local and overall coral community structure of Koh Tao, coral genera were divided in categories of resistance to bleaching according to McClanahan and Muthiga (2014), Marshall and Schuttenberg (2006), Guest *et al.* (2012) and Marshall and Baird (2000) as follows: most resistant (*Porites, Goniastrea, Diploastrea, Lobophyllia, Symphyllia*) and Less resistant genera (*Acropora, Pocillopora* and *Montipora*).

2.2.2. Semi-quantitative data

Physical, Anthropogenic, Coral condition, Fish Groups and Connectivity were assessed by estimation of indicators using a reference table (Resilience Indicators Table, IUCN, 2009, in Appendix) that specifies levels for recording each indicator. Information is collected over general site observation, and by consulting with scientists and managers familiar with the local setting.

Based on the information by McClanahan *et al.* (2012) and Mayard *et al.* (2012), certain factors believed to have less significance in calculating resilience (Temperature, Slope, Compass Direction, Visibility, Depth and Depth of Reef base) or insufficient data and low feasibility (Soft Coral, CCA, Currents) were excluded from the final analysis. Fleshy Algae and Turf Algae were replaced by NIA (Nutrient Indicator Algae). Temperature variability was excluded due to the fact that on such a small island variability is not significant. Bleaching was excluded because surveys were not undertaken during thermal anomalies so the presence or absence of bleaching would not indicate resistance to thermal stress. This information is included in survival of past bleaching events. For the same reason Corallivores was left out because at the time of the survey there were no major outbreaks of Crown-of-Thorns starfish, so this would not be a differentiating factor between sites. Obligate feeders, Branching residents, Competitors and external and internal Bioeroders were excluded due to not being primary indicators of reef resilience, so lower priority than others-coral associates is attributed to them (Obura and Grimsdith, 2009). There is no significant population of Excavators in the study area of Koh Tao so they were also excluded. In the end, a total of 17 factors were excluded.

Resilience scores were calculated using two methods. The IUCN Resilience score for each site was calculated using the methodology described in IUCN (2009), as an overall average of the average scores for each factor group. For further analysis, resilience factors were arranged in 3 categories relating to “Resistance”, “Recovery” and “Management” according to Maynard *et al.*, (2012) methodology (Table 2), referred as R^2M from now on in this paper. Some factors may appear in more than one category. Factors for Management category are chosen as those which managers can influence and affect directly with management actions and regulations. Scores for each category were calculated as an average of individual factors. In this way, alternative resilience scores were calculated as the average of resistance, recovery and management scores for each site. This resilience will be from now on referred to as

Resilience. Higher scores indicate higher resilience and sites are ranked from highest to lowest resilience score for each of the 14 study areas. Scores for all categories (Resilience IUCN, Resilience, Resistance, Recovery and Management) were classified on a relative scale presented in a color coded table: low – dark grey, medium – grey, high – light grey (Table 3). This was done by subtracting the lowest score from the highest score for each category and then dividing the total range by three to identify the ranges for low, medium, and high.

Table 2. Resistance, Recovery and Management factors

Resistance	Recovery	Management
Wave energy / exposure	NIA	Nutrient imput
Deep water (30-50m)	Hard coral	Pollution (chemical)
Physical shading	Rubble	Pollution (solid)
Canopy corals	Topographic complexity - macro	Turbidity/ Sedimentation
Exposed low tide	Topographic complexity - micro	Physical damage
Ponding/ pooling	Sediment Layer	Fishing pressure
Survival of past bleaching	Sediment texture	Destructive fishing
Nutrient input	Recruitment	Dispersial barrier (anthropogic)
Turbidity/ sedimentation	Fragmentation	Management biodiversity
Pollution (chemical)	Dominant size class	Management Resources
Largest corals	Largest corals	Management Environmental Quality
Environmental quality	Self-seeding	Herbivores
	Local seeding (10km)	Scrapers
	Distant seeding (100km)	Grazers/Browzers
	Currents	Piscivores
	Dispersal barrier (connectivity)	

All factors, including those for which more detailed quantitative data was collected, were considered using resilience index scale of 1-5 (Resilience Indicators Table, IUCN, 2009, in Appendix).

2.2.3. Data treatment

To help reveal patterns in the dataset that includes multiple variables a Multi-Dimensional Scaling (MDS) analysis was performed using PRIMER software. Pearson Correlation vectors indicate higher or lower scores according to position and length of vectors. The closer a vector is to a site position, the better score for this variable the site has. Clusters of similarity show resemblance between different sites based on a Bray–Curtis similarity matrix on square root-transformed data.

III. Results

III. Results

The most common families were Faviidae (37%), Poritidae (29%), which include most resistant genera, Pocilloporidae (16%), and Acroporidae (11%). Least observed families were Oculinidae, Merulinidae, Dendrophyliidae and Mussidae with less than 5% each, of total number of colonies (Fig.2).

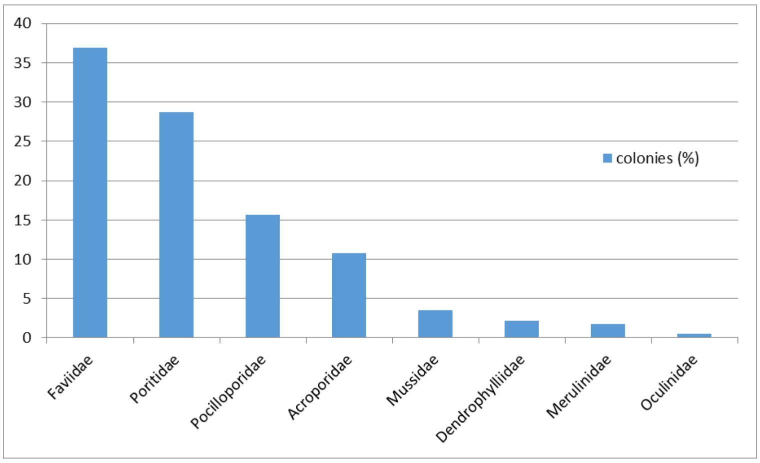

Fig.2. Percentage of each coral family observed on transect lines during the time period of February-Jun 2014, Koh Tao.

As can be seen in Fig.3, most sites had high proportion of families that include most resistant coral genera (Favidae, Poritidae) except for Tao Tong, Shark Bay and Chalok. Only a few sites had higher number of colonies from a susceptible family; Tao Tong, Shark Bay, Chalok presented high number of colonies of Pocilloporidae and HinWong of Acroporidae. Ao Leuk, Tanote and Hin Ngam present the highest numbers of Mussidae colonies which include Lobophylia and Symphylia resilient genera.

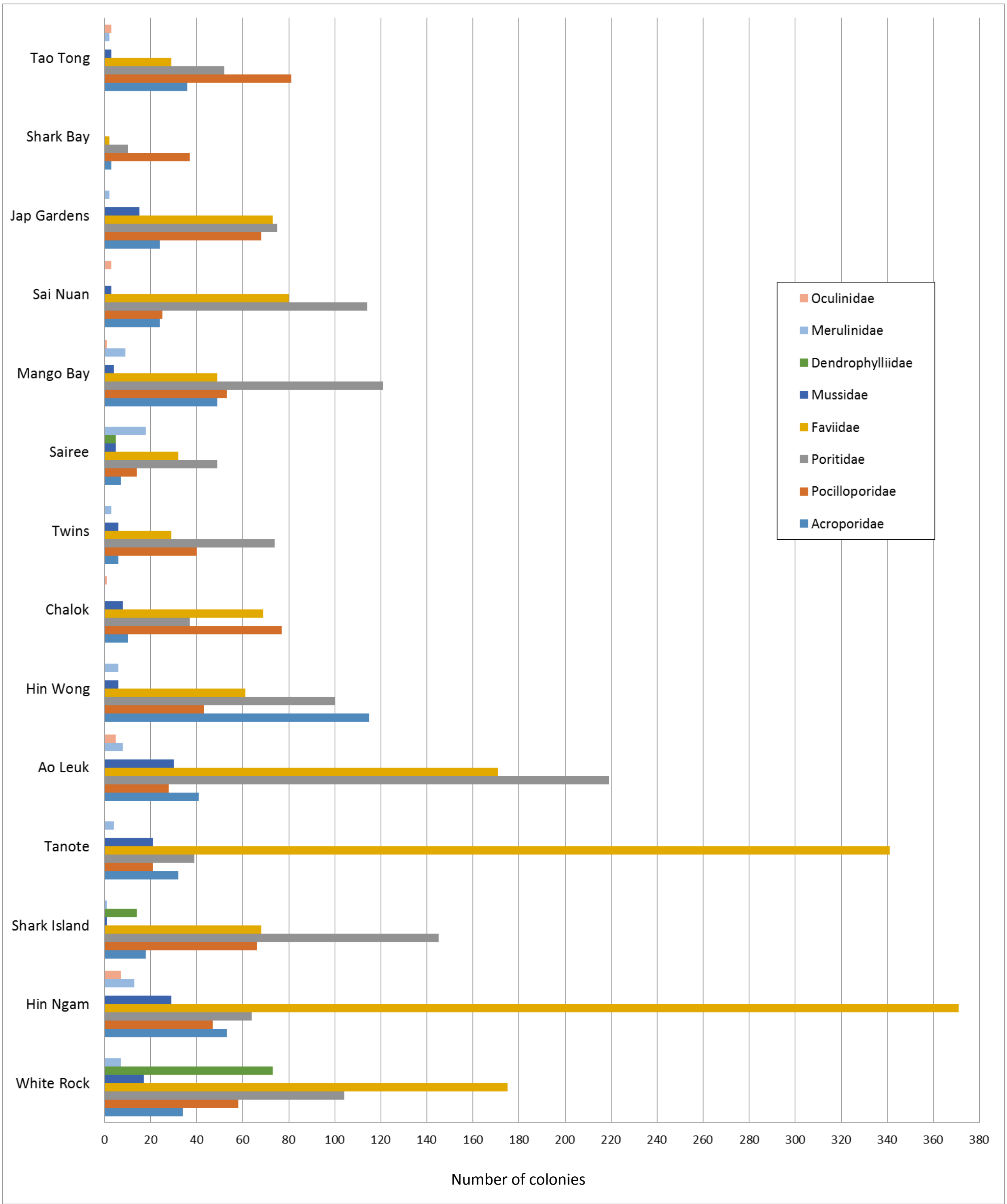

Fig.3. Number of colonies of each coral family per site.

As can be seen in Fig.4, the most abundant genera, from those selected, were *Porites (±25%), Pocillopora (±16%)*, *Goniastrea (±13%)* and *Montipora (±9%)* followed by *Favites (5%) and Platygyra (5%).* The less observed coral genera were *Turbinaria, Astreopora*, *Hydnophora* and *Galaxea* representing less than 1% each.

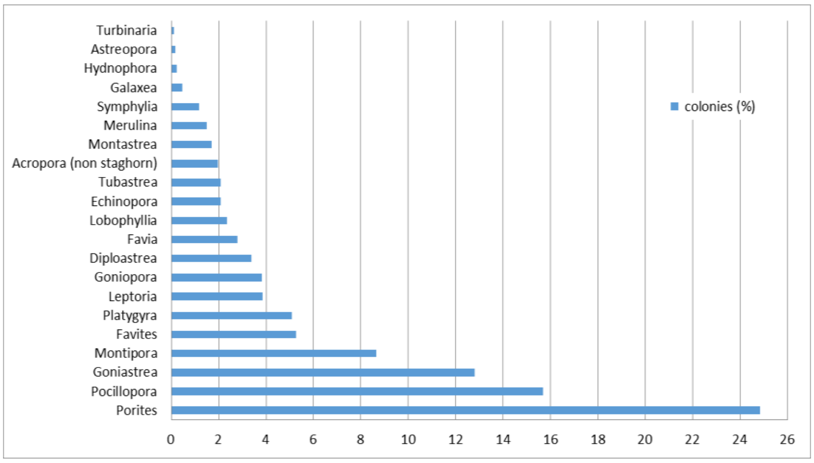

Fig.4. Percentage of colonies of each coral genera (considered in this survey) on transect lines

In Fig.5 Size Class distribution can be seen for resistant and less resistant genera. *Porites, Goniastrea* and *Pocillopora*, presented roughly a normal distribution curve for size classes as well as *Montipora* with most colonies belonging to medium size classes from 11-80 cm. In general small sized corals, which represent recruitment (0-10 cm) were observed less than medium size corals. *Porites, Pocillopora* and *Goniastrea* had the highest recruitment rates followed by *Montipora*. *Diploastrea*, *Lobophylia* and *Symphylia* had a different trend, with more colonies of larger size in the 41-80 cm size class (*Lobophylia* and *Symphylia)* and in the 81-160 cm size class (Diploastrea); all three genera showing low recruitment rates. Non-staghorn *Acropora,* in digitate and tabulate growing form, was found mostly in 11-20 cm size class and in small numbers for large sizes. Large coral colonies (161-320 cm) were found for *Porites, Diploastrea* and *Montipora,* being *Diploastrea* the one with most colonies >320 cm size.

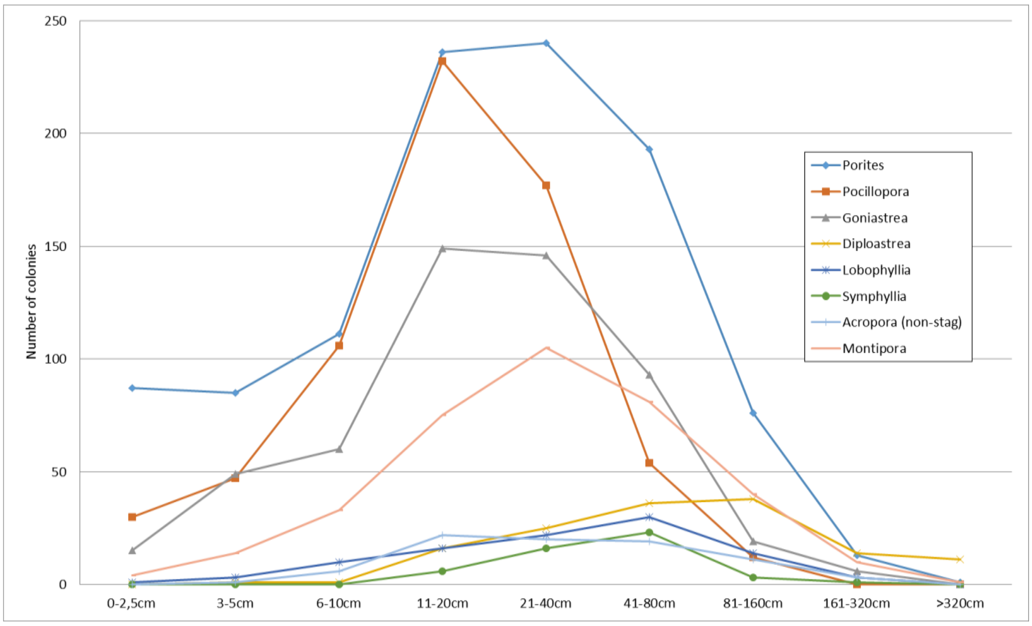

Fig.5. Size Class distribution of colonies of resistant genera (*Porites, Goniastrea, Diploastrea, Lobophyllia* and *Symphyllia*) and less resistant genera (*Acropora, Pocillopora* and *Montipora*)

Scores for each of 11 groups and for each site are given in Table 3, which indicates final Resilience (IUCN) score and ranking. The most Resilient (IUCN) sites are White Rock, Hin Ngam and Shark Island and the least Resilient (IUCN) sites are Sai Nuan, Japanese Gardens, Shark Bay and Tao Tong. The groups that have most influence on reducing resilience potential can be identified by lowest group means. In this measure the groups that act by reducing resilience across sites are Shade and Screen, Extremes, Management and Fish Groups.

Table 3. Resilience ranking (IUCN) of 14 sites of Koh Tao island, with scores for 11 groups and group means

Ranking	Site	Resilience IUCN	Benthic	Subtrate & Morph	Cooling & Flush	Shade and Screen	Extremes	Anthropogic	Management	Coral Cond	Coral Pop	Fish Groups	Connectivity
1	White Rock	3,51	4,30	4,00	4,50	3,50	1,67	4,75	2,00	4,25	3,25	3,00	3,40
2	Hin Ngam	3,35	3,70	3,75	3,50	3,00	2,00	4,62	3,00	4,00	3,25	2,40	3,60
3	Shark Island	3,28	3,00	3,50	5,00	2,00	2,00	4,60	3,33	4,50	3,00	2,00	3,20
4	Tanote	3,20	3,60	3,25	3,50	2,50	1,60	4,50	3,00	3,25	3,25	3,00	3,80
5	Ao Leuk	3,20	3,00	3,75	3,50	2,00	2,00	4,50	3,00	3,75	3,25	2,60	3,80
6	Hin Wong	3,17	3,60	4,50	3,50	3,50	1,67	4,50	2,00	3,00	3,25	2,40	3,00
7	Chalok Bay	3,00	2,70	3,50	3,00	2,00	2,70	3,87	3,00	3,75	3,25	2,20	3,00
8	Twins	3,00	3,30	3,75	3,50	1,50	1,70	4,62	2,60	3,00	3,25	2,80	3,00
9	Sairee	2,98	3,00	3,50	2,00	3,00	3,33	3,50	2,00	3,75	2,75	2,20	3,80
10	Mango Bay	2,95	3,33	3,50	2,50	2,50	2,30	4,12	2,00	2,50	3,50	2,80	3,40
11	Sai Nuan	2,89	2,67	2,50	3,50	1,00	1,30	4,37	4,00	3,25	3,00	2,40	3,80
12	Jap Gardens	2,84	3,30	3,75	2,50	2,00	1,67	3,87	2,00	3,25	3,25	2,40	3,20
13	Shark Bay	2,76	2,00	4,00	3,50	1,00	2,30	4,12	2,00	2,50	2,50	3,00	3,40
14	Tao Tong	2,64	2,33	3,50	2,50	1,50	1,66	4,50	2,00	3,00	2,00	2,20	3,80
Group Mean		3,05	3,13	3,63	3,32	2,21	1,99	4,32	2,57	3,41	3,05	2,53	3,44

MDS (Multi-Dimensional Scaling) analysis in Fig.6 shows similarity between sites according to scores in all 11 groups. The main outliers are Tao Tong, Shark Bay and Sai Nuan, all scoring poorly for all groups standing out for low resilience. Sairee (one of the most developed areas on the island) has higher potential for acclimatization of corals to higher temperatures due to exposed low tide (Extremes) but poor Management, Cooling and Flush (large distance from deep water) and high Anthropogenic impact. At sites such as Shark Island, Hin Ngam, Tanote and Ao Leuk resilience potential is driven by better management and less anthropogenic impact. Shark Island has higher protection by cooling from upwelling (Cooling and Flush) and White Rock has particularly favorable Coral Population combined with good Coral Condition.

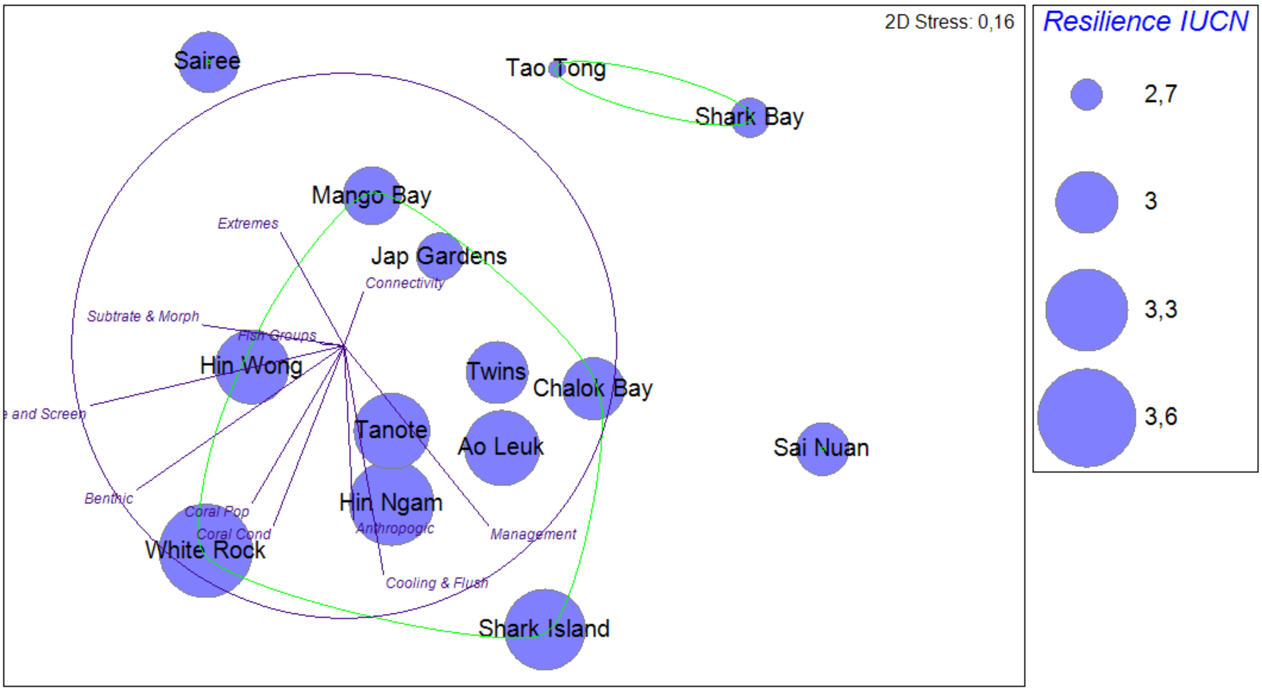

Fig.6. MDS for IUCN 11 group scores with Resilience super-imposed (bigger bubbles represent higher resilience) and Pearson Correlation vectors. Green circles show clusters of similarity (95 Resemblance level) between sites according to scores in all 11 groups based on a Bray–Curtis similarity matrix on square root-transformed data.

At 60% coral community similarity, two clusters are clear. White Rock, Hin Ngam, Tanote and Ao Leuk, which are among the best ranking sites for Resilience (Table 3), and all other sites excluding Shark Bay. Shark Bay is an outlier presenting a less abundant and diverse community.

Tanote and Hin Ngam present a similarity of 80% of coral community (Fig.7).

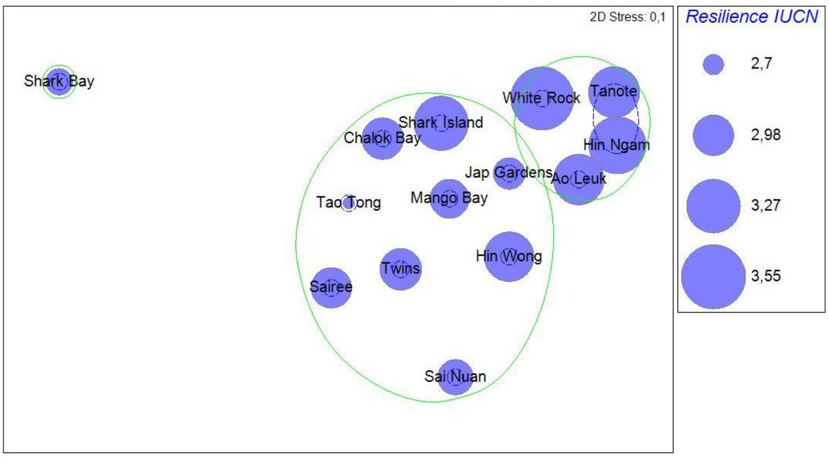

Fig.7. MDS for coral community (adults) with IUCN Resilience super-imposed (bigger bubbles represent higher resilience). Blue and green circles (80 and 60 Resemblance level respectively) show clusters of similarity between sites according to coral community (number of colonies of different genera) based on a Bray–Curtis similarity matrix on square root-transformed data.

In the MDS plot for shallow reef area, at 60% similarity for coral community we can see four clusters; Hin Ngam, Tanote, White Rock, Ao Leuk, and Shark Island are in one group including sites with high resilience. The main outliers are Sai Nuan, Chalok Bay and Shark Bay with different community structure in shallow part of the reef. Hin Ngam and Tanote share 80% similarity of shallow part of reef (Fig.8).

The MDS plot for deep reef area shows two clusters of similarity at 60% resemblance; Twins, Chalok, Sairee and Tao Tong in one cluster that includes sites with higher resilience, and Tanote, Hin Ngam, Ao Leuk, White Rock, Mango Bay and Hing Wong in another. Shark Island stands out with high resilience and main outliers are Shark Bay and Sai Nuan. Hin Ngam and Ao Leuk present 80% similarity in coral community at the deeper part of reef (Fig.9).

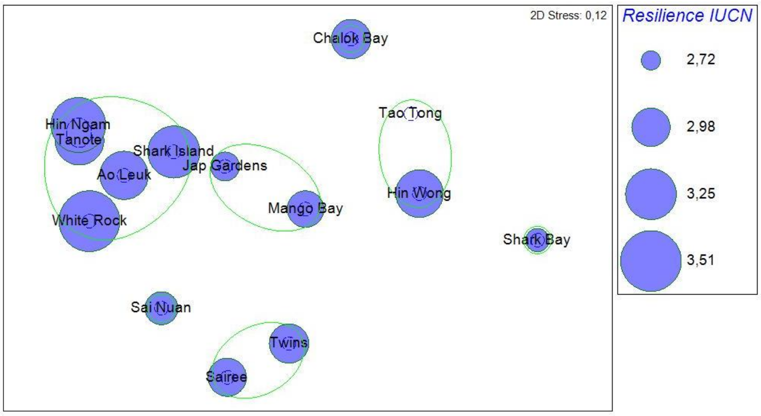

Fig.8. MDS for coral community (adults) on **Shallow** transects with IUCN Resilience super-imposed (bigger bubbles represent higher Resilience). Blue and green circles show clusters of similarity (80 and 60 Resemblance levels respectively) between sites according to coral community (number of colonies of different genera) based on a Bray–Curtis similarity matrix on square root-transformed data.

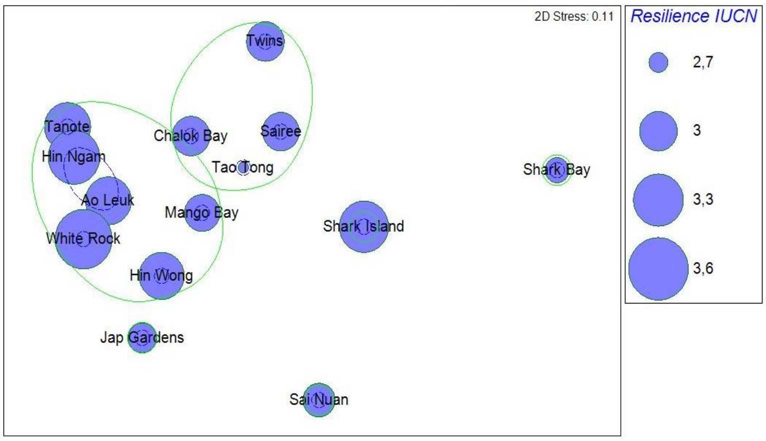

Fig.9. MDS for coral community (adults) on **Deep** transects with IUCN Resilience super-imposed (bigger bubbles represent higher Resilience). Blue and green circles show clusters of similarity (80 and 60 Resemblance levels respectively) between sites according to coral community (number of colonies of different genera) based on a Bray–Curtis similarity matrix on square root-transformed data.

In Table 4 resilience, resistance, recovery and management scores are presented for each site as well as sites included in development areas on Koh Tao, according to R^2M methodology. Six sites are considered to have high resilience, namely White Rock, Hin Ngam, Shark Island, Tanote, Hin Wong and Ao Leuk. Only White Rock and Hin Ngam present high scores for all four categories. All high resilience sites belong to Non-Developed areas except for Tanote. Low resilience sites are Chalok Bay, Shark Bay, Sairee, Japanese Gardens and Tao Tong, all sites from Developed areas. The most resistant sites are White Rock, Hin Ngam, Shark Island and Hin Wong. Most high resilience sites show also high resistance (except for Tanote and Ao Leuk with medium level resistance) and high recovery (except for Shark Island). Sai Nuan, SharkBay, Japanese Gardens and Tao Tong are in low resistance category and as for recovery, Sai Nuan, Chalok Bay, Shark Bay and Tao Tong score poorly. Regarding Management, Sairee and Japanese Gardens have lowest scores.

Table 4. Resilience ranking (R^2M) for 14 sites of Koh Tao island, with scores for 3 groups, zoning and development

Ranking	Site	Resilience	Resistance	Recovery	Management	Zoning	Developed Area
1	White Rock	3,54	3,25	3,69	3,69	No Take	x
2	Hin Ngam	3,53	3,42	3,56	3,62	Use	x
3	Shark Island	3,49	3,42	3,25	3,81	No Take	x
4	Tanote	3,44	3,08	3,50	3,75	Use	√
5	HinWong	3,42	3,33	3,56	3,37	Use	x
6	Ao Leuk	3,40	3,08	3,50	3,62	Use	x
7	Twins	3,31	2,92	3,31	3,69	No Take	x
8	Mango Bay	3,22	2,92	3,44	3,31	Use	√
9	Sai Nuan	3,17	2,75	3,06	3,69	Use	√
10	Chalok Bay	3,10	3,00	3,12	3,19	Use	√
11	Shark Bay	3,09	2,83	3,06	3,37	Use	√
12	Sairee	3,04	3,00	3,31	2,81	No Take	√
13	Japanese Garden	3,03	2,67	3,37	3,06	No Take	√
14	Tao Tong	2,96	2,58	3,00	3,31	Use	√

IV. Discussion

IV. **Discussion**

The results of this work support the previous notion that there is a variability of resilience among sites on Koh Tao and that the factors taken in account in this study have substantial influence on this variability.

Families that include most resistant genera are in higher percentage overall (see Fig.2) as well as the proportion of these families across sites. The 5 most resilient (IUCN) sites (see Table 3) present more abundance of colonies and high proportions of these resistant families (see Fig.3). As expected, more resilience is conferred upon sites that have a high abundance of resistant coral species (Maynard *et al*., 2010), backing up the idea that resistant coral species constitute one of the most important ecological factors for resilience (McClanahan *et al*., 2012). For this reason it should be included within the IUCN and R^2M groups, along with other significant factors.

The general dominance of resistant families in most sites (see Fig.3) indicates that susceptible corals may have been reduced by previous bleaching stress, as the bleaching events of 2010 and 1998, and/or by anthropogenic disturbance. Hing Won´s high abundance of coral colonies from Acroporidae family could be explained by site´s resilience which is medium (IUCN) / high (R^2M), allowing for less resistant genera to subsist.

Although Pocilloporidae is considered susceptible to bleaching, it exists in high proportion and can be seen in fair abundance among all sites, even less resilient ones. This corresponds to the *Pocillopora* life strategy, an early colonizing coral that reproduces quickly and colonizes disturbed environments (Grimsditch, 2009). Massive, slow-growing taxa, such as *Porites* and some from the Faviidae family (E.g. *Goniastrea, Favites, Platygyra*) are more resistant to bleaching (Baird and Marshall, 2002), therefore appear in higher percentage.

Most abundant genera (*Porites, Pocillopora*, *Goniastrea* and *Montipora*) also have the best recruitment rates, indicating that at the time being, these genera are best adapted to Koh Tao´s environment. Size class distributions (Fig.5) are indicative of the history of mortality of reefs 'coral population (Grimsditch, 2009). Large coral colonies were found mainly for resistant genera, *Porites* and *Diploastrea.* This suggests that these colonies have subsisted through disturbances over a long time scale. Montipora also presents itself in massive growth form explaining relative abundance of large sizes. Acropora presents low numbers for large sizes, possibly due to past disturbances such as past bleaching events (1998 and 2010). *Pocillopora* size distribution curve shows high recruitment rates but few large size colonies, as expected based on it´s life-strategy (Grimsditch, 2009) meaning that it recovers rapidly after disturbance.

From the groups that have most influence on reducing resilience potential across sites, only two (Management and Fish Groups) can be directly influenced by managers (see Table 3), thus it should be on these factor groups that managers should focus on.

In the MDS analyses we can see that Hin Ngam, together with Tanote and Ao Leuk have a high level of similarity of coral community, suggesting that there might be connectivity between them.
The results showed that Sairee has the potencial to raise it´s resilience score by addressing management problems since it has natural resistance and recovery. Likewise, Japanese Gardens has the possibility to enhance it´s resilience by addressing management issues. In order to protect coral reefs with characteristics indicative of greater resilience to climate change (Baskett *et al*., 2010), Hin Ngam, Tanote, Hin Wong and Ao Leuk should be included in No Take zone, as they are all high resilience sites (R^2M).

Comparing IUCN and R^2M methodology we can see that IUCN ranking shows more sites in medium level resilience, that is, scores tend to regress toward their group average due to a high number of potentially indiscriminant factors (McClanahan *et al.*, 2012). However, ranking results are not far from each other and there are some similarities between both methods (IUCN and R^2M). All sites with highest resilience belong to non-developed areas (except Tanote) and all sites with lowest resilience are in developed areas, proving the impact of human development on these sites. Sites in bays (Chalok Bay, Mango Bay and Shark Bay) are in medium or low resilience ranking, and best resilience sites include one pinnacle and an island (White Rock and Shark Island), showing that these physical characteristics are important for resilience but unfortunately they are aspects that cannot be changed or influenced by managers.

R^2M method is more “*manager friendly*” in the sense that it requires less factors to be measured and assessed, making it a more feasible protocol. In addition, the table resulting from the assessment is easier to interpret and gives a direct view of where to focus management efforts. Nonetheless, protocols need to be improved to help biologists and conservationists communicate on resilience in ways that managers understand what actions can and should be taken to maintain and support reef resilience (Mayard *et al.*,2012).

V. Conclusions and Recommendations

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The data collected for this thesis gives way to classify sites by ecological condition and resilience capacity, therefore providing information on which spatial management planning can be based and helps focus management efforts. Most coral reefs on the island have medium or high resilience and coral community with resistant coral family/genera dominance. There are however, management actions that can provide better chances in coping with future bleaching events, maintain overall island biodiversity and enhance resilience.

This study makes the following recommendations in order to maximize overall conservation of Koh Tao´s reefs:

- High resilience sites, with good coral populations that are not already fully protected (Hin Ngam, Ao Leuk and Tanote) should be included in No-Take zoning as to maintain them as source reefs, and serve as a sanctuary of a healthy reef ecosystem (See Fig.10).
- For fostering the highest abundance of Acroporidae colonies and showing high resilience, Hing Wong should also be considered for protection in subsequent zoning of Koh Tao´s coral reefs, creating a continuous No-Take zone on the east-side of the island.
- In case expanding MPA is not feasible, then a second option is to create a No-Take zone including most resilient sites (Hing Wong, Tanote, Ao Leuk, Hin Ngam, Shark Island and White Rock) and create a buffer zone around White Rock (including Japanese Gardens, Twins and Sairee), where activities are regulated.
- Specifically for Japanese Gardens and Sairee, efforts should be targeted on alleviating nutrient input, pollution, sedimentation and physical damage from divers in order to raise resilience.
- Management should be reinforced at all sites to “effective” and levels of compliance and awareness to “reasonable or high”. Enhanced control of pollution and other disturbances to water and substrate quality is required (land-based regulations on waste management, nutrient input and sedimentation) especially at Hin Wong, Mango Bay, Chalok Bay, Shark Bay and Tao Tong.
- Full control of resource extraction and protection of stock integrity and population dynamics are necessary around the island (fishing regulations).

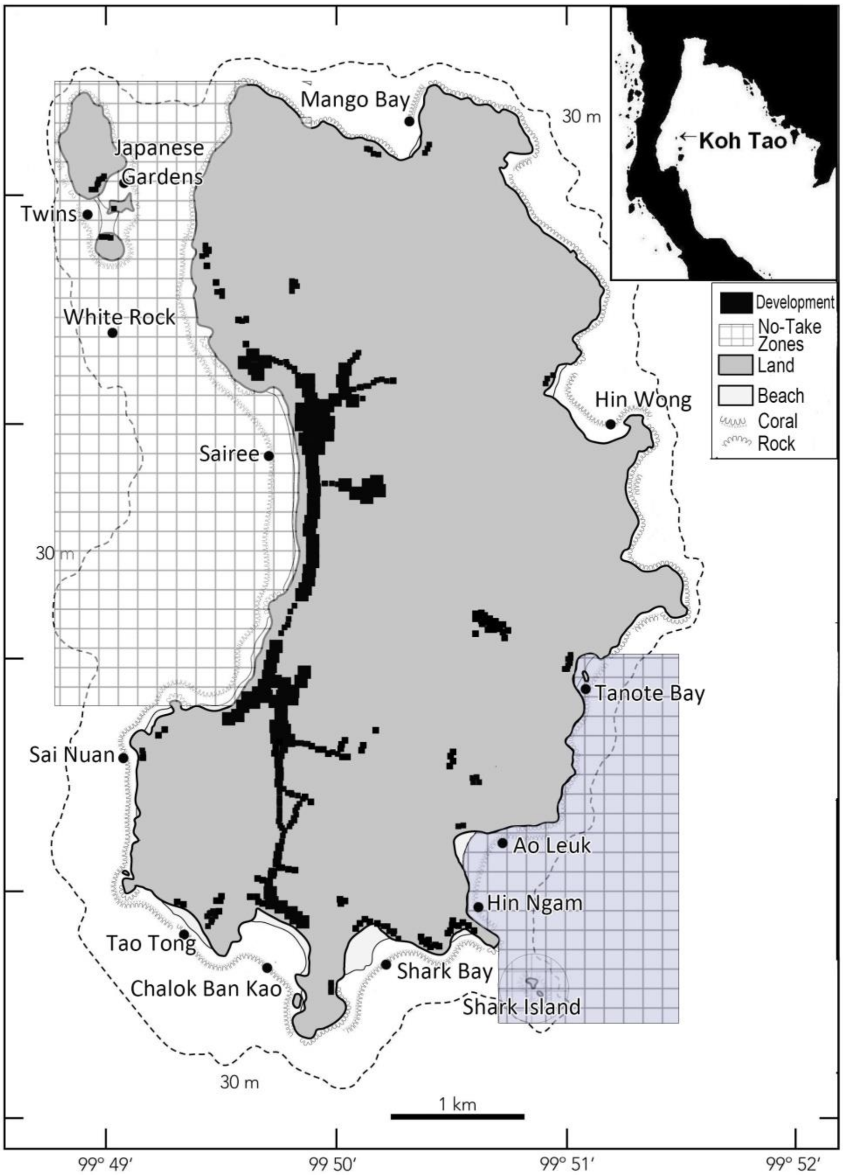

Fig.10 Koh Tao map with 14 dive sites surveyed, development areas and proposed zoning

VI. References

References

Baird, A.H. and Marshall, P.A. (2002) Mortality, growth and reproduction in scleractinian corals following bleaching on the Great Barrier Reef. *Marine Ecology Progress Series* 237: 133–141.

Baskett, M.L., Nisbet, R.M., Kappel, C.V., Mumby, P.J., Gaines, S.D. (2010) Conservation management approaches to protecting the capacity for corals to respond to climate change: a theoretical comparison. *Global Change Biology* 16: 1229–1246. doi: 10.1111/j.1365-2486.2009.02062.x

Burke, L., Reytar, K., Spalding, M., Perry, A. (2011) Reefs at Risk Revisited. World Resources Institute, Washington, DC, 114.

Guest, J.R., Baird, A.H., Maynard, J.A., Muttaqin, E., Edwards, A.J., *et al*. (2012) Contrasting Patterns of Coral Bleaching Susceptibility in 2010 Suggest an Adaptive Response to Thermal Stress. PLoS ONE 7(3): e33353. doi:10.1371/journal.pone.0033353

Grimsditch, G., Tamelander, J., Mwaura, J., Zavagli, M., Takata, Y., Gomez, T. (2009) Coral Reef Resilience Assessment of the Pemba Channel Conservation Area, Tanzania. IUCN: 40pp.

Hughes, T. P., Baird, A. H., Bellwood, D. R., Card, M., Connolly, S. R., Folke, C., *et al.* (2003). Climate change, human impacts, and the resilience of coral reefs. S*cience*, *301*(5635), 929-933.

Maina J., McClanahan, T.R., Venus, V., Ateweberhan, M., Madin, J. (2011) Global Gradients of Coral Exposure to Environmental Stresses and Implications for Local Management. *PLoS ONE* 6(8): e23064. doi:10.1371/journal.pone.0023064

Marshall P.A., Baird, A.H. (2000) Bleaching of corals on the Great Barrier Reef: differential susceptibilities among taxa. *Coral Reefs* 19: 155-163

Marshall, P. and Schuttenberg, H. (2006) A Reef Manager's Guide to CORAL BLEACHING, Great Barrier Reef Marine Park Authority

Maynard J, Marshall, P. A., Johnson, J. E., Harman, S. (2010) Building resilience into practical conservation: identifying local management responses to global climate change in the southern Great Barrier Reef. *Coral Reefs* 29:381–391 doi: 10.1007/s00338-010-0603-8

Maynard, J., Wilson, J., Campbell, S., Mangubhai, S., Setiasih, N., Sartin, J., Ardiwijaya, R., Obura, D., Marshall, P., Salm, R., Heron, S., and Goldberg, J. (2012) Assessing coral resilience and bleaching impacts in the Indonesian archipelago. Technical Report to The Nature Conservancy with contributions from Wildlife Conservation Society and Reef Check Foundation Indonesia. 62 pp.

Keller, B. D., Gleason, D. F., McLeod, E., Woodley, C. M., Airamé, S., Causey, B. D., *et al*. (2009). Climate change, coral reef ecosystems, and management options for marine protected areas. *Environmental management*,*44* (6), 1069-1088.

McClanahan, T.R., Donner, S.D., Maynard, J.A., MacNeil, M.A., Graham, N.A.J., *et al.* (2012) Prioritizing Key Resilience Indicators to Support Coral Reef Management in a Changing Climate. *PLoS ONE* 7(8): e42884. doi:10.1371/journal.pone.0042884

Mcleod, E., Salm, R., Green, A., and Almany, J. (2009) Designing marine protected area networks to address the impacts of climate change. *Frontiers in Ecology and the Environment* 7(7):362-370.

Obura, D.O. and Grimsditch, G. (2008) – Resilience-Integrating Science and Management in Coral Reefs Relevant to Climate Change. In: Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008) Ten years after bleaching – facing the consequences of climate change in the Indian Ocean. CORDIO Status Report 2007

Obura, D.O. and Grimsdith, G. (2009). Resilience Assessment of coral reefs – Assessment protocol for coral reefs, focusing on coral bleaching and thermal stress. IUCN working group on Climate Change and Coral Reefs. IUCN

Platong, S., Chaloem, S., Charoenmart K., *et al.* 2012. Strategic Plan: Integrated Coastal Management for Koh Tao. Center for Biodiveristy of Peninsular Thailand, Prince of Songkla University, Hat Yai, Thailand.

Phongsuwan, N., Chankong, A., Yamarunpatthana, C., Chansang, H., Boonprakob, R., Petchkumnerd, P., *et al* (2013) Status and changing patterns on coral reefs in Thailand during the last two decades. *Deep Sea Research Part II: Topical Studies in Oceanography*, 96, 19-24

Rio+20 Resolution adopted by the General Assembly A/RES/66/288 – "The future we want"

Richmond, R. H., and Wolanski, E. (2011) Coral research: past efforts and future horizons. In: *Coral Reefs: An Ecosystem in Transition,* 3-10

Rinkevich, B. (2008) Management of coral reefs: We have gone wrong when neglecting active reef restoration. *Marine Pollution Bulletin* 56: 1821–1824

Sale, P. F. (2008) Management of coral reefs. *Marine Pollution Bulletin,* 56 805–809

Sale, P. F., Agardy, T., Ainsworth, C. H., Feist, B. E., Bell, J. D., Christie, P., ... & Sheppard, C. R. (2014). Transforming management of tropical coastal seas to cope with challenges of the 21st century. *Marine Pollution Bulletin*, *85*(1), 8-23. doi: 10.1016/j.marpolbul.2014.06.005

Scott, C. (2008) Koh Tao Ecological Monotoring Program. Save Koh Tao Marine Branch

Smith, J.E., Shaw, M., Edwards, R.A., Obura, D., Pantos, O., Sala, E., Sandin, S.A., Smriga, S., Hatay, M. and Rohwer, l. (2006) Indirect effects of algae on coral: algae-mediated, microbe-induced coral mortality. *Ecology Letters* 9, doi: 10.1111/j.1461-0248.2006.00937.x.

Sutthacheep, M., Yucharoen, M., Klinthong, W., Pengsakun, S., Sangmanee, K., & Yeemin, T. (2013). Impacts of the 1998 and 2010 mass coral bleaching events on the Western Gulf of Thailand. *Deep Sea Research Part II: Topical Studies in Oceanography*, *96*, 25-31

Szuster, Brian W. and Dietrich, John (2014) Small Island Tourism Development Plan Implementation: The Case of Koh Tao, Thailand. *Environment Asia* 7(2): 124-132

UNEP, (2006) Marine and coastal ecosystems and human wellbeing: a synthesis report based on the findings of the millennium ecosystem assessment. In: Current State and Trends Assessment.

UNEP, (2007) National Reports on Coral Reefs in the Coastal Waters of the South China Sea. UNEP/GEF/SCS Technical Publication No. 11.

UNEP, (2011) Taking Steps toward Marine and Coastal Ecosystem-Based Management - An Introductory Guide

Wilkinson, C.R. (2008) Status of the coral reefs of the world: 2008. Global Coral Reef Monitoring Network and Australian Institute of Marine Science, Townsville.

West, J.M. and Salm, R.V. (2003) Resistance and Resilience to Coral Bleaching: Implications for Coral Reef Conservation and Management, *Conservation Biology* 17(4): 956–967 doi: 10.1046/j.1523-1739.2003.02055.x

Appendix

IUCN-CCCR Resilience Assessment datasheet - adapted - Koh Tao 2014

Date:	Site:	Collector:

	Group	Factor	Value		Comments
Benthic	Coral	Hard coral			
		Soft coral			
	Algae	NIA			
	Substrate	Rubble			
Physical	Substrate morphology	Top.Compl - Micro			
		Top.Compl - macro			
		Sediment texture			
		Sediment layer			
	Cooling and flushing	Temperature			
		Currents			
		Wave energy			
		Deep water			
		Depth of reef base			
	Shade & screen	Depth			
		Visibility			
		Compass direction			
		Slope			
		Physical shading			
		Canopy shading			
	Extremes & Acclimatization	Exposed low tide			
		Ponding/pooling			
		Temperature variability			
		Survival of past bleach			
Anthropogenic	Anthropogenic impacts	Nutrient input			
		Pollution (chemical)			
		Pollution (solid)			
		Turbidity / Sedimentation			
		Physical damage			
		Fishing pressure			
		Destructive fishing			
		Dispersal barrier			
	Management	MPA/biodev			
		MPA/biodev			
		Environment/ICZM			

Site	Description:

	Factor	Value		Comments
Coral condition	Bleaching			
	Mortality-recent			
	Coral disease			
	Mortality-old			
	Recovery-old			
Coral population	Recruitment			
	Fragmentation			
	Dominant size class			
	Largest corals (3)			
Coral associates	Obligate feeders			
	Branching residents			
	Competitors			
	Bio-eroders (external)			
	Bio-eroder (internal)			
Fish groups	Herbivores			
	Scrapers			
	Grazer/browser			
	Piscivores			
Connectivity	Self-seeding			
	Local seeding (10km)			
	Distant seeding (100)			
	Currents			
	Dispersal barrier			

IUCN_CCCR Resilience Assessment datasheet - adapted - KoTao 2014												
Coral Size												
Date:	**Site:**				**Collector:**							
Large corals	**Transect 1 Deep/Shallow**						**Transect 2 Deep/Shallow**					
Genus/Family	11-20cm	21-40cm	41-80cm	81-160cm	161-320cm	>320cm	11-20cm	21-40cm	41-80cm	81-160cm	161-320cm	>320cm
Acropora (Non Staghorn)												
Pocillopora												
Porites												
Montipora												
Platygyra												
Favia												
Favites												
Goneastrea												
Montastrea												
Leptoria												
Lobophylia												
Symphylia												
Diploastrea												
Tubastrea												
Juvenile corals	0-2,5cm	3-5cm	6-10cm				**Juvenile corals**		0-2,5cm	3-5cm	6-10cm	
Fragments	0-2,5cm	3-5cm	6-10cm				**Fragments**		0-2,5cm	3-5cm	6-10cm	

Resilience-based assessment for targeting coral reef management strategies in Koh Tao, Thailand

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