Vulnerability, Resilience and Conservation Strategies for Thailand's Coral Reef Marine Protected Areas in a Changing Climate

by

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Bachelor of Science, Kasetsart University, 1995
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A Dissertation Submitted in Partial Fulfillment
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Supervisory Committee

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Abstract

In 2010, Thailand's Andaman Sea experienced unprecedented mass coral bleaching. Between 50% to 90% of corals suffered bleaching along the Andaman coast both inside and outside Marine Protected Areas (MPAs). This dissertation examines the implications of climate change for these coral reef ecosystems in MPAs. The study explores the potential and effectiveness of conservation management strategies using MPAs and resilience building to address this global challenge in the context of Thailand.

This dissertation examines how resilience-based management can be enhanced in Thailand's MPAs on the Andaman coast in the face of climate change. In particular, the research: 1) Identifies resilient reefs in the Andaman bioregion, 2) Assesses coral reef resilience in a specific MPA to identify management interventions, 3) Examines current MPA coverage and suggests strategies to improve coverage, and 4) Illustrates the potential of social media to enhance coral reef resilience in Thailand.

The study employs a mixed methods approach consisting of literature review, a review of available secondary data, workshops, field surveys and social media data tracking. Twenty-two resilience indicators were selected and used to assess reefs at 62 survey stations across the eastern Andaman bioregion. A review of existing Andaman MPA coverage, spacing and design was conducted to determine the gaps and opportunities for expanding the MPA network. A science communication campaign focused on the importance of parrotfish in saving coral reefs using online social media was launched and monitored.

The study sites were classified into high (28), moderate (23) and low (11) resilience based on resilience scores. The results provide the first comprehensive resilience assessment of coral reefs in the Andaman sea. The identified resilient reef areas serve as cornerstones in developing a more resilient MPA network and provide a conservation-based platform for long-term marine spatial planning in the eastern Andaman region.

Resilience scores for Mu Ko Surin National Park were analyzed in more detail to provide an example of the process for undertaking a finer scaled analysis with a localized

weighting system. Management interventions were developed accordingly including strict protection areas and recovery zone designations aiming to improve coral resilience.

Expanding MPA coverage and developing MPA networks is an urgent priority for Thailand to reach the CBD target of at least 10% of marine and coastal habitat protected by 2020. This study suggests three important areas for consideration: 1) Expanding MPAs by prioritizing resilient areas and incorporating other types of conservation areas; 2) A 'bottom-up' approach that incorporates adaptive and flexible governance; and 3) Implement biological corridors to address key shortcomings of current MPAs.

The findings from the parrotfish campaign highlighted the importance of science communication and the usefulness of social networks for conservation. The campaign demonstrated that social media, when used properly and effectively, is powerful for public engagement and helps create an enabling environment for change in public policy and practice for marine conservation.

This dissertation offers insights into opportunities to improve the management of large tropical marine ecosystem and how coral reef resilience can be enhanced by developing MPA networks in the face of climate change.

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Dedication

'*In Wilderness is the Preservation of the World'* – Henry David Thoreau

This dissertation is dedicated to my daughter, Pukka, my parents, Manoon and Supannee Manopawitr, and my great friend, the late Dr. Kanjana Adulyanukosol, who never stopped believing in me.

Chapter 1
Introduction and Overview

1.1 Climate change and coral reefs: enhancing resilience, improving management

Coral reefs are often called the 'rainforests' of the sea because of their rich diversity of marine life. They are the most biologically diverse, socially important and economically vital marine system in the world. The complex structure of coral reefs supports the apex of marine biodiversity and provides livelihoods for millions of people living along tropical coastlines through fisheries, tourism and other ecosystem services (Knowlton 2001; Hoegh-Guldberg et al. 2017; IPBES 2019). Coral reefs, however, are also among the most vulnerable ecosystems on the planet and are being exposed to unprecedented challenges (Hughes et al. 2003, 2017; Carpenter et al. 2008; Wilkinson 2016). The causes of coral reef degradation are no longer from local disturbances alone such as physical damage from human use, overfishing, pollution and coastal development, but also from global threats like climate change. Conserving coral reefs will require not only improved knowledge of this ecosystem and understanding of the impacts of climate change, but also concerted efforts at multiple levels and integrative conservation strategies.

Protected areas are cornerstones of most conservation strategies because they are one of the most effective tools for curbing biodiversity loss and over-exploitation of natural resources (Dudley et al. 2010; Stolton & Dudley 2010; UNEP-WCMC, IUCN & NGS 2018). Similarly, Marine Protected Areas (MPAs) are the most widespread management strategy employed to protect coral reefs and enhance marine ecosystem resilience (Mora et al. 2006; IUCN-WCPA 2008; Halpern et al. 2010; Selig & Bruno 2010; Steneck et al. 2018). When appropriately planned and

well managed, MPAs can produce long-lasting and often rapid increases in the abundance, diversity and productivity of marine organisms (Halpern & Warner 2002; Lester et al. 2009; McLeod et al. 2009; Sala & Giakoumi 2018). Most MPAs, however were not designed to address the threats posed by climate change such as mass coral bleaching caused by increased sea surface temperature. In recent years, this has changed and MPAs are being increasingly promoted as a tool to address the impacts of climate change through increasing ecosystem resilience (Keller et al. 2009; McClanahan et al. 2009; Micheli et al. 2012; Anthony et al. 2015; Roberts et al. 2017). Long-term data from Australia's Great Barrier Reef has shown that within MPAs, reef communities are more stable, the level of disturbance impacts are lower and recovery is faster than that in adjacent unprotected habitats (Mellin et al. 2016). Incorporating climate change impacts and resilience-building principles into MPA planning and implementation is critical to safeguard the future of coral reefs around the world.

This dissertation examines the implications of climate change for coral reef ecosystems. The study explores the potential and effectiveness of conservation management strategies using MPAs and resilience building to address this global challenge in the context of Thailand.

1.2 Research Question and study objectives

The primary question addressed by the study is to determine how resilience-based management can be enhanced in Thailand's Marine Protected Areas on the Andaman coast in the face of climate change? In particular, the research will:

1. Examine potential climate change implications for the current marine protected area network on the Andaman coast of Thailand, and suggest management strategies to enhance resilience;

2. Identify resilient reefs in marine protected areas on the Andaman coast of Thailand using a resilience assessment protocol adapted and designed for this purpose;

3. Assess coral reef resilience in a specific marine protected areas to help illustrate potential management interventions; and

4. Illustrate the potential of social media to help enhance coral reef resilience in Thailand

1.3 Overview

Chapter 2 begins by reviewing the main aspects of coral vulnerability to key climate change drivers; i.e., from increased sea temperatures, ocean acidification, and changes in patterns of currents. Ocean warming is a topic of particular concern because it has led to more frequent and severe mass coral bleaching events, changes in community composition, and increased incidence of coral disease. It is predicted that without urgent management efforts to reduce carbon emission and mitigate human-induced stressors, we could lose 90% of coral reefs by mid-century (IPCC 2018).

Coral reef resilience and climate change are discussed as an overarching framework linking theory to practices such as the role of biodiversity and functional groups, local environmental factors and connectivity. Next, different management strategies to minimise the likely impacts of climate change are discussed. Marine Protected Areas (MPAs) are a critical tool for management and conservation of coral reefs and are central to this discussion. Broader management interventions such as MPA networks, marine spatial planning and other

management schemes are also considered. The role of social media in science communication is discussed as part of developing integrated conservation strategies.

Chapter 3 describes the MPA network in the Andaman Coast of Thailand in detail. Thailand's coastal and marine ecosystems are vulnerable to predicted climate change as a result of rising sea level, increased sea surface temperature, acidification and associated impacts. These marine resources are already under threat from coastal development, agriculture, tourism, fisheries and other uses. Twenty Marine National Parks and non-hunting areas located in the Andaman Sea form a network of large MPAs. This Chapter introduces their history, natural characteristics, and importance including current threats of climate change, and management responses.

Chapter 4 discusses the methods and analyses used in this study including development of the resilience assessment framework through participatory workshops, primary and secondary data review, interviews with experts and use of a Geographic Information System (GIS) to undertake a gap analysis. Social media tracking was used to monitor the impact of the online communication campaign.

Chapter 5 presents the results divided into four parts; i) Identifying resilient reef areas after the 2010 catastrophic mass coral bleaching in Thailand's Andaman Sea; ii) Assessing coral reef resilience to help identify management actions at Mu Ko Surin National Park, Phang-Nga; iii) Designing the MPA network on the Andaman Coast of Thailand to build ecosystem resilience and improve coral reef conservation, and iv) Communicating resilience for change: a successful case of using social media to ban parrotfish sales to save coral reefs in Thailand.

Chapter 6 concludes with the key results from the study and summarizes insights, policy and management implications, the role of social media in conservation, and opportunities for future research and cooperation.

Chapter 2

Coral reefs and resilience-based management: A review

Coral reefs are severely threatened and endangered worldwide and could potentially be the first major ecosystem to become ecologically extinct in the Anthropocene (Nystrom et al. 2000; Hughes et al. 2003, 2017, 2018; Hoegh-Guldberg et al. 2007, 2017; Knowlton & Jackson 2008; Obura & Grimsditch 2009; Norström et al. 2016; IPCC 2018; Williams et al. 2019). Coral reef managers face the challenge of conserving reefs from combined stressors of global and local-scale disturbances e.g. overfishing, coastal development, sedimentation, pollution, ocean warming and ocean acidification. Two management challenges associated with reef vulnerability are: i) Reducing pressure and exposures to stress; and ii) Supporting resilience to these threats (Anthony et al. 2015). Local management must not only address immediate threats but also enhance ecosystem resilience to promote recovery and enhance adaptive capacity (Maynard et al. 2015). This Chapter reviews the main aspects of coral vulnerability to key climate change drivers and the ecological implications of these changes. The resilience principle and resilience-based management are discussed in relation to climate change including four main factors that enhance the resilience of coral reef ecosystems, namely, biodiversity, local environmental conditions, connectivity and effective governance. In addition, the Chapter provides some background on the role of Marine Protected Area (MPAs) and social media to provide some context for the case study in the thesis on mechanisms to change current dominant modes of exploitation.

2.1: Coral reef crisis: compounding local stresses with global disturbances

Over the last 40 years, the health and extent of coral reefs has declined by approximately 50-75% in almost every region on the world (Gardner et al. 2003; Bruno & Selig 2007; Wilkinson

2008; De'ath et al. 2012; Jackson et al. 2014; Hughes et al. 2018) and around 75% of coral reefs worldwide are now threatened from various stressors (Hughes et al. 2018, Eakin et al. 2019). Coral reefs in the Caribbean have declined by 80% in 30 years (Gardner et al. 2003; Jackson et al. 2014), while almost 95% of coral reefs in Southeast Asia are threatened with the extent of coral loss much greater than previously thought (Bruno & Selig 2007; Burke et al. 2011). Around half of Australia's Great Barrier Reef died out during the global coral bleaching in 2016-17 and the amount of larvae recruitment in 2018 was reduced by 89% compared to historical levels (Hughes et al. 2019). Coral reefs suffer from multiple stresses, including local threats such as overfishing, sedimentation, diseases, invasive species, and global threats like climate change, which is considered the single most important large-scale threat for reefs today by many scientists (Hughes et al. 2017, 2018; Darling et al. 2019).

To achieve effective conservation strategies for coral reefs, we require an understanding of their inherent vulnerability and the key threats which they face. This section provides an overview of these aspects in relation to climate change drivers.

2.1.1 Warming seas and mass coral bleaching

Coral reef ecosystems normally occur in warmer water (22-32 °C) and shallow seas with average Sea Surface Temperature (SST) > 27 °C. SST is an essential factor determining coral reef distribution. Median SSTs for coral reefs were 1.8 °C warmer than non-reefs with less variable SST (80% of months within 3.3°C range) compared to non-reef areas (80% of months within 7.0 °C range (Lough 2012). Additionally coral reefs are vulnerable to climate change as they bleach rapidly and widely in response to warmer SST. Increases in SSTs of only 1-2°C above the average maximum temperatures thresholds (30°C-32°C) for prolonged periods can trigger such

mass bleaching events because many corals already live close to their upper thermal thresholds (Hoegh-Guldberg 1999; Cole & Brown 2003).

Coral bleaching is the breakdown of the symbiotic relationship between coral and the dinoflagellate algal symbiont in the genus *Symbiodinium*, commonly referred to as 'zooxanthalae', that supply up to 90% of a coral's energy requirement (Davies 1984; Sheppard, Davy & Pilling 2009). Stresses, including changes in temperature, light, bacterial infection, pollutants and low salinity, can damage the symbionts' photosynthetic system (in the case of temperature and light) and cause coral to expel zooxanthalae resulting in bleaching (Brown, 1997; Dove & Hoegh-Guldberg 2006). Bleached corals become weakened and susceptible to diseases and may ultimately die depending on the severity and the length of exposure of the coral to stress (Douglas, 2003).

The frequency and the scale of mass coral bleaching events has been escalating since the early 1980s at both regional and global scales associated with human-induced climate change (Glynn 1993; Hoegh-Guldberg 1999; Buddemeier, Kleypas & Aronson 2004; Baker, Glynn & Riegl 2008; Hughes et al. 2018; Eakin et al. 2019). As the global climate system responds to increasing levels of atmospheric greenhouse gases, the ocean has taken up more than 90% of the excess heat in the climate system and marine heatwaves have doubled in frequency since 1982 and are increasing in intensity (IPCC 2019). Increased SSTs have led to more frequent bleaching events (Lough 2012). Between 1880 and 2009, global land and sea temperatures had warmed by 0.79°C and warming through 2016 was 0.90°C, an additional warming of 0.11° C (IPCC 2019). The year 2018 was the fourth warmest year on record since 1880 (NASA, 2019).

The first global-scale coral bleaching in 1997-98 killed approximately 16% of coral communities globally and was a wake-up call for reef scientists regarding the threat from a warming climate (Wilkinson 2004). Since then, regional-scale bleaching events have affected many coral reef ecosystems, such as the Great Barrier Reef, Australia in 2002 (Berkelmans et al. 2004), the Caribbean in 2005 (Eakin et al. 2010) and Western Australian reefs in 2011 (Moore et al. 2012). Global-scale coral bleaching events occurred again in 2010 and from 2014 to 2017 (Eakin et al. 2017; Hughes et al. 2018). Some locations such as Hawaii and the Great Barrier Reef have experienced consecutive years of bleaching which greatly affected their ability to recover (Eakin et al. 2019).

The intensity and duration of temperature anomalies are important factors in predicting a mass bleaching event since they indicate stress levels on the reefs (Marshall & Schuttenberg 2006). The National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Watch program combines these two factors using satellite-driven data to produce Degree Heating Weeks (DHW)[1] maps to alert resource managers worldwide about bleaching risks. At 4 DHWs, bleaching events are expected and at 8 DHWs severe bleaching and mortality are likely to occur (Liu, Strong & Skirving 2003). However, record bleaching on the Great Barrier Reef in 2016 showed that mortality occurred well below 6 °C-weeks and instead beginning at 3–4 °C-weeks, and with mortality exceeding 50% at 4–5 °C-weeks (Hughes et al. 2018). Other methods to determine bleaching thresholds include comparing past bleaching events with temperature records (e.g. analyses in the Great Barrier Reef, (Berkelmans 2002), and Indian Ocean region (Sheppard 2003), and observations from experiments (Coles & Jokiel 1978; Berkelmans, 2002).

[1] One DHW is equivalent to 1 week of 1°C above the average maximum temperatures (AMT) of that geographical location of the same month. Two DHWs are equivalent to two weeks at 1°C or one week of 2°C above AMT.

The risk of mass bleaching is also influenced by other climate variables such as air temperature, cloud cover, wind and tidal currents. Higher risk is predicted when forecasts are for high air temperatures, extended periods of clear skies, low wind and neap tides (Liu, Strong & Skirving 2003). The relationship between temperature and solar radiation has important implications for management such as providing shade in key coral areas during the peak of bleaching event and can help explain observations of reduced bleaching in coral colonies shaded by large landforms or periods of high cloud cover (Brown et al. 2000; Mumby et al. 2001; Baird & Marshall 2002)

Even though major mass bleaching events can be predicted remotely, the vulnerability of coral reefs to bleaching varies geographically according to the susceptibility of the dominant coral reef species present and the local environment (Marshall & Baird 2000; Jokiel & Brown 2004). Typically, fine-structured and fast-growing corals with thin tissue such as *Pocilloporids* and *Acroporids* tend to be most susceptible to bleaching while solid, massive skeletons with thick tissue and slow growth rates such as *Porites*, *Faviids* and *Mussids* are more resistant (Fitt et al. 2000, 2001; Loya et al. 2001; LaJeunesse, Reyes-Bonilla & Warner, 2007). In most cases after severe bleaching, reefs transform from dominance by fast-growing, branching and tabular species that are important providers of three-dimensional habitat, to a much less complex structure dominated by taxa with simpler morphological characteristics and slower growth rates (Hughes et al. 2018).

Bleaching patterns in the same reef area or even in the same colony are not uniform and can be explained by genetic differences in zooxanthalae that live within the corals (Baker 2003). Thermal resistant zooxanthalae, found more commonly in reefs regularly exposed to high temperatures and/or turbid conditions, are likely the result of an evolutionary and ecological

response to long-standing environmental conditions (Rowan 2004; LaJeunesse et al. 2010). A number of studies have shown that coral can shift their zooxanthalae composition toward thermal tolerant varieties to adapt to warmer water (Rowan et al. 1997; Baker et al. 2004; Jones 2008; LaJeunesse et al. 2010). Some fast-growing corals can both acclimate and adapt to elevated temperatures e.g. in American Samoan reef pools, where high-temperature extremes are common (Palumbi et al. 2014). Nevertheless, this adaptive mechanism is unlikely to come without a biological cost e.g., early reports from Australia indicated reduced growth rate (Bay et al. 2008), and growth may be too slow to keep pace with current rates of climate change where severe mass bleaching has become more frequent (Hoegh-Guldberg et al. 2002; Hoegh-Guldberg & Bruno 2010; Eakin et al. 2019).

2.1.2 Ocean acidification and reef accretion

Coral reefs build their three-dimensional calcium carbonate structure by combining calcium with carbonate ions from seawater (Cohen & Holcomb 2009). This calcifying mechanism is crucial for reef-accretion of corals because in order for complex reef structure to persist, their calcification rate must outpace skeleton erosion caused by predation and ocean currents (Kleypas & Yates 2009).

Ocean acidification is the change in seawater chemistry primarily driven by the oceanic uptake of rising atmospheric carbon dioxide (CO_2) (Doney et al. 2009; Kleypas 2019). Every year approximately one-third of total CO_2, or about 3 million tons, emitted by human activities, is absorbed by the ocean (Sabine et al. 2011, 2004). Dissolved CO_2 forms carbonic acid (H_2CO_3) with seawater, lowers pH levels and reduces carbonate ion concentration (CO_3^{2-}), which is

fundamental for coral reef calcification (Kleypas & Langdon 2006). Since industrialisation, rising atmospheric CO_2 has increased the oceans' average temperature by 0.9°C, reduced pH levels by 0.1 pH units (equivalent to a 30% increase in surface acidity) and decreased CO_3^{2-} to ~210 micro moles kg^{-1} (Hoegh-Guldberg et al. 2014; Lough & Van Oppen 2018).

Current CO_2 levels are over 400 parts per million (ppm), unprecedented for coral reefs during the past 800,000 years. More CO_2 in the atmosphere means more carbonic acid and less carbonate ion in seawater. Coral reefs are unlikely to exist in waters with carbonate ion concentration (CO_3^{2-}) < 200 micro moles kg^{-1} because at that level reef erosion will probably exceed reef accretion (Hoegh-Guldberg et al. 2014). Coral reefs may exhibit several responses to reduced calcification, all of which have adverse consequences for reef ecosystems including slower calcification that results in slower coral growth and more fragile structures (Madin et al. 2008; Albright 2018). Corals could potentially shift from net accretion to net dissolution with implications for greater susceptibility to storm damage and slower recovery rates between disturbances (Silverman et al. 2009; Andersson & Gledhill 2013; Perry et al. 2013).

If future levels of CO_2 exceed 450-500 ppm, the diversity and density of coral reefs are predicted to decline, resulting in vastly reduced habitat complexity and loss of associated fish and invertebrate diversity (Jones et al. 2004, Wilson et al. 2006) and overall reef resilience will be reduced (Anthony et al. 2011).

The actual effects of ocean acidification on the ability of coral reefs to build their skeletons has been observed in both laboratory and field studies. These findings suggest that a doubling of the pre-industrial CO_2 level could lead to a decreased skeletal growth rate of approximately 10% to

50% (Dove et al. 2013; Albright et al. 2016) which would presumably lead to dramatically increased rates of bioerosion (Guinotte & Fabry 2008). Evidence from field studies that support this impact on coral growth and reef accretion is growing. Studies of coral cores in the Great Barrier Reef have revealed that calcification by these corals has declined by 14.2% since 1990 and appears to be unprecedented for at least 400 years (De'ath, Lough & Fabricius 2009). Similar decreases have been observed for Thai reefs in the Andaman sea around Phuket and several locations in Southeast Asia (Tanzil et al. 2009). In addition, ocean acidification has been shown to induce bleaching and cause productivity loss in coral reefs and act synergistically with increased temperature to lower thermal bleaching thresholds (Anthony et al. 2008; Albright 2018).

The scientific community concluded in the Honolulu Declaration on Ocean Acidification and Reef Management (2008) that if current CO_2 emission trends continue unabated, the ocean will undergo such high levels of acidification that it may result in the significant alteration of the marine environment to an extent and at rates that have not occurred for tens of millions of years (McLeod et al. 2008). Such changes could compromise the long-term viability of coral reef ecosystems and the ecosystem services that they provide. However, these predictions are dependent on the overall health of the coral community. Coral communities with high coral cover and active coral growth will likely be able to maintain a reef structure for longer than those with greatly reduced live coral. For example, the reefs of the Galápagos illustrate the critical relationship between coral health and resilience to stress, as coral reef communities were eroded away within a decade following the near total mortality of corals during the 1982-83 bleaching event (Manzello et al. 2008). The latest global assessment confirms with high confidence the

impacts of acidification on coral reefs, and reef dissolution and bioerosion affecting coral species distribution, and leading to community change (IPCC 2019).

2.1.3 Changes in current patterns, and other climate related stresses

Climate change is likely to have significant impacts on oceanographic processes in coral areas (e.g., current strength, circulation pattern, the timing and frequency of upwelling, storm frequency) because those processes are strongly driven by water temperature (Siedler et al. 2001; Hoegh-Guldberg et al. 2014; IPCC 2018). Intensification of storms in the tropics will likely cause increasing physical damage to reefs and associated ecosystems such as mangroves and seagrasses (Hoegh-Guldberg et al. 2014). Anthropogenic climate change has so far resulted in decreased ocean productivity, altered food web dynamics, shifting species distributions, reduced abundance of habitat-forming species, and a greater incidence of disease (Hoegh-Guldberg & Bruno, 2010; Hoegh-Guldberg et al. 2014).

In tropical regions like the Indian Ocean and Pacific, SST have warmed 1°C since 1950 higher than the global average 0.7°C ocean warming. The circulation of large gyres, important heat transporters, is likely to be slowed down. The impacts in tropical regions are much less studied than temperate regions and the nature of these changes are not well understood (Yang et al. 2016). Nevertheless, it is logical to assume that considerable alteration of the oceanography might affect function and processes of coral reef ecosystems at the regional and sub-regional scales in the future.

Diseases are an emerging threat for coral reef conservation. Disease outbreaks are predicted to become more prevalent with warming oceans as a result of increased pathogen virulence and/or

host susceptibility (Selig et al. 2006; Harvell et al. 2009, 2019; Bruno et al. 2007). Disease outbreaks can cause significant mortality in coral reefs as evident in the Caribbean (Hughes 1994) and increasingly observed in the Indo-Pacific (Harvell 1999; Bruno et al. 2007; Lamb et al. 2018). Abundance of disease on Australia's Great Barrier Reef increased by as much as 20 fold during and following the high temperatures that caused coral bleaching in 2002 (Willis et al. 2004).

The frequency and severity of diseases seem to be facilitated by high nutrient environments, temperature anomalies, bleaching events and compromised health condition of the corals (Bruno et al. 2003; Miller et al. 2006; Bruno & Selig, 2007). The implications of these factors for management will be discussed in more detail in the following section.

A further climate change-related threat to coral reefs comes from sea level rise. Latest estimates of sea level rise by IPCC range between 44 and 74 cm by the end of the century with projected rises of 3.2 mm year (Hoegh-Guldberg et al. 2014, IPCC 2018). Given the sudden and substantial loss of summer Arctic Ice over the past five years, the rate of sea level is already accelerating based on 25 years of NASA Satellite data (NASA 2018). Sea level rise will vary geographically, due to fluctuations in natural variability and ocean circulation. Rates of sea level rise are three times higher than global average in the Western Pacific and Southeast Asia, for example, and decreasing in many parts of the Eastern Pacific for the period 1993-2012 (Hoegh-Guldberg 2014).

The current rates of coral growth and reef accretion appear to be able to keep up with the present rate of sea level rise and scientists believe that a more likely threat from sea level rise is increased sedimentation due to shore erosion (Buddemeier et al. 2004). A study in Hawaii

indicates that rising sea levels will likely lead to higher suspended sediment concentration, increased erosion and turbidity, and add more stress to the near-shore coral reefs (Ogston & Field 2010). Another study of a 121,000-year old fossil reefs from the northeast Yucatan peninsula, Mexico suggest that corals had trouble with sea level changes that exceeded 30 mm per year (Blanchon et al. 2009), especially if coral growth and calcification had been compromised by thermal stress and ocean acidification. In contrast, a recent study using 40 years monitoring data of shallow reefs in Phuket, Thailand, shows that a rising sea level, currently estimated at ~11 mm per year, has not only promoted coral cover but also has the potential to limit damaging effects of thermally-induced bleaching (Brown et al. 2019). The positive role of rising sea level for future bleaching events needs further investigation.

2.1.4 Interactions among global and local impacts

The collapse of many of the Caribbean reefs in the 1980s is prime evidence of ecological transitions from a coral-dominated system to a fleshy algal-dominant system or other alternative assemblages, a phenomenon that is now observed worldwide and referred to as 'phase-shifts' (Done 1992; Hughes 1994; Hughes et al. 2007; Ledlie et al. 2007). The back-to-back mass coral bleaching during 2016-17 triggered catastrophic loss of coral and a regional-scale shift in the coral assemblage along the 2,300 km length of the Great Barrier Reef (Hughes et al. 2018). As a result, fast-growing *Acropora* corals (staghorn and tubular) suffered an unprecedented die-off and transformed the three-dimensional structure and ecological functioning of around 50% of the world's largest reef (Hughes et al. 2019a). The transformation also caused a collapse in stock recruitment in 2018 with the amount of coral larval declining by 89% compared to historical levels (Hughes et al. 2019b). The new assemblage, characterized by altered community

composition and structure (Nystrom et al. 2008), often leads to biodiversity and structural simplification, and provides fewer ecosystem services (Mora et al. 2016; Nystrom et al. 2008).

Phase-shifts in coral reefs have offered new insight that coral reefs are heterogeneous, fragile and globally stressed ecosystems driven by positive and negative feedbacks as opposed to homogenous, stable, predictable and biologically accommodating systems (Mumby & Steneck 2008; Hoegh-Guldberg et al. 2017; Hughes et al. 2018). In most reefs, the interaction and the combination of multiple disturbances especially overfishing of herbivorous fishes (a top-down process), added nutrients from land-based activities (a bottom-up process), and elevated coral mortality and recruitment failure (from superimposed impacts of climate change, introduced species and emerging diseases) were the cause of persistent phase-shifts, rather than a series of individual short-term disturbances (McClanahan et al. 2002; Roger & Miller 2006; Anthony et al. 2015; Mcleod et al. 2019). The latest five-yearly outlook report by the Great Barrier Reef Marine Park Authority has downgraded overall condition of the reef from 'poor' to 'very poor' and highlighted two key impacts, global warming and water quality due to nutrient and sediment runoff from farming practices (Great Barrier Reef Marine Park Authority 2019).

Multiple synergistic disturbances among local stressors, particularly fishing, pollution and sedimentation, are common major drivers for reef degradation (McClanahan et al. 2002; Rogers & Miller 2006; De'ath et al. 2012). These local factors act synergistically (the sum is greater than its parts) or additively (the sum is equal to its parts) because the system has been shown to respond differently to these factors in isolation. For example, nutrified reef areas that were not fished proved to be less vulnerable to coral-algal phase-shifts than fished areas (McCook 1996; McClanahan & Obura 1997). Growing evidence also suggests that global stressors (e.g.,

increasing sea temperatures and ocean acidification) are likely to interact in a number of ways. In experiments, increasing seawater acidity lowers the thermal bleaching threshold of corals and when the pH was dropped to 7.6 may lead to coral bleaching without a rise in sea temperatures (Hoegh-Guldberg et al. 2017). Similar interactions are possible with respect to sea-level rise. Coral reefs may no longer be able to keep pace with the sea-level change if the combination of high mortalities from mass bleaching and slower coral growth rates continue (Blanchon et al. 2009; Keller et al. 2009).

The key uncertainties of how climate change will affect coral reefs remain in the interaction between local and global drivers (Hoegh-Guldberg et al. 2009, 2014). The prevailing view is that synergies between local stressors and climate impacts are major factors driving coral reef decline and degradation (Bellwood et al. 2004; Hoegh-Guldberg et al.2007; Knowlton & Jackson, 2008). Since many reefs are already threatened by multiple and co-occurring stressors, the addition of climate change impacts may exacerbate negative effects of pollution (Almany et al. 2009), overfishing (Mumby et al. 2006; Jackson et al. 2001; Jackson, 2008) and diseases (Harvell et al. 2002, 2019; Lafferty, Porter & Ford 2004) and move the system beyond its ecological threshold. A study in the Great Barrier Reef showed that reducing the number of herbivorous fish on the reef reduced the recovery rate from mass bleaching by a factor of three (Hughes et al. 2007). A recent study in the island of Bonaire, Dutch Caribbean concluded that maintaining sufficiently high levels of herbivory to control algal abundance can create conditions that facilitate survival and growth in both juvenile and adult corals. As a result, macroalgae declined and both juvenile coral density and total adult coral cover returned to pre-hurricane and bleaching levels within 8-10 years (Steneck et al. 2019).

Nevertheless, some analyses suggest that other forms of stressor interactions such as additive and antagonistic (the sum is less than its parts) are equally likely (Cote & Darling 2010). A study on fishing and climate change impacts in Kenyan reefs observed antagonistic interactions between fishing and climate factors and suggested bleaching to be a dominant stressor of coral loss (Darling, McClanahan & Cote 2010). Consequently, the authors pointed out that controlling fishing alone (e.g. set up MPAs) may not be the key to address climate change impacts. Similarly, a recent review of MPAs and implementation of herbivorous fish protection, argued that such measures have had little empirical effect on improving coral resilience (Bruno et al. 2019). A main reason is that the impacts of local stressors (e.g. pollution and fishing) are often overruled by the much greater effect of ocean warming.

Interestingly, a similar study on fishing and climate in kelp beds in Tasmania resulted in the opposite conclusion, finding a synergistic impact between two stressors and emphasizing the significance of MPAs in restricting fishing impact and increasing ecosystem resilience (Ling et al. 2009). A review of 20 years time series data from the Great Barrier Reef also demonstrated that by conserving and managing biodiversity, MPAs can increase the resilience of coral reef communities to natural disturbances including coral bleaching, coral diseases, Crown-of-thorns starfish (*Acanthaster planci*) outbreaks and storms (Mellin et al. 2016). These studies suggest that interactive effects on contributing stressors may be dependent on both ecological context and magnitude of impact.

A number of adaptive strategies have been proposed to enhance coral reef resilience at the local level such as improving water quality and reducing fishing pressures on key functional groups

(Marshall & Schuttenberg 2006, Steneck et al. 2018). Some underlying mechanisms of coral reef resilience and contributing factors are discussed in the next section.

2.2 Coral reef resilience and climate change: from theory to practice

The resilience of a complex system (e.g. ecosystem or society) generally refers to the capacity of the system to resist and recover from recurrent disturbances or shocks and adapt to change while maintaining key functions and processes (Holling 1973; Nystrom & Folke 2001). In ecology, resilience is the degree of change (resistance) or rate of return to a pre-disturbance state (recovery) of a population or community after major pressure (Chapin et al. 2009). Under this framework, a system that tends to return to the same state after major pressures has high resilience, while one that shifts into another stable alternative state has low resilience. Thus, resilience can be used to describe system stability and response to external disturbances (Ives & Carpenter 2007). Under global climate change and ecological uncertainty, the concept of resilience has gained popularity and become crucial for understanding the complexity and the management of ecosystems (Adger et al. 2005; Anderies, Walker & Kinzig 2006; Palumbi, McLeod & Grünbaum 2008; Chapin et al. 2009; Peterson, Allen & Holling 2010; McLeod at al. 2019). Many researchers have developed and reviewed the application of resilience theory to coral-reef conservation (Nyström, Folke & Moberg 2000; West & Sam 2003; Obura 2005; Hughes et al. 2007; Diaz-Pulido et al. 2009; Obura & Grimsditch 2009; Baskett et al. 2010; Anthony et al. 2015; Norstrom et al. 2016), because it offers an innovative way to consider interactions between humans and the environment that recognises unpredictability and unforeseen ecological responses.

Phase shifts from coral-dominated systems to algae dominant or rubble systems are evidence of a system that has lost its resilience. The reverse from algae to coral is possible but can be slower and more difficult because of reinforcing feedbacks and a tipping point shift, a phenomenon known as hysteresis (Graham et al. 2013). For example, a mature coral might be able to resist a high level of sedimentation, but once coral cover is lost (e.g. from bleaching), juvenile corals are susceptible to much lower levels of sediment (Hughes et al. 2010).

Resilience-based management (RBM) for coral reefs has been developed largely based on the precautionary principle and maintenance of the adaptive capacity of ecosystems to resist and recover from external major threats (Chapin et al. 2009; Anthony et al. 2015; Mcleod et al. 2019). RBM is defined as using knowledge of current and future drivers affecting ecosystem functions to prioritize and implement management actions that enhance system resilience and support ecosystem processes (e.g. recruitment and recovery) (Mcleod et al. 2019). RBM guides proactive decision-making under risk and uncertainty and recognizes that humans are capable of adapting and transforming (Nystrom et al. 2008; Folke 2016). If management actions are not able to maintain resilience, building adaptive capacity for transformation will be necessary for coastal communities (Morecroft et al. 2012). Transformation in coastal communities can be used as conservation strategies, for example, development of alternative livelihoods that reduces human pressures on the reef.

Recent global-scale bleaching events have reduced the time window for reefs to recover from 25-30 years a few decades ago to just 6 years (Hughes et al. 2018). Darling and Cote (2018) proposed that future resilience will need to focus on the ability of corals to resist rather than recover. Identifying these ‘super corals’ with intrinsic resistance, locating good refuges (e.g.

deeper reefs and colder waters) and connecting survivors to serve as sources of adaptation after major bleaching events are becoming priorities for resilience-based management (Darling & Cote 2018; Darling et al. 2019). Key contributing factors of reef resilience and their implications for management are discussed in the following sections.

2.2.1 Coral reef resilience assessment

Coral reef resilience assessments were developed to identify factors that may correlate with resistance and recovery to coral bleaching. West and Salm (2003) identified a list of factors that may correlate with resistance and resilience to coral bleaching. Subsequently, Obura and Grimsditch (2009) under the IUCN Climate Change and Coral Reefs working group (IUCN-CCCR) proposed an operational framework for assessing resilience. The physical and ecological characteristics of coral reefs and local environments that influence the likelihood of corals resisting and/or recovering from disturbances have been referred to as 'resilience indicators'.

Obura and Grimsditch (2009) developed the first comprehensive resilience assessment protocol that included 61 resilience indicators encompassing a wide range of potentially important parameters. The main aspects of this resilience assessment that differs from standard monitoring are more detailed measurement of coral populations (size classes, recruitment, etc.), more detailed measurement of algal heights, fish sampling focused on herbivorous fish, and identification of indicators that affect thermal stress at a local site to assist in reef management (Obura & Grimsditch 2009). However, the large number of indicators to be assessed and measured make surveys resource intensive and costly, and may be both impractical and ineffective (McClanahan et al. 2012).

Maynard et al. (2010) applied a resilience assessment framework in the southern Great Barrier Reef using a sub-set (30) of the indicators recommended within the Obura and Grimsditch (2009) report. The study was the first to assess resilience indicators based on perceived relative importance and the first coral reef resilience assessment to inform management actions; the designation of no-anchoring areas to reduce physical damages (Maynard et al. 2010; Beeden et al. 2014).

McClanahan et al. (2012) further advanced the concept and proposed key resilience indicators to support coral reef management based on scientific evidence and the feasibility of quantifying the factors. Eleven key factors important to resistance and recovery, which are important components of resilience, were identified : 1) Resistant coral species; 2) Temperature variability; 3) Nutrients (pollution); 4) Sedimentation; 5) Coral diversity; 6) Herbivore biomass; 7) Physical human impacts; 8) Coral disease; 9) Macroalgae; 10) Recruitment; and 11) Fishing pressure. The abundance of resistant (heat-tolerant) coral species and past temperature variability was perceived to provide the greatest resistance to climate change, while coral recruitment rates, and macroalgae abundance were most influential in the recovery process (McClanahan et al. 2012).

Anthony et al. (2015) developed a set of guidelines for identifying 'levers' that link to the resilience and vulnerability of the ecosystem, and how and where resilience can be enhanced via management interventions. The study suggested that gradual stressors e.g. pollution, sedimentation, overfishing, ocean warming and acidification are key threats to coral reef resilience by affecting processes underpinning resistance and recovery, while acute stressors e.g. storms, bleaching events, crown-of-thorns starfish outbreaks increase the demand for resilience.

Key steps in operationalizing resilience for adaptive coral reef management[2] under global climate change include:

(1) Identify and manage specific patches of reef where local conditions are likely to result in reduced temperature-related bleaching and mortality, to protect them from direct human impacts.

(2) Enhance the capacity for coral reef recovery by minimizing other direct local stressors and maintaining conditions optimal for larval dispersal and recruitment to damaged sites.

(3) Consider a wide range of management strategies and prioritize which management interventions provide the greatest benefits to supporting reef resilience (West et al. 2003; Anthony et al. 2015; Maynard et al. 2015; Mcleod et al. 2019).

2.2.2 Biodiversity and the role of functional groups

Biodiversity is believed to play an important role in determining resilience through genetic diversity within a species, and species diversity within the systems e.g. (Tilman 1997; Naeem 1998). Implications of this can be found within genetic variation of zooxanthalae that influence coral resistance to mass bleaching (Baker, Glynn & Riegl 2008; Baskett, Gaines & Nisbet 2009;) or coral diversity which respond differently to heat stress (Marshall & Baird, 2000; McClanahan et al. 2004). This characteristic is referred to as response diversity (Stat, Morris & Gates 2008). Species richness and abundance are also usually associated with ecological redundancy (or functional redundancy) meaning that a range of species can play the same ecosystem function

[2] Adaptive management recognizes that management actions create opportunities to learn and improve. The adaptive management cycle is a structured, continual process that provides a basis for robust decision-making in the face of uncertainty through the use of monitoring and learning feedbacks.

and therefore provide a buffer against the risks of environmental stress and the effects of species loss or reduction (Nyström 2006). A number of studies show that diverse functional groups of herbivores can enhance coral recovery (Bellwood et al. 2006; Mumby et al. 2007; Burkepile & Hay 2008; Steneck et al. 2018, 2019). A high diversity of coral habitat types helps to ensure that a wide range of functional groups, due to adaptations to local environmental conditions, are represented within the seascape (Nyström et al. 2008).

In the Philippines, functionally diverse reef-fish communities in MPAs ameliorate coral disease compared to fished areas (Raymundo et al. 2009). Another long-term study in East Africa indicated that well-managed coral reefs showed considerable resilience to climate change by having fast recovery after major bleaching events (McClanahan, Muthiga & Maina 2009).

The importance of biodiversity in enhancing reef resilience is well demonstrated by the critical role of herbivorous fishes in controlling algal growth and ensuring the availability of substrate for coral recruitment after major disturbances, consequently reducing the risk of phase-shifts (Mumby et al. 2007; Ledlie et al. 2007; Green & Bellwood, 2009; Steneck et al. 2019). Insights on how species can play different roles during different ecosystem phases come from 30 months of herbivore exclusion experiments in the Great Barrier Reef after a mass bleaching event. The overgrown seaweed, a clear sign of phase shift, was removed once herbivores were allowed back in (Hughes et al. 2007). However, instead of the usual parrotfish and surgeonfish that are responsible for maintaining low algae abundance, batfish species played a key role in reversing the system back to coral dominant (Bellwood, Hughes & Hoey 2006). This result highlights the importance of identifying critical species and functional groups that can facilitate the recovery process from undesirable regimes (Hughes 2010; Steneck et al. 2018, 2019).

2.2.3 Overfishing and the role of parrotfish

Overfishing is one of the most pressing human impacts on coral reefs (Jackson 2001; Halpern et al. 2015). Within the coral reef ecosystem, parrotfish (Family Labridae) are widely recognised as a key functional group in facilitating the recovery of reefs from recurrent disturbances (Mumby et al. 2006; Hughes et al 2007; Banoldo et al. 2014). Parrotfish are commonly viewed as herbivores, playing an important role in the top-down control of algal communities, however, their unique jaws allow them to feed on almost all coral-reef substratum types (Banaldo et al. 2014). Consequently, parrotfish also play an essential role in a number of key ecological processes on coral reefs, namely, bioerosion, sediment production and transport, provision of space for coral settlement, and predation of live coral colonies (Fig. 1; Bellwood et al. 2004; Banaldo et al 2014).

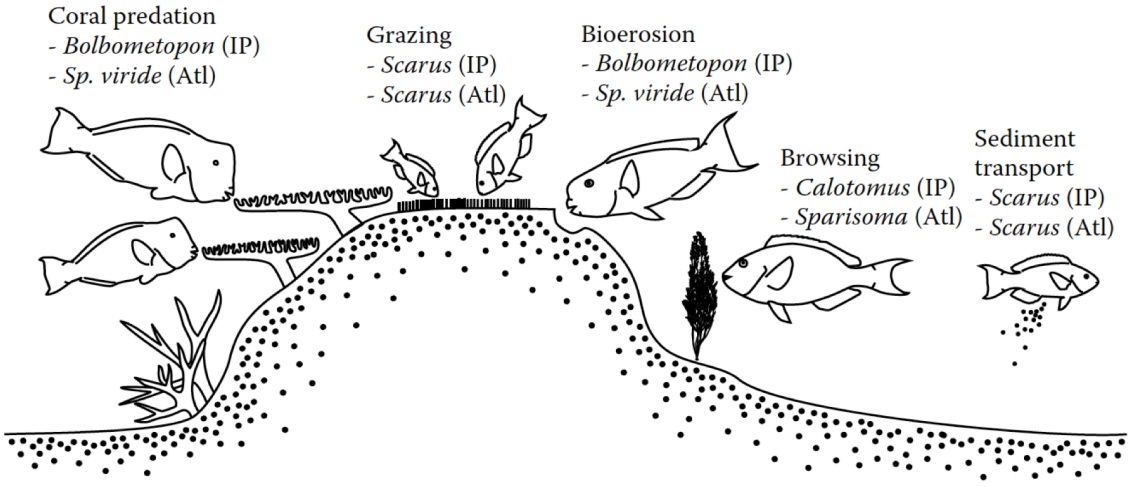


Figure 1. The graphic from Banaldo et al. 2014 represent the primary functional roles of parrotfishes on tropical reefs: bioerosion, grazing (scraping), coral predation, browsing, and sediment transport. The dominant taxa responsible foreach function on tropical reefs in the Atlantic (Atl) and in the Indo- Pacific (IP) are given.

Many studies have shown that coral reefs with severely depleted parrotfish communities are less resilient to human disturbances or natural threats as documented in the Caribbean, the Great Barrier Reef and Seychelles (Hughes 1994; Hughes et al 2007; Ledlie et al. 2007; Cheal et al 2010). Particularly, a number of landmark studies highlight the critical role of parrotfish in keeping ecological systems intact and also suggest that reefs are highly sensitive to parrotfish exploitation (Mumby et al 2007, Jackson et al 2014). One major experiment in the Great Barrier Reef demonstrated that exclusion of large herbivorous fishes like parrotfish resulted in a dramatic expansion of macroalgae, which suppressed recruitment, fecundity and survival of corals (Hughes et al. 2007). Once total herbivore fish biomass fell below a threshold, many reef sites in the Indian Ocean were associated with less coral and more algae (McClanahan et al. 2011). Conserving herbivorous fish is hence a top management priority to enhance coral reef

resilience in the face of climate change where mass bleaching events are expected to become more severe and frequent (Hughes et al. 2017).

Previous studies demonstrate the role of parrotfish in suppressing algal cover (Williams & Polunin 2001; Burkepile & Hay 2006; Mumby et al. 2006; Burkepile et al. 2009) and reducing competition for space, chemical inhibition, disease transmission, and overgrowth of corals by macroalgae (Nugues et al. 2004; Smith et al. 2006; Hughes et al. 2007; Dixson et al. 2014), thus playing a critical role in recovery of coral population after major disturbances. Bruno et al. (2019), however, argued that the protection of herbivorous fish (especially parrotfish) has had no significant effect on coral resilience especially on coral cover loss in 18 studies that measured coral resilience in 66 MPAs and 89 unprotected sites. Possible explanations could be that the metadata analysis could not detect all relevant parameters in term of resilience and the effects of localized stressors are swamped by major bleaching event in those areas. Most recently, a 15 year case study from Bonaire, Caribbean, (Steneck et al. 2019) reaffirmed the importance of protecting parrotfish biomass to enhance coral reef resilience after the major bleaching event in 2010. Herbivorous parrotfish in Bonaire had been declining in abundance but stabilized around 2010, the year fishing for parrotfish was banned. The average parrotfish biomass from 2010 to 2017 increased two-fold compared to other coral reefs of the Eastern Caribbean. During the same period, macroalgae declined and both juvenile coral density and total adult coral cover returned to pre-hurricane and bleaching levels. Protecting parrotfish and restricting fishing are still key management actions in promoting reef resilience and recommended and supported by many coral scientists, NGOs, governments and the International Coral Reef Initiatives (ICRS 2019).

Parrotfish are often a key component of artisanal fisheries throughout much of their range, providing a cheap source of protein for local people (Wing & Wing 2001; Aswani & Hamilton 2004; Craig et al. 2008; McClanahan & Cinner 2008; Cinner et al. 2009). In recent years, there has been an increase in fishing pressure on parrotfish due to the depletion of other commercial reef fisheries, improved fishing techniques and commercialization (Brewer et al. 2009; Aswani & Sabetian 2010). Improved storage facilities and the capacity to transport products internationally by air have increased the scale of exploitation and made parrotfish a global commodity (Sadovy 2001; Sadovy & Vincent 2002; Hughes et al. 2003; Sadovy et al. 2003; Bellwood et al. 2004). Herbivorous fish are now a component of the international reef fish trade (Bellwood et al. 2004) and parrotfish can be found in supermarkets in Sweden (**Figure 2a**; Thyresson et al. 2011), Hong Kong (See **Figure 2b**; WildAid 2017) and Canada (**Figure 2c**; Author 2018). Increasing market demand has made parrotfish a target species for cross border commercial fishery even in remote reef areas in Myanmar (Dearden 2018 **Figure 3a**). Bringing in new species is an often-used marketing strategy to boost sales for seafood supermarkets (Blank 2018). Commercial sales of parrotfish will continue to expand due to market pressures despite what we know about protecting this key species to enhance reef resilience.

Figure 2. Parrotfish can now be found in supermarkets in Sweden (2a left) Hong Kong (2b middle) and Canada (2c right) driving market demand for the species in tropical reefs.

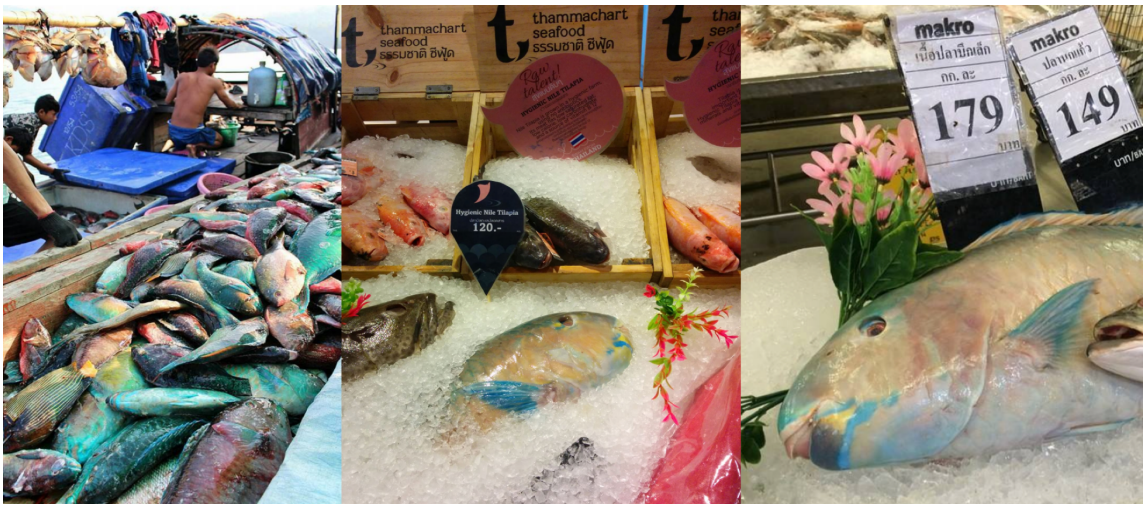


Figure 3. Parrotfish are targeted for cross border trade even in remote reefs in Myanmar (3a left) and was found in at least five major retailers in Thailand in early 2014 (3b middle) Villa Supermarket, (3c right) Makro.

2.2.4 Local environmental factors

Studies of coral bleaching patterns infer that some local environmental factors contribute to the system's resistance to major stress (West & Salm 2003; Marshall & Schuttenberg 2006). Identifying inherently less vulnerable areas to climate change based on these factors, regardless of their conservation status, is critical for building resilience in the reef system (McClanahan et al 2009; Cote & Darling 2010). When the magnitude of disturbances is far greater than ecological thresholds (e.g. severe mass bleaching event) the effects on local reef areas in both pristine (more diverse/protected) and impacted (less diverse/unprotected) reefs may be indiscriminate. For example, the first mass coral bleaching in north western Hawaii Islands (Aeby et al. 2003) and the 2010 severe bleaching in the Andaman Sea of Thailand (Phongsuwan & Changsaeng 2012; Phongsuwan et al. 2013) affected coral inside and outside protected area indiscriminately.

Environmental factors that support coral resistance and recovery processes include those that: 1) *reduce temperature stress* e.g. cooling by upwelling, proximity to deep water, strong currents (Goreau 2000, Berkelmans 2004, Wooldridge & Done 2004); 2) *decrease light stress* e.g. shading from topography, screening from suspended sediments and organic material, natural turbidity, cloudy weather (Goreau et al. 1998; Mumby et al. 2001); 3) *build stress-tolerant communities* (i.e. coral communities that are regularly exposed to geographical and environmental stress) e.g. those exposed during low tides or naturally warm water (Done et al. 2004, van Oppen, Mieog, Sánchez & Fabricius, 2005;); and 4) *enhance recovery potential* e.g. high herbivore populations, low level of disease (Marshall & Schuttenberg 2006; Salm, Done & McLeod 2006).

For example, many coral reefs found in naturally turbid waters or exposed at low tides proved to be important refuges and source of recovery in the 1998 mass bleaching event (Goreau et al. 2000), and should be incorporated and better represented in the protected area system (McLeod et al. 2009). Some reef areas in the Indo-Pacific showed no thermal anomalies greater than 1 C° during a 17 year analysis (1985-2001), potentially due to a combination of upwelling and strong current (Hansen, Biringer & Hoffman 2003).

Together with environmental factors, past bleaching records can be examined to reveal possible responses of reef areas when exposed to major threats. The areas that have either avoided massive mortality or recovered quickly from severe mass bleaching indicate high levels of resilience and should be targeted for protection (Salm, Done & McLeod 2006).

Current methods to identify resilient areas maximise the use of geographic information systems (GIS) and remote sensing technology to incorporate different environmental parameters with climate models to assess the susceptibility of the reef areas to climate change (Maina et al. 2008; Eakin et al. 2010; Hedley et al. 2016). Such models can be further integrated with social adaptive capacity and ecological parameters to identify appropriate conservation strategies (McClanahan et al. 2008, 2009; Cinner et al. 2014;). The identification of resilient areas is now being applied as part of ecosystem management strategies in coral reef countries worldwide (e.g., Palau, Belize, Papua New Guinea, the Maldives and the coral triangle countries) (Marshall & Schuttenberg, 2006; IUCN-WCPA, 2008; Maynard et al. 2015; McLeod et al. 2019)

2.2.5 Connectivity

A key spatial factor for coral reef resilience is connectivity or the degree, to which local populations in the system are connected between marine habitats (Nyström & Folke 2001; Jones et al. 2009; Hock et al. 2017). Many coral reef species, including broadcast spawning corals, invertebrates, and most reef fishes, are relatively sedentary as adults, but have a pelagic larval phase and release great numbers of eggs and young into the open ocean that can potentially travel vast distances (Jones et al. 2009). Thus connectivity occurs via larval dispersal, and also by the movement of juvenile and adult organisms of more mobile species (Lundberg & Moberg 2003; Sale et al. 2005). Connectivity plays a key role in coral recovery processes following perturbation by ensuring larval exchange and replenishment of biodiversity from other distant populations (Roberts, 1997), which consequently help determine how coral reef populations persist, how they respond to natural and human disturbances, and how they can be managed through a system of MPAs (Almany et al. 2009).

The strength of connectivity is influenced by many factors including the abundance and fecundity of source populations, ocean currents, the natural patterns of larval dispersal, larval behavior, larval duration, and predation and other disturbances (Jones et al. 2009; Salm, Done & McLeod, 2006). Emerging knowledge on connectivity suggests that: 1) larval recruitment occurs on a smaller scale than previously thought (Jones et al. 2009), 2) inter-archipelagic connectivity is limited (Jone, Planes & Thorrold 2005; Almany et al. 2007), 3) short-lived species may require more regular recruitment from nearby connected sites (Jones et al. 2009), and 4) long-term monitoring is a critical component to understanding population dynamics (Cowen et al. 2000). This realization has emphasised the critical need for effective management at the local scale.

Current recommendations on minimum spacing to ensure larval connectivity among MPAs in networks range between 10 to 20 km (Shanks, Grantham & Carr 2003; Mora et al. 2006).

Connectivity in reef ecosystems also depends on the condition of intact and healthy associated habitats such as mangroves and seagrasses since those ecosystems play essential roles as nursery grounds and sediment filters (Nagelkerken et al. 2000; Mumby et al. 2004; Rogers 2009). A system-wide approach to protect entire bioregions or seascapes including all the critical habitat types is strongly advised where possible (Mumby & Harborne 2006; Green et al. 2009; McLeod et al. 2019).

Hock et al. (2017) revealed that around 100 reefs of Australia's Great Barrier Reef, or around 3% are ideal to facilitate recovery of disturbed areas because they: (1) are highly connected by ocean currents to the wider reef network, (2) have a relatively low risk of exposure to disturbances, and (3) have an ability to promote recovery of desirable species. It is estimated that these 'robust source reefs' may supply 47% of the ecosystem in a single dispersal event because of the interaction between oceanographic conditions and geographic location. Identifying these source reefs will become increasingly crucial as the frequency of disturbances accelerates under climate change.

Our understanding about connectivity is expanding rapidly in recent years due to improving study techniques and research interest (Jones et al. 2009; Hock et al. 2017). However there is still much to learn about underlying mechanisms and to identify specific measures for effective protection of connectivity (McCook et al. 2009). Guidelines for incorporating connectivity into conservation management under uncertainty have been developed and include: implementing a precautionary approach, considering the risk-spreading principle by representation and

replication, the networking of MPAs, applying comprehensive and integrative regional planning beyond the MPAs (McCook et al. 2009; Anthony et al. 2015). Many of these principles are not limited to connectivity and can be applied to reef conservation management as a whole and will be discussed further in section 2.3.

2.3 Conserving coral reefs in a changing climate

Climate change impacts on coral reefs have been studied for over 20 years through mass bleaching phenomena and more recently ocean acidification. The most important action to save coral reefs today remains in carbon emission reduction because if no action is taken to address the current trend in carbon emission rates (Hoegh-Guldberg et al. 2014; IPCC 2018), it is likely that most coral reefs around the world are committed to an irreversible decline under extreme climate conditions (Veron et al. 2009; Hoegh-Guldberg et al. 2010; Hughes et al. 2018;). The consequences of ecosystem collapse are ecologically, economically and socially paramount across multiple scales and such changes will unlikely be confined to just the coral reefs but the state of the world.

Fundamentally, global climate change and key local stressors, such as overfishing and runoff from land, are not separate issues and are indicative of cumulative human actions from centuries ago. These stressors are highly interactive in social-ecological systems and need to be addressed simultaneously. Today coral reef ecosystems are already changing, degrading in most cases, and yet local and proactive interventions have proven to be useful in helping build coral reef resilience. In the following section, conservation strategies that are centred on MPAs and the resilience framework to address coral reefs and the climate change challenge, are discussed.

2.3.1 Using Marine Protected Areas to enhance ecosystem resilience

Protected areas are cornerstones of most conservation strategies (Soule 1991; Stolton & Dudley 2010; UNEP-WCMC, IUCN & NGS 2018) because they are one of the most effective tools for curbing biodiversity loss and over-exploitation of natural resources (Dudley et al. 2010; Sala & Giakoumi 2018). Similarly, MPAs are the most widespread management strategy employed to protect coral reefs and enhance marine ecosystem resilience (Mumby & Harborne 2010; Micheli et al. 2012; Mellin et al. 2016; Steneck et al. 2018) When appropriately planned and well managed, MPAs produce long-lasting and often rapid increases in the abundance, diversity and productivity of marine organisms (Halpern & Warner 2002; Acala et al. 2005; Russ et al. 2008). A global analysis of fully protected MPAs, often referred to as marine reserves, showed significant increase in biomass (466%), density (166%), size (28%) and richness (21%) of marine organisms within the protected areas (Lester et al. 2009). Specifically, MPAs have proven effective in preventing coral loss (Selig & Bruno 2010), mitigate coral disease (Raymundo et al. 2009), producing significant 'spill over' effects to nearby fisheries (Alcala et al. 2005; Halpern et al. 2010), and helping to alleviate poverty in some communities by fostering sustainable livelihoods (Leisher, Van Beukering & Scherl 2006).

Effective MPAs require good design and implementation. There are numerous research studies outlining MPA design criteria, including recommendations on MPA size, shape, spacing, selection criteria and management (Roberts et al. 2003a, 2003b; Shanks et al. 2003; Palumbi et al. 2004; Edgar et al. 2014; Anthony et al. 2015; Gill et al. 2017;). Traditionally, however, MPAs did not specifically address the threats posed by climate change, such as coral bleaching (Salm & Coles 2001). In recent years, this has changed and MPAs are being increasingly promoted as a potential tool to address the impacts of climate change through increasing system resilience (Salm et al. 2006, 2009; Mellin et al. 2016; Roberts et al. 2017)

Drawing from experiences and recommendations from around the world, McLeod *et al.* (2019) incorporated MPA design criteria with resilience-building principles, and proposed guidelines for developing resilient MPAs to address the impact of climate change (See **Table 1**). The recommendations were based on the precautionary approach and best design and management practices. Four key principles for building resilience into MPA design are: 1) Representation and replication: ensuring full representation of all key habitat types in the bioregion and reducing the risks of localised catastrophes by replicating a range of reef types and related habitats, 2) Protecting critical areas or refugia: giving maximum protection to the areas identified as resilient or critically important so they can serve as a source of recovery, 3) Connectivity: creating a best scenario for recovery after major disturbance based on ocean currents, larval dispersal and other known connectivity factors, and 4) Effective management: actively manage local stressors to optimise coral reef conditions so that they may resist and recover better from major disturbances.

This approach is timely and appropriate as it incorporates climate change impacts into planning (Hansen et al. 2010) and is continually building on existing knowledge and scientific evidence about MPAs. By adopting a resilience approach, the importance of evaluating management effectiveness is reinforced (Pomeroy, Parks & Watson 2004; Hockings et al. 2006), and conservation actions are made more proactive by improving local environments effectively and taking future threats into consideration (Chapin et al. 2010). To date, discussions on resilience-based management have been centred around the issues of resilience indicators, management priorities and broader management interventions. Based on ecological and spatial factors, a number of reviews recommend that resilience indicators in coral reefs should include high periodic recruitment, diverse and disease-free corals, a range of coral colony sizes and ages

(suggesting persistence and recruitment over time), and robust populations of herbivorous fishes (Nyström et al. 2008; McLeod et al. 2009, 2019). These new metrics imply that coral cover alone is not a reliable indicator for coral reef resilience. Monitoring effort should therefore focus on recruitment processes as well as monitoring critical functional groups (Bellwood 2006; Hughes et al. 2007; Green & Bellwood 2009), because a healthy recovering reef can have substantially less coral than one that is degraded (e.g. Caribbean reefs in the 1980s (Hughes, 1994). A framework for assessing resilience by selecting relevant resilience indicators from the literature and implementing collaborative selection processes (weighting score and ranking) has been developed in the southern Great Barrier Reef (Maynard et al. 2010). This assessment framework can potentially identify the most beneficial local actions both inside and outside MPAs in a participatory manner and build support among local communities and stakeholders for management responses to climate change.

The intuitive prediction that high diversity can serve as a resilience indicator to climate change was supported by a quantitative framework using data from empirical studies conducted worldwide (Baskett et al. 2010). The study suggests three priorities for conservation management of coral reefs: 1) Protection of diverse coral communities with presence, but not necessarily higher abundance, of thermally tolerant coral species and symbiont types, 2) Mitigation of additional human impacts that affect coral-macroalgal competition, coral juveniles and coral survivorship, and 3) Protection of connectivity and naturally resilient areas aided by oceanographic features. Achieving these priorities demands scaling-up efforts by creating a network of MPAs and a comprehensive management approach that essentially goes beyond

MPA boundaries (Pandolfi et al. 2003; Bellwood et al. 2004; IUCN-WCPA, 2008; Anthony et al. 2015).

Table 1. General recommendations for developing resilient MPA network design (from IUCN-WCPA, 2008 and McLeod *et al.* 2009)

Category	Guidelines
Size	MPAs should be a minimum of 10–20 km in diameter to be large enough to protect the full range of marine habitat types and the ecological processes on which they depend and to accommodate self-seeding by short distance dispersers.
Shape	Simple shapes should be used, such as squares or rectangles, rather than elongated or convoluted ones, to minimize edge effects while maximizing interior protected area.
Risk-spreading principles	*Representation* protect at least 20–30% of each habitat type.
	Replication protect at least three examples of each marine habitat type.
	Spreading: ensure that replicates are spread out to reduce the chances they will all be affected by the same disturbance event.
Critical areas	Protect critical areas that are biologically or ecologically important, such as nursery grounds, spawning aggregations, and areas of high species diversity. Protect critical areas that are most likely to survive the threat of climate change (e.g. areas that are naturally more resilient to coral bleaching;
Connectivity	● Take biological patterns of connectivity into account to ensure MPA networks are mutually replenishing, to facilitate recovery after disturbance. MPAs should be spaced a maximum distance of 15–20 km apart to allow for replenishment via larval dispersal. ● Take connectivity among habitat types into account by protecting adjacent areas of coral reefs, seagrass beds, and mangroves. ● Model future connectivity patterns to identify potential new coral reef substrates, so that measures can be taken to protect these areas now, and accommodate expansion of coral distribution to higher latitudes.
Effective management	● Manage human stressors such as fishing and inputs of nutrients, sediments, and pollutants within MPAs. ● Improve water quality by raising awareness of adverse effects of land-based activities on marine environments, implementing integrated coastal and watershed management. ● Manage functional species groups necessary to maintaining the health of reefs and other ecosystem.

2.3.2 Scaling up management efforts with Marine Protected Areas networks

Effective MPAs are one of the most hopeful solutions for conserving coral reefs and yet, only 1.4% of the world's roughly 527,072 km^2 of coral reefs are designated in areas where no extraction is permitted. In addition, less than 0.1% of these areas actually received full protection and are at low risk from threats outside (e.g., land-based pollution and coastal development) (Mora et al. 2006; Sala & Giakoumi 2018; UNEP-WCMC, IUCN & NGS 2018). Even though the number of established MPAs is increasing rapidly, many of them are of small size where long-term effectiveness appears limited (Week et al. 2010; Lubchenco et al. 2015)

Since the 5th World Park Congress in 2003, there has been a policy campaign to create and expand MPA networks globally to increase the areas of marine protection that amount to at least 20-30% of each habitat type to ensure sustainability of biodiversity conservation and ecosystem services (IUCN-WCPA, 2014). Well-designed MPA networks can improve connectivity between local populations and major habitats as well as overall ecosystem resilience by spreading the risk of localised catastrophes (Palumbi, 2004; IUCN-WCPA, 2014).

Clearly, there is an urgent need to expand the areas of protection for coral reefs but economic, social and political constraints make it impractical, if not impossible, in a human-dominated world to create a single large MPA of sufficient size to support viable populations of all species. Establishing a network of several moderately-sized MPAs with multiple-use zones can potentially help achieve conservation goals beyond what individual MPAs can, and with moderate socio-economic cost (Roberts et al. 2001; Christie, White & Deguit 2002; Hamilton, Cinner et al. 2012; Potuku & Montambault 2012). Exceptions to this are several recently created super large MPAs (over 1,000,000 km^2) that are mostly free of human settlement e.g. Ross Sea

Region Marine Protected Area (2,060,058 km^2) in Antarctic, Cook Islands Marine Park (1,981,965 km^2) in central Pacific ocean, Papahanaumokuakea Marine National Monument (1,508,870 km^2) or Northweatern Hawaii Island, and Natural Park of the Coral Sea (1,292,643 km^2) in New Caledonia (UNEP-WCMC & IUCN 2019). An assessment from these relatively pristine reefs observed high resilience as indicated by high coral recruitments, low disease prevalence and healthy top predators (Sandin et al. 2008; Ferretti et al. 2018; White et al. 2018; Letessier et al. 2019). These low human impacted areas could serve as important and rigorous baselines of pristine conditions for coral reef conservation elsewhere.

The rezoning process of the Great Barrier Reef Marine Park Authority (GBRMPA) is arguably the most well known case of MPA network design. The new zoning, guided by biophysical principles and socio-economic cost, has increased the level of protection within no-take areas substantially from less than 5% to 33% (Fernandes et al. 2005). Rapid increases in fish numbers within 1.5-2 years following the creation of new no-take areas have been observed (Russ et al. 2008) and reaffirm the efficacy of this approach. At one point, GBRMPA was held as a role model for establishing a large, ecologically comprehensive, socially accepted and politically successful MPA network. Several factors were considered key to the success of this effort, for example, focusing initial communication on the problems (i.e. overfishing, land-based pollution, risks and uncertainty from climate change) needing to be addressed, applying precautionary principles, using independent experts, facilitating extensive participatory consultations and early input from stakeholders, developing high-level support, building on existing MPAs that encompassed much of the ecosystem and addressing issues related to displacement of neighbouring communities (Fernandes et al. 2005; Milin et al. 2016). These factors are important

lessons learned for developing a large MPA network elsewhere. Regardless of recent mass coral bleaching events, GBRMPA has continued to play a key role in advancing knowledge on this front (Fernandes et al. 2010; McLeod et al. 2012; Maynard et al. 2016; Day et al. 2019).

Another major advancement exemplified by the GBRMPA rezoning process is the practical use of systematic conservation planning (Margules & Pressey 2000; Harris et al. 2019) with decision support software to create optimal MPA networks. The software, in this case, Marxan, allows multiple sets of spatial data on biophysical characteristics and socio-economic costs to be considered simultaneously and efficiently, and to derive various optimal options for no-take area designation (Ball & Possingham, 2000; McDonnell, Possingham, Ball & Cousins, 2002). Establishing transparent selection criteria and clear graphic displays of multiple MPA design options allows more room for stakeholder input and negotiation during consultation processes. The use of this technology fosters participation, collaboration and effective decision-making based on science. In more data-poor areas of the world, this comprehensive approach can still be useful in identifying gaps of knowledge, guiding research and monitoring efforts. Decisions on conservation management still need to be made regardless of data availability. A resilience-based approach coupled with systematic planning that builds on best practices elsewhere can and will help minimise risks of bad management decisions in many coral countries under a climate change regime.

2.3.3 Large scale marine spatial planning: towards a more holistic approach

Even though MPAs play key roles for biodiversity conservation and produce multiple benefits, they cannot be viewed as a panacea for all threats to the ocean ecosystems. Many of the threats

originate outside MPA boundaries, beyond management agency jurisdiction and are often intertwined with larger development objectives that cannot simply be addressed with any particular extraction control (Lubchenco et al. 2003). In the real world, many MPAs are poorly designed and inadequately managed. This is particularly true in developing countries where technical expertise and resources are scarce (Agardy et al. 2011, 2016)

Resource managers need to be mindful about the shortcomings of MPAs because management failures could result in negative consequences including wasted resources, scepticism about MPAs and most importantly lost opportunities (Agardy, di Sciara & Christie, 2011). Agardy *et al.* (2011) outline five categories of risks inherent with poorly planned and poorly implemented MPAs including MPAs that are 1) Too small, poorly designed and ecologically insufficient, 2) Inappropriately planned and managed, 3) Failed due to degradation of unprotected surrounding ecosystems 4) Do more harm because of displacement and unintended consequence of management and 5) Creating the illusion of protection.

To address such shortcomings, a number of studies have suggested a more comprehensive, integrative, coordinated management framework to be used in conjunction with MPAs for large marine and coastal areas (Roberts et al. 2006; Halpern, Lester & McLeod, 2010; Anthony et al. 2015; McLeod et al. 2019). These integrated management frameworks include marine spatial planning, ocean zoning, ecosystem-based management and integrated coastal zone management. The scope and focus of these frameworks are sometimes similar and overlap and should be applied on a complementary basis according to the context. Comprehensive guiding ecological principles have been developed for ecosystem-based marine spatial planning with emphasis on maintaining or restoring: native species diversity, habitat diversity and heterogeneity, key

species, and connectivity (Foley et al. 2010; Hock et al. 2017). Two additional guidelines are the need to account for context and uncertainty that should be used in concert with socio-economic principles and governance in the planning process.

Essentially, these system-level analytical tools aim to capture the complexity, interconnectedness and interplay between sustaining long-term ecosystem health and supporting human well-being by synthesising information on ecological functions, ecosystem services, uses and values and the current threats and potential threats in the future. management of many locations will often have multiple goals, and a key aspect of these tools is to assess the necessary tradeoffs (Halpern et al. 2010). Accountability and adaptive management, where the results of intervention are continually monitored and evaluated to provide feedback into current management regimes, are crucial components of these platforms. Adaptive management enables a flexible and timely decision structure based on new information and lessons learned from previous interventions.

A global analysis on the contribution of MPAs to achieving ecosystem-based management goals revealed large coastal and marine areas where MPAs can play a major role in reducing cumulative impacts and improving overall ecosystem integrity (Halpern, Lester & McLeod 2010; Roberts et al. 2017; Sala & Giakoumi 2018). At the same time, the study highlighted the limitations of MPAs as a single tool to achieve comprehensive and integrated management at a broader scale. Current large-scale marine ecosystem projects such as the Coral Triangle Initiative (CTI, 2010), the Bay of Bengal Large Marine Ecosystem program (BOBLME, 2014) and country-level ecosystem-based management like the long-term sustainable fisheries management

plan in the Philippines and Thailand (DoF, 2018) are indicative of the current trend that could make coral reefs and marine conservation in general more holistic.

2.3.4 Role of social media in conservation science

Social media have fundamentally transformed the way that people engage, communicate ideas and information. Traditional media outlets such as newspapers, magazines, television and radio used to be a one-way flow of information. The rise of social media has allowed an interactive two-way sharing of ideas using the internet and online communities (Thaler et al. 2012). Scientists are encouraged to use the power of social media to fundamentally speed up the pace at which they are sharing knowledge both within scientific communities and with the general public (Darling et al. 2013).

Social media data have increasingly been used in conservation science including species distribution (Stafford et al. 2010, Barve 2014); ecosystem services mapping (Richards & Friess 2015), conservation marketing and education (Wood et al. 2013; Roberge 2014); management (Barry 2014) and conservation and communication (Papworth et al. 2015). Minin et al. (2015) suggested that social media data could be used to learn more about the spatio-temporal patterns, values, and activities related to biodiversity conservation of different groups of people, in order to identify both threats to biodiversity and opportunities for conservation.

Social media allows people to share, co-create and rate online content. Social media is now instrumental for conservation organizations and scientists to reach audiences, raise public awareness and positively influence civic participation (Papworth et al. 2015). Public awareness is often a crucial first step toward policy change and management interventions because societal

values determine whether particular interventions gain support (Brown et al. 2010). In the time of the climate crisis, scientists have a moral obligation to communicate more with the public to inform them about scientific facts and promote beneficial behavior (Ripple et al. 2019).

In 2014, there was an emerging problem of the commercial sale of parrotfish in major retailers in Thailand. Well-known supermarkets in the country started to have parrotfish on sale. This species is not protected and it is not illegal to sell or buy parrotfish. To counter this a public campaign was launched to address this potential problem in order to maintain coral reef resilience.

In Thailand, fast internet access is almost universal and is expected that by 2020 about 84 per cent of the Thai population or 59 million people will have access to the Internet (Digital Global 2018). Currently, Thailand ranks in the world's top 10 for social media usage with 49 million Facebook users, 13.6 million Instagram users, and 12 million Twitter users (BKK Post 2018). Bangkok alone has 24 million Facebook users, the largest number of active users in the world's cities (Facebook 2018). Social media especially Facebook thus could be used as a channel to communicate with the public and create an enabling environment for changing public opinion and policies to address the parrotfish challenge.

The Chapter 3 will describe the context of Thailand's Andaman MPAs and different drivers affecting coral reef vulnerabilities and the sustainability of marine resources.

Chapter 3

Marine Protected Areas in the Andaman Coast of Thailand: Study Sites

The Andaman coast of Thailand, also known as the Andaman Bioregion (Figure 4), extends about 740 km from the border with Myanmar at the north to Malaysia at the south and covers a marine area of 112,498.9 km^2 (BOBLME 2011). This marine area supports some of the most abundant and diverse ecosystems in the world. Extremely high marine diversity results from the mixing of the north Indian Ocean and Western Pacific/Indonesian biotas (DNP 2018). The predominant ecosystems along the coast include mangrove forests, seagrass beds and fringing coral reefs and the bioregion is home to many threatened species such as dugong, several other marine mammal species (l 25 species), and five species of sea turtles including the only known nesting site for Leatherback turtles on the north-eastern margin of the Indian Ocean (DMCR 2017, 2018).

The Thai government has invested a significant amount of effort in establishing Marine Protected Areas (MPAs) and the management of the marine resources with at least 20 MPAs on the Andaman coast (**Appendix I**) (BOBLME 2011, DNP 2018). The Andaman MPAs (**Figure 4**) consist of more than 280 islands and 3,845 km^2 of marine area and 1,535 km^2 of coastal wetlands, forests and peat swamps along the six provinces of Ranong, Phang Nga, Phuket, Krabi, Trang and Satun (DNP 2018).

There are more than 240 species of hard corals found on the Andaman coast with total coverage estimated at 78 km^2 of which 62% is under the protection of MPAs (DMCR 2018). Mangrove coverage along the Andaman coastline is approximately 2,047.62 km^2 of which about 20% is

inside the MPAs (DMCR 2018). Sea grass bed coverage is about 95.51 km^2 of which about 39% is within the boundaries of MPAs (DMCR 2018).

Tourism is the most important economic activity in the region with annual revenue of more than 300 billion THB (USD 10 billion) in 2015 or about 25.59% of total regional revenue followed by agriculture and fisheries 19.15%, logistic 16.59%, merchandise 7.59% and industry 4.54% (Andaman Province Cluster Development Plan 2018-2021). There has been a steady increase in the number of visitors to the Andaman coast each year from 19 million in 2013 to 25 million in 2015 to 30 million in 2018 with a 3:5 ratio for Thai and Foreign visitors (OSM Andaman 2018). This growth has put tremendous pressures on marine resources as a result of continued unplanned coastal development. Many of the reefs and MPAs see very high levels of reef-based tourism activities particularly the southern provinces of Phuket, Phang-nga, Krabi and increasingly Satun (BOBLME 2011, OSM Andaman 2018).

Marine fisheries in Thailand contribute significantly to GDP and were valued at around 50 billion THB (USD 1.66 billion) in 2014-15. The fisheries of the Andaman Sea account for about one third of this total and were valued at 16 billion THB (USD 0.53 billion) (NESDB 2016). Declines in fishery resources along this coast, primarily caused by overfishing and the use of destructive fishing gear such as trawlers and push-nets in coral reef and sea grass areas are of growing concern (BOBLME 2011). As a result of this decline a number of fishermen have converted their fishing boats into touring boats as well as moving away from small-scale fisheries to other sectors completely (Bennett & Dearden 2014).

In the Andaman Nature Reserve world heritage nomination document, the Andaman Bioregion is grouped into 6 ecoregions based on geological and biotic characteristics (**Figure 4):** 1) The

Northern Mangrove and Inshore Island, 2) The Northern Offshore Islands, 3) The Central Beaches and Coastal Gallery Forests, 4) Greater Ao Phang-nga, 5) The Southern Coastal Forests, and 6) The Southern Offshore Islands. These ecoregions are represented by different groups of MPAs and display characteristics of geological, faunal and floral features within the large marine ecosystem which extends northward to the Myeik Archipelago in Myanmar and southward to the Langkawi Archipelago in Malaysia (DNP 2018). For example, the Northern Offshore islands and Southern Offshore islands are separated by distinct oceanic biota of the eastern Indian Ocean and the Indonesian Through-flow from the Pacific. The Northern Mangrove and Inshore Island and the Central Beaches and Coastal Gallery Forest are categorized by their dominant ecosystem (i.e. Mangrove and Beach Forest). The Ecoregion approach has provided a strong basis for further development of ecosystem-based management and an MPA network. This Chapter introduces the history, current status and bio-physical overview of the Andaman bioregions, including the legislation and governance as well as threats and challenges.

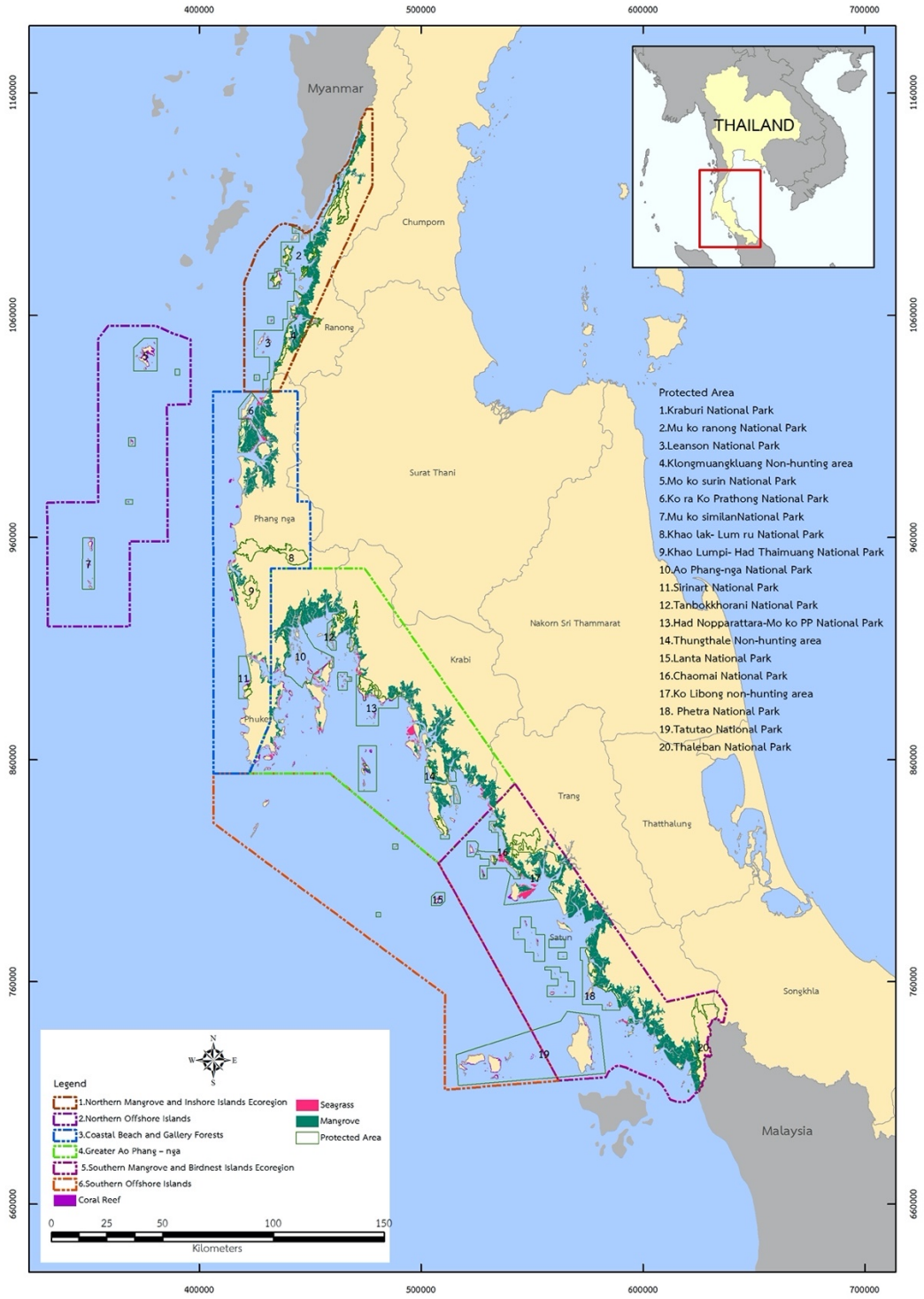


Figure 4. Map of the six Andaman ecoregions and Marine Protected Areas

3.1 History and current status

The history of protected areas in Thailand dates back to the 1960s following the enactment of the Wild Animals Reservation and Protection Act (1960) and the National Park Act (1961) that aims to preserve and protect threatened species and natural resources in the landscape and seascape. In 1962, Khao Yai National Park was gazetted by the Royal Forest Department (RFD) as Thailand's first protected area. Subsequently, in 1966, Khao Sam Roi Yot National Park in Prachuap Khiri Khan was designated as the fourth National Park and the first marine and coastal protected area or marine protected area (MPA) in the country.

Most MPAs are established as national parks and managed under the National Park Office within the Department of National Parks, Wildlife and Plant Conservation (DNP). In practice, MPA's share the management procedures, overlapping and ambiguous jurisdictions and challenges between the authorities responsible for parks, fisheries, tourism and transportation (BOBLME 2011). MPA legislation and governance arrangements are discussed in the following sections.

The overall figures on levels of existing and proposed marine protection for Thailand has yet to be verified as there are many questions regarding the interpretation of protection and what International Union for Conservation of Nature (IUCN) would consider an MPA under its definition as referred in section 2.3.

Thailand has committed to the Convention on Biological Diversity (CBD)'s Aichi Target 11 which states that "*By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically*

representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes" (CBD 2013).

While Thailand has exceeded the CBD target of at least 17% of terrestrial areas protected, there has been much confusion over the coverage of coastal and marine protected areas. According to the United Nations Convention on the Law of the Sea (UNCLOS), Thailand's maritime area under Exclusive Economic Zone (EEZ) is 323,488 km^2 (MOFA, 1982). The DMCR (2010) manual on Marine Protected Areas in Thailand claims a figure of 79,757 km^2 or 24.65% of Thailand's EEZ combining 9 types of protected area including Fisheries Management Zones which account for over 52,000 km^2 (Nateewattana, 2008). In Thailand's CBD fifth national report (ONEP, 2013), marine and coastal protected areas total coverage was 72,094 km^2 or 22.28% of Thailand's EEZ. However, the report noted that this information is not clearly identified since there were problems of overlapped areas and some definition of MPAs. There was even an aspiration to increase MPA area to 30% by 2012 under the 10th National Economic and Social Development Plan (2007-2011). In the latest CBD national report (ONEP, 2018), the coverage of MPAs include national parks, coral reefs, sea grass, fishery management zone etc. totals to 84,444.48 km^2 which would be 26.1% of Thailand's EEZ. The report misquoted the total marine areas (EEZ) of the country to 426,616 km^2 and projected MPA coverage to be 19.7% (ONEP, 2018).

In my role as Deputy of IUCN Southeast Asia Group, I advised Thailand's DMCR to adopt the Guidelines for Applying the IUCN Protected Area Management Categories to Marine Protected Areas (Day et al. 2012). I translated the guidelines into Thai for mutual understanding and to raise awareness among multi-agencies officers and policy makers through a series of workshops.

Based on these guidelines, "*Fisheries Management Areas*" described as "*Temporary or permanent fishing closures that are established primarily to help build up and maintain reserve stocks for fishing in the future, and have no wider conservation aims or achievements"* are not considered to be MPAs (Day et al. 2012). This definition applied to most of Thailand's fishery management zone including the no-trawl area that ranges from 3-5 km from shore and does not meet IUCN's definition of a protected area because there is no designated area manager who would address the overall health and diversity of the ecosystem of these coastal areas.

Internationally, Thailand's MPA coverage are much is much smaller in the World Database on Protected Area (WDPA) under management of UN Environment - World Conservation Monitoring (UNEP-WCMC) with support from IUCN and its World Commission on Protected Area (WCPA), the marine area of 5,774 km^2 in Thailand is considered protected or a mere 1.88% based on total marine area of 306,891 km^2 (UNEP-WCMC, 2019). In the atlas of marine protection, another global database on MPAs managed by the Marine Conservation Institute launched in 2012, the marine area of 4,413.1 km^2 in Thailand is classified as implemented MPAs or 1.48% based on total marine area of 298, 685.4 km^2 (Morgan et al. 2018). It is clear that only marine national parks are included in those two MPA global databases and there is a need to communicate and update the country's progress regarding MPA.

The objectives of the National Park Act are centered around the protection of ecological integrity, biodiversity and the provision of ecosystem services while providing the general public opportunities for recreation as well as a place for research and environmental education (DNP 2017). In the past decade, there has been much effort to improve the management of Thailand's protected area system to be more integrated and participatory with support from international

organizations such as United Nations Development Programme (UNDP), German Corporation for International Cooperation (GIZ), International Union for Conservation of Nature (IUCN), and World Wide Fund for Nature (WWF) among others. Some of the major initiatives include the Integrated National Park Master Plan 2017-2021; Ecological Corridor of Thailand's Protected Areas, Payment for Ecosystem Services; and the Natural World Heritage Nomination preparation for large landscapes and seascapes, including the Andaman Bioregion (DNP 2017, 2018).

The northern part of the Andaman Bioregion has been included in the preparation of a world heritage nomination (Ao Phangnga-Mu Ko Surin-Mu Ko Similan National Marine Parks Complex) since 1998 (ONEP 1998) and expanded to cover the whole bioregion of six provinces in Andaman Sea Nature Reserve nomination since 2009 (DNP 2018). Although the process has been stalled for several years due to uncertainty surrounding mega-development projects, including a proposed deep seaport and industrial estates in Southern Thailand, the preparation was reinvigorated in 2018. The current administration has requested DNP to consult with all relevant agencies as well as regional development plans to update the boundaries of the proposed property (DNP 2018). The total area of the nominated property encompasses most of the existing protected areas that include 17 marine national parks and 3 non-hunting areas with a total area over 480,000 ha. Additionally, the proposed buffer zones and management areas around the core area cover over 1.1 million ha. The combined area of the proposed Andaman Sea Nature Reserve management area represents more than 80% of the Andaman coast of Thailand (See **Figure 4**).

After the 2010 mass coral bleaching event where the northern part of Thailand's Andaman Sea suffered unprecedented coral mortality, the idea of transboundary marine conservation between Thailand and Myanmar was introduced to enhance recovery in Thailand from the coral reservoir upstream in Myanmar's Myeik Archipelago (Yucharoen et al. 2015). Considerably more information about coral and marine biodiversity in the Myeik Archipelago has been gathered in recent years, although MPA development in Myanmar is still in its early stage (Dearden 2018). The Thai government has been proactive and initiated transboundary marine conservation with Myanmar through capacity building and information sharing workshops since 2016 (DMCR 2019). The Myeik Archipelago was placed on the UNESCO tentative list for World Heritage nomination by the Myanmar government in 2014. If Thailand's proposal for the Andaman Sea Nature Reserve is also accepted transboundary cooperation between Thailand and Myanmar will become even more significant.

3.2 Bio-Physical Environment

This section summarises the main characteristics of the different ecoregions contained within the Andaman Sea Bioregion (see **Figure 4**).

The Northern Mangroves and Inshore Islands ecoregion extends along the Kraburi River from its mouth to a point roughly 12 km. inland and captures the entire coast of Ranong province. This ecoregion covers 4 coastal wetland MPAs (**Appendix I,** No.1-4) from an estuary near the Myanmar border in the north to the mangrove and beach forests in neighboring Phang-nga province. This is the largest undisturbed area of old-growth mangrove remaining in the eastern Indian Ocean (DNP 2018). The area supports a very high-level of mangrove-associated biodiversity. Nationally important seagrass areas also occur outside MPAs providing essential feeding ground for the northern population of dugongs and turtles.

The Central Beaches and Coastal Gallery Forests occupies almost the entire western part of Phang-nga Province, extending down to the northern part of Phuket in the south, featuring 4 coastal beach forest MPAs (**Appendix I,** No. 5-8). A continuous fringing coral reef is found about 500-3,000 m offshore extending southwards to the northern part of Phuket. Locating mostly outside MPAs, this reef system is not well studied and monitored (DMCR 2017). This feature could function as a barrier reef and serve as a critical stepping-stone between inshore and offshore habitats. This area contains the only remaining nesting beach for the endangered leatherback turtles (*Dermochelys coriacea*) on the eastern continental region of the Indian Ocean (DNP 2018).

The Northern Offshore Islands comprise the archipelagos of Mu Ko Similan and Mu Ko Surin National Parks (**Appendix I,** No. 9-10), approximately 50 km. off the Phang-nga coast. The Surin and Similan Islands boast some of the most ecologically diverse coral reefs in Thailand and very high diversity of fishes and marine life including more than 700 species of marine fishes, 140 species of marine crustaceans and 160 species of hard corals (DNP 2018). Marine macrofauna, including giant manta rays (*Manta birostris*), several types of whales and dolphins (*Cetacea*) as well as whale sharks (*Rhincodon typus*) frequent the waters between the islands. These islands are also an important nesting area for sea turtles (DMCR 2017).

Greater Ao Phang-nga ecoregion extends from the mountainous mainland throughout the bay between Phuket and Krabi provinces. The outstanding seascape is dominated by a series of vertical limestone inselbergs and karst topography covering 5 coastal wetland and nearshore island MPAs (**Appendix I,** No.11-15). Vast mangrove and estuaries offer prime habitat for migratory birds and both Phang-nga Bay and Krabi estuary are recognized as Ramsar Sites, wetlands of international importance. Although reef conditions in Phang-nga Bay and nearby range from poor to fair corals here have shown signs of resistance to bleaching events. The similar trait has been found in nearshore reefs of Phuket where damage from bleaching was less severe on the deeper reef flat where corals were subject to less aerial exposure, rapid flushing and longer submergence in turbid waters (Brown et al. 2019).

The Southern Coastal Forests lie in Trang and Satun Provinces featuring 5 coastal forest and island MPAs that extends to the Malaysian border (**Appendix I,** No.16-20). The coast of Trang Province supports extensive seagrass beds and estuaries that provide key habitat for the largest population of dugongs in Thailand (Hines, Adulyanukosol & Duffus 2005; DMCR 2018). Hat Chao Mai– Libong– Trang River Estuaries are also recognized as Ramsar sites. Coral

assemblage of the southern region around Mu Ko Phetra and Tarutao National Parks are largely different from the northern Andaman region. Corals here suffered much less damage in the 2010 mass coral bleaching event (Phongsuwan & Chansang 2012). These shallow resilient reefs could potentially be an important refugia for reseeding corals after climate disturbance in the southern region.

The Southern Offshore Islands are high islands lying in the Southern Andaman Sea from offshore islands south of Phuket, Krabi and Satun and extend to the maritime boundary between Thailand and Malaysia covering part of Tarutao and Mu Ko Lanta National Parks. The offshore islands are geologically similar to the northern offshore islands, but differ significantly in term of biological assemblage (DNP 2018). Marine species diversity is extremely high; more than 400 fish species have been recorded here (DMCR 2017; DNP 2018). Almost all of more than 160 species of hard coral species in the Andaman biogeographic province are documented here (DNP 2018). Damage to the corals in this area was caused by an outbreak of Crown-of-Thorn Sea Star in 1986 but during the 2010 mass bleaching event the area did not suffer the same level of mortality as the northern region (Phongsuwan et al. 2013). The offshore islands in this ecoregion are frequently used by endangered whale sharks, manta rays, several types of whales and dolphins as well as sea turtles (DNP 2018). Description of each MPA in the Andaman ecoregions can be found in **Appendix II**.

3.3 MPA legislation and governance

Most of the MPAs covered by this study are managed under the authority of the Department of National Parks, Wildlife, and Plant Conservation (DNP), although many other parts of the

government have shared responsibility in managing marine and coastal resources, especially the Department of Marine and Coastal Resources (DMCR) and the Department of Fisheries (DoF).

Historically, the Royal Forest Department (RFD) served as the primary agency responsible for marine park management. Within the RFD, the National Park Division was responsible for managing both terrestrial and marine parks. Management responsibilities shifted following major public sector reforms in late 2002, during which time a number of new agencies were established, namely DNP and DMCR, under the Ministry of Natural Resources and Environment (MONRE), which is responsible for the protection and conservation of protected areas, water resources, marine and coastal resources and environmental quality.

Under DNP jurisdiction, there are two main categories of protected areas that are applicable to MPAs. National Parks usually cover a large area and are established under the National Park Act (IUCN Protected Area Category II) while Non-Hunting Areas are established under the Wild Animals Reservation and Preservation Act, and are normally small areas that aim to give protection to threatened species (IUCN Protected Area Category IV). Twenty-two marine national parks and 6 non-hunting areas have been designated totaling 7,976 km^2. Traditionally, DNP manages all protected areas in a strong top down approach. Recent efforts focus on public participation and effective communication through financial support of international organization and cooperation with local conservation NGOs. However, it is difficult to imagine that additional marine National Parks will be established because of public resistance towards DNP and limited opportunities still remaining in the landscape.

DMCR was established to implement marine and coastal resource management focusing on critical habitat and threatened species through conservation and rehabilitation initiatives (DMCR

2018). Its mission also includes knowledge dissemination and research to achieve ecological balance for sustainable development (DMCR 2018). Under the new Promotion of Marine and Coastal Resources Management Act 2015, DMCR can designate Mangrove Conservation Areas and Marine and Coastal Resources Protected Areas in order to protect important coastal and marine resources. The new law also encourages the participation of communities and local governments in conservation by forming multi-stakeholder platforms that can propose management plans for marine and coastal resources. Currently, DMCR is still in the process of establishing their own MPAs according to the new legislation. Well-planned and effectively managed MPAs under DMCR could provide much needed additions to existing MPAs and form a resilient MPA network.

The DoF also shares governance and responsibilities in managing marine resources. Fifty six Species Conservation Areas, totaling over 166 km^2, have been established under the Fisheries Act and are managed by the DoF. However, the boundaries of these conservation areas are not recognized by the public and enforcement is largely absent (McNeely 2015). Incorporating these small strategic managed areas into an MPA network could provide significant benefit to the larger marine ecosystem. The Fisheries Law also allows for the establishment and extension of "no trawl" areas which normally extend 3-5 km from shoreline. Additionally, in cooperation with DMCR, the DoF is responsible for declaring and managing protected fisheries spawning areas. Some fisheries spawning areas for certain species have been declared. e.g. seasonal closure for spawning Short Mackerel *(Rastrelliger brachysoma)* in the Gulf of Thailand. Temporal closure of certain area could be effective to add more protection to MPAs but are much underutilized. Currently, these fisheries management areas are not included in the total coverage of MPAs because they lack of clear biodiversity conservation objective.

In the past five years, there have been major revisions in key legislation concerning MPAs and marine resource management in Thailand, namely the Marine and Coastal Resources Management Act (2015), the Fisheries Act (2015), the National Forest Reserve Act (2016), the National Park Act (2019) and the Wild Animals Reservation and Protection Act (2019). Brief summaries of the legislations and key revisions can be found in Appendix III.

The legislation amendments aim to promote better coordination across the institutes and agencies (national reform committee), improve public participation (through officially appointed multi-stakeholder committees) and promote more effective law enforcement (stronger punishment including both jail time and fines). The new laws also emphasize the need to resolve the conflict between protected areas and local people (e.g. see Lunn & Dearden 2006; Bennett & Dearden 2014) through various mechanisms such as provincial committees that represent civil society organizations and researchers. DMCR, whose mandate is to provide baseline information and technical support for coastal management is now tasked to produce a 'State of the Coast' report for all coastal provinces annually. The first report "State of the Coast 2016" was published in 2017 containing information about critical coastal habitats (coral, mangrove and seagrass), threatened species (dugong, turtle, whale and dolphins), alien species, coastal erosion, pollution etc. These reports will help standardize information regarding marine and coastal resources and will be very beneficial for open data and resource monitoring in the future (DMCR 2016).

3.4 Threats and challenges

The Andaman Coast of Thailand has undergone rapid development in the past 40-50 years, resulting in numerous threats and resulting degradation of the marine and coastal environment (DMCR 2017). The challenges facing the Andaman MPAs can be grouped into four categories:

jurisdictional limitations, management effectiveness, anthropogenic threats and climate change (BOBLME 2011, Phongsuwan & Chansang 2012).

3.4.1 Jurisdictional limitations

Policies and regulations governing marine resource use are often inconsistent and fragmented and coordination/communication among many government agencies involved in implementing regulations is often inefficient (Weigel 2009; Yeemin 2005). There is still ambiguity over the definition of MPAs that are not marine national parks, and existing laws and regulations for coastal and marine resources are complex (ICEM 2003). Enforcement can be particularly challenging and ineffective because regulations are often unclear (Yeemin 2005). For example, some management measures that are widely practiced (e.g. allowing small-scale fisheries to operate inside parks) are technically illegal or at least not covered by the existing legislation. Penalties are often outdated and insufficient to serve as a e disincentive to those who break the laws, and the establishment of site-level National Park Committees that represent park stakeholders, is not compulsory. Some of these issues have recently been addressed in major legislative amendments in 2019. However, even though the DNP has full authority over the management of marine national parks, the health of ecosystems inside the park can be affected greatly by activities that occur outside the boundaries. Land-based pollution and infrastructure development are clearly evident along the coast and can have devastating effects on ecosystem health in MPAs (BOBLME 2011). Infrastructure development proposal such as seawalls, harbours and marinas often hinder effective management of MPAs (DMCR 2016).

3.4.2 Management effectiveness

Although recent years have seen marked improvements in the management of marine national parks, many challenges remain. Most notable, there is insufficient personnel with adequate knowledge for marine area management, funding shortages and lack of effective enforcement (IUCN 2012). Generally, the parks lack public support and participation in natural resource conservation and often receive negative feedback towards protected areas (IUCN 2012; Bennett & Dearden 2014). Policies and regulations do not have enough control over the use of resources leading to coastal development around and within the national parks and activities such as boat traffic and wastewater discharge, and quantities of garbage that exceed the ability of national park management and surrounding communities. Budget allocation is also problematic where the basic needs of enforcement officers, such as fuel for patrol boats, is often lacking. Furthermore, it is difficult to control entry into some marine parks (such as Mu Ko Phi Phi), resulting in unrealized revenue (IUCN 2012). There is now relatively extensive monitoring of coral reef health throughout the country as DMCR and DNP monitor coral coverage throughout the Andaman Sea but there is still relatively little information available about the overall effectiveness of the MPAs (McNeely 2015).

3.4.3 Anthropogenic threats

Anthropogenic threats to the Andaman MPAs are numerous and evident. Overfishing, land-based pollution and tourism development are the most prominent. Destructive commercial fishery practices such as light trap fishing boats, trawl nets, and push nets in prohibited areas still operate abundantly and are almost impossible to control during the off season (BOBLME 2011). The coastal tourism industry has continued to expand unchecked, and tourism infrastructure

development is frequently associated with the deterioration of near-shore marine habitats due to sedimentation overflow and wastewater discharge (DNP 2017). Sewage and plastic pollution problems are of growing concern, and treatment facilities on many islands (e.g, Phi Phi Island, Lanta Island) are often non-existent or inadequate (DNP 2017). In recent year, over carrying capacity tourism has caused serious degradation of coral reefs in Mu Ko Similan, Mu Ko Phi Phi resulting in area closure for restoration (Ellis-Petersen 2018). The impact of chemical fertilizers, insecticides and untreated wastewater from agricultural production and aquaculture are not well understood in Thailand but clearly an emerging issue (BOBLME 2011).

3.4.4 Climate change

An extensive review of climate change impacts on coral reefs and marine ecosystem is given in Chapter 2. Climate change will affect all ecosystems in Thailand, including those in protected areas. Impacts will be felt strongly on the coast from rising sea levels, ocean acidification, changing current pattern and storm surges. Bleaching of coral reefs within Andaman MPAs as a result of ocean warming represents a serious threat to their ecological integrity as well as economic viability (Phongsuwan & Chansang 2012).

Widespread coral bleaching on the Andaman Sea coast of Thailand was first documented in 1991, and has subsequently recurred in 1995, 1998, 2003 and 2010 (Phongsuwan & Chansang, 2012). Mass coral bleaching occurred again in 2016 and 2019 but not extensive (DMCR 2018, 2019). Phongsuwan & Chansang (2012) reported that coral mortalities before the 2010 bleaching event were moderate, with mortality between 0 and 66.7% (mean percentage mortality = 24.5%), whereas mortality in 2010 ranged from between 44.2% and 99.0% (mean = 68.3%).

In particular, Mu Ko Surin suffered unprecedented mass bleaching with an extremely high mortality of 86.6% on average (ranging from 68.5% and 98%).

In 2010, when bleaching was most severe, there were 95 days >30.34 C (Bleaching threshold); followed by 65 days in 1995 (moderate bleaching) and 55 days in 1998 (mild bleaching). The impact varied widely from place to place depending on the structure of the coral communities and the intensity of current or waves affecting local temperatures. Generally, coral bleaching intensifies in areas where water is not well circulated and most staghorn coral (*Acropora* spp.) show mortality after 1 month of bleaching. The response of corals to a temperature anomaly is also very variable. Some species can resist warmer temperatures while some species are very susceptible. Combining the results from all transects over all bleaching years, (involving a total of 47 coral species), it is clear that *Acropora spp., Hydnophora rigida, Porites lutea, Porites rus, Porites nigrescens, Pectinia spp., Pavona clavus, Fungia spp., Montipora spp. and Pavona varians* are all sensitive species, although some are clearly more sensitive than others e.g. *Acropora spp. > Porites* spp. and the most resistant species are *Pavona decussata, Diploastrea heliopore, Heliopora coerulea.* (Phongsuwan et al. 2013).

However, there was variation in bleaching susceptibility of the same species at different study sites and in different years which may be due to variation in environmental parameters such as SST, turbidity, wave intensity, current flow and temperature tolerance within species. For example *Porites lutea* on shallow reef flats was more resistant to bleaching than those colonies on reef slopes due to acclimatization to higher temperature (Phongsuwan, N. 2011). The decreases in live coral cover after the 2010 bleaching event varied greatly from site to site and region to region, for example, Surin Islands 75-95% with an average 84.3%; Phi Phi Islands 36-

94**%** with an average 63.1%; Phuket 28-83% with an average 56.4%; and Tarutao 2-72% with an average 20% (**Figure 5-6**).

Large-scale disturbance such as the 2010 bleaching event provides a unique opportunity to review the configuration and management systems of the Andaman MPAs in consideration of current and potential future climate change impacts and identify appropriate management response to global climate change. It is assumed that reduction of multiple threats to coral reefs within MPAs may improve their overall resilience to bleaching events and reduce their vulnerability to climate change over long period of time (Green et al. 2009; Mumby & Harborne 2010; Micheli et al. 2012; Mellin et al. 2016; Roberts et al. 2017; Steneck et al. 2018; Mcleod et al. 2019). The next Chapter will describe methods and analysis employed for assessing the system vulnerability and conservation strategies development.

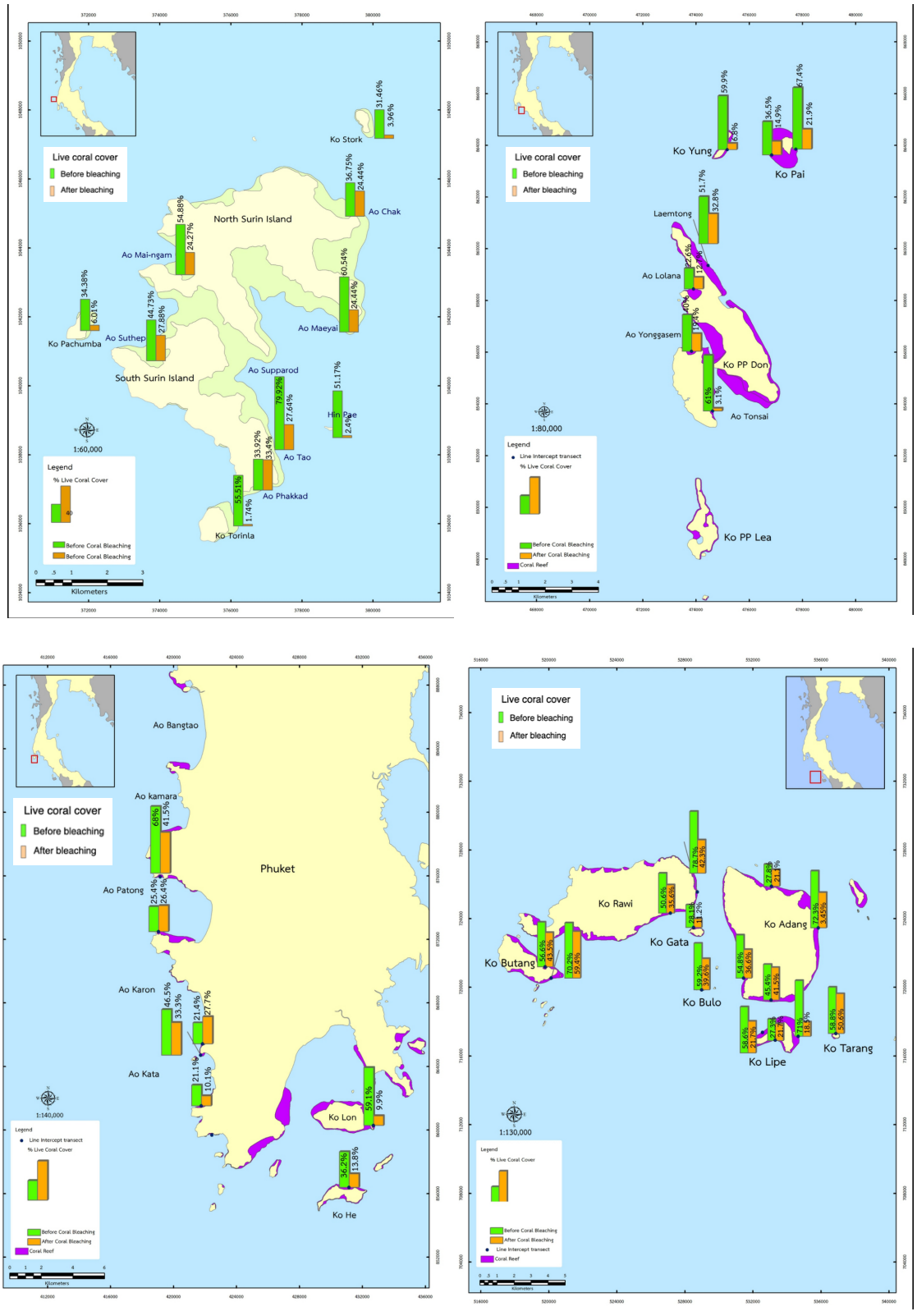


Figure 5. Some coral bleaching pattern in 2010 across Andaman bioregion (Mu Ko Surin and Mu Ko Phi Phi, Phuket and Adang Islands (updated with DMCR 2012)

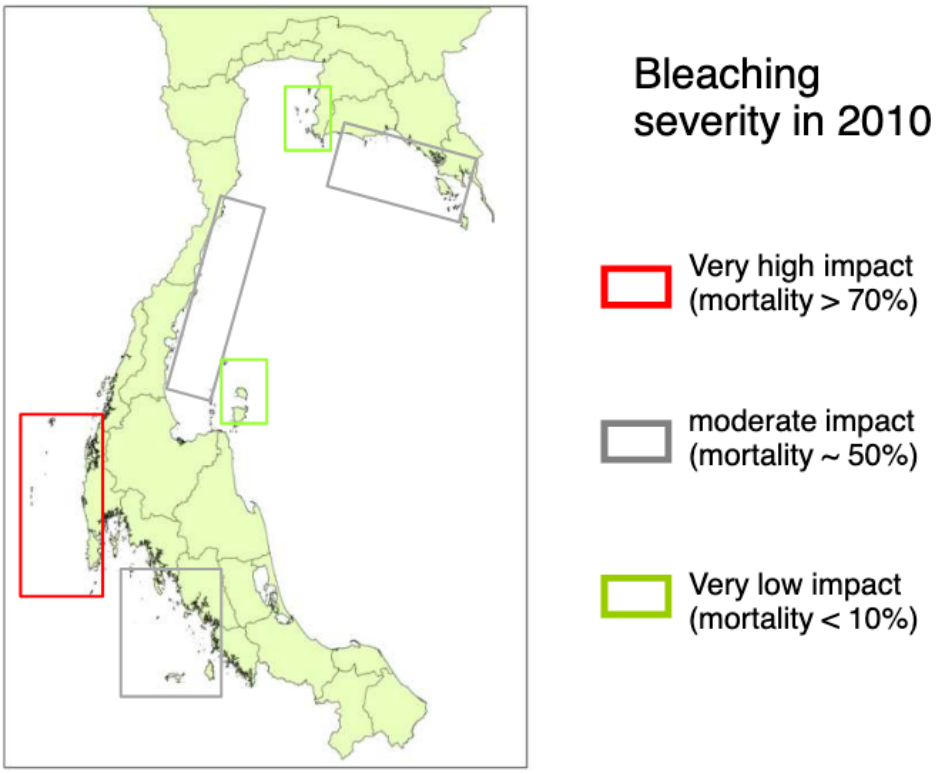


Figure 6. Bleaching severity in 2010 showing very high impact and moderate impact in the Andaman (Updated with DMCR 2012).

Chapter 4

Methods and Analysis

The study employed a mixed methods approach to assess the vulnerability and resilience of coral reefs on the Andaman coast of Thailand and to develop conservation strategies for an Andaman Marine Protected Area (MPA) network. The process for gathering information and data analysis is illustrated in **Figure 7** and discussed in the following sections .

4.1 Literature review and secondary data assessment

A literature review was conducted to explore the latest knowledge about marine conservation, MPAs, resilience assessments, climate change and vulnerability. This literature review on coral reef vulnerability to climate change and the role of MPAs in building ecosystem resilience was presented in Chapter 2. A review of available secondary data on the state of the marine and coastal resources, conservation status, governance on Thailand's Andaman Coast was undertaken. The review more detailed review of coral bleaching situation in 2010 was presented in Chapter 3. In order to verify overall figures on levels of existing and proposed marine protection for Thailand, I advised Thailand's DMCR to adopt the Guidelines for Applying the International Union for Conservation of Nature (IUCN) Protected Area Management Categories to Marine Protected Areas (Day et al. 2012) and served as advisor throughout the reclassification progress. I translated the guidelines from English into Thai for mutual understanding of definition and terminology around MPAs.

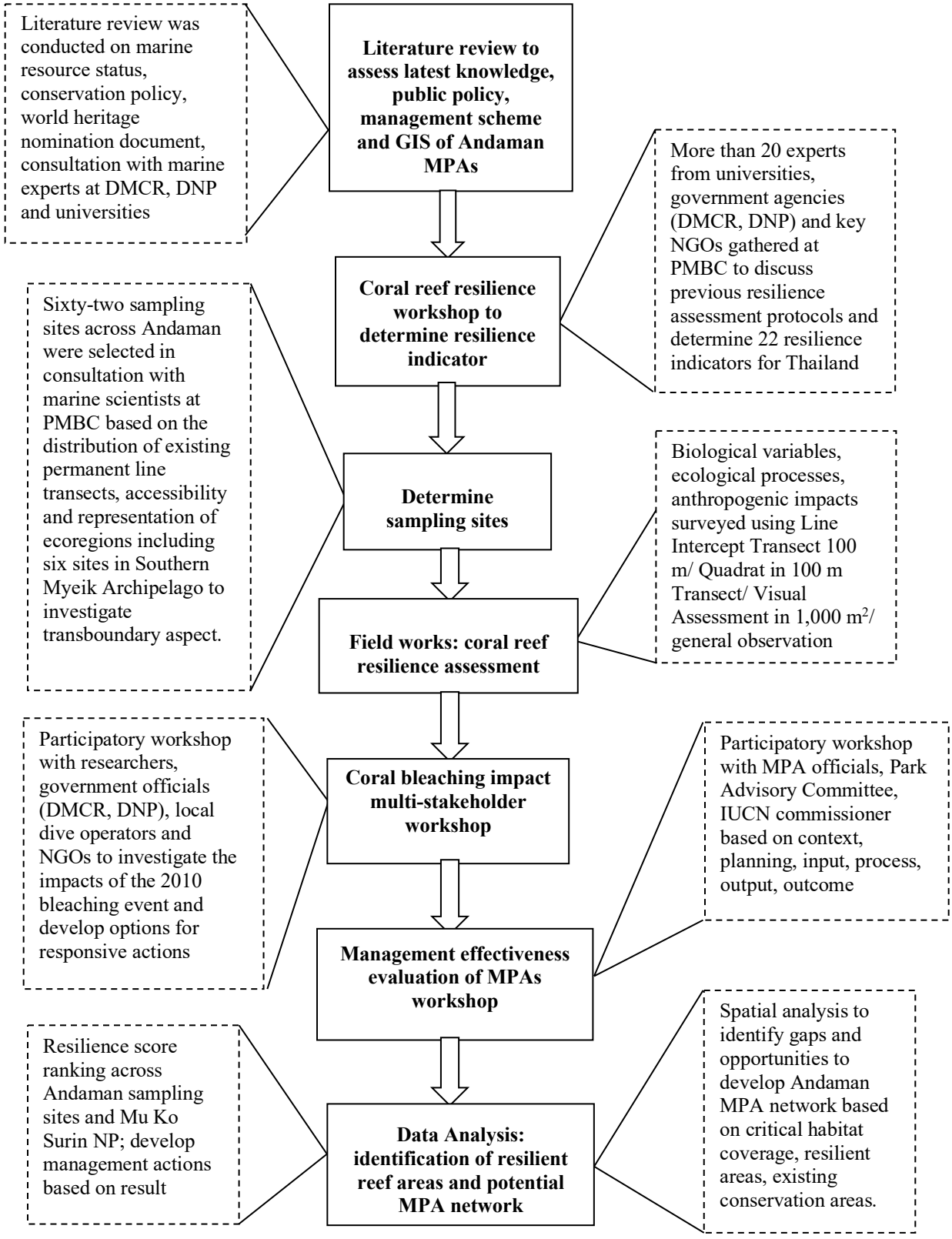


Figure 7. Mixed methods and working processes for gathering information and data analysis.

Based on these guidelines, "*Fisheries Management Areas*" described as "*Temporary or permanent fishing closures that are established primarily to help build up and maintain reserve stocks for fishing in the future, and have no wider conservation aims or achievements"* are not considered to be MPAs (Day et al. 2012). This definition applied to most of Thailand's fishery management zone including the no-trawl areas that range from 3-5 km from shore and do not meet IUCN's definition of a protected area because there is no designated area manager who would address the overall health and diversity of the ecosystem of these coastal areas. With this interpretation, recalculation of Thailand's MPA coverage against the global MPA database (Morgan et al. 2018; UNEP-WCMC, 2019) was conducted.

4.2 Coral reef resilience workshop

I co-organized a marine expert round table workshop to discuss coral reef vulnerability and climate change and the development of resilience indicators with the Department of Marine and Coastal Resources (DMCR) from 11-13 July 2011 at Phuket Marine Biological Center (PMBC) in Phuket. The workshop was attended by 23 participants including officials from PMBC, (DMCR) (Bangkok), Marine National Park Operation Center (MNPOC) Phuket, MNPOC Trang, MNPOC Chumporn, Burapha University, Chulalongkorn University, Kasetsart University, Phuket Rajabhat University and Prince Songkla University (See agenda and the list of participants in **Appendix IV**).

The resilience assessment builds on a foundation from standard monitoring procedures of coral reef ecosystems, adding more details on the coral community and site-based resistance/resilience to coral bleaching (Obura & Grmsditch 2009). The main aspects of the resilience assessment based on Obura & Grimsditch (2009) and Maynard et al. (2010) were discussed including more

detailed measurements of coral populations, more detailed measurement of algal coverage, fish sampling focused on herbivorous fish, and identification of indicators that affect thermal stress at a local site to assist in reef management. Information on human impacts such as physical damage, fishing pressure, sediment loading was also discussed.

IUCN's rapid assessment protocol for coral reefs, focusing on coral bleaching and thermal stress listed sixty one parameters including benthic (e.g. coral, algae, substrate), physical (e.g. cooling, shading, extreme acclimatization), historic (e.g. bleaching record, recovery), coral population (e.g. recruitment, dominant size class, largest corals), fish group (e.g. herbivorous, excavators, scrapers), connectivity (e.g. currents, seeding) to anthropogenic (e.g. fishing, pollution, sedimentation). Workshop participants agreed that the large number of indicators to be assessed and measured would make surveys resource intensive, costly, and impractical.

From sixty one variables, a suite of twenty two resilience indicators were identified for Thailand by workshop participants based on field evidence, previous studies, relevance, and practicality. The 22 indicators can be broadly classified as biological variables (e.g. abundance of resistant species, diversity of living corals, coral disease), those that influence ecological processes (e.g. substrate availability, diversity and herbivore abundance), anthropogenic impacts (e.g., fishing pressure, physical damage, pollution and sedimentation), and physical variables (e.g., cooling and shading) and management categories (**Table 2).**

The resilience assessment is designed to provide an overarching assessment of all components of reef resilience with respect to climate change. A semi-quantitative scale (Likert) of 1-5 was used for estimation of all the resilience indicators, including those for which more detailed quantitative data was collected. The 5-point scale was selected to facilitate estimation of minimum (1),

maximum (5) and moderate (3) levels for each indicator for the region of application, and intermediate levels of low (2) and high (4). For indicators with detailed quantitative data, the specific range for each value is indicated in **Table 2.** For example, live cover from 0-20% scores 1, 21-40% scores 2, 41-60% scores 3 and so on.

Another coral reef resilience workshop was held on 21-24 November 2015 at PMBC, Phuket to revisit the indicators and discuss challenges and preliminary results. The workshop was attended by 26 participants from the same government agencies and universities (See the list of participants in **Appendix V**). More recent publications (McClanahan et al. 2012; Maynard et al. 2015) indicated eleven key factors important to resistance and recovery to support coral reef management i.e. 1) Resistant coral species, 2) Temperature variability, 3) Nutrients (pollution), 4) Sedimentation, 5) Coral diversity, 6) Herbivore biomass, 7) Physical human impacts; 8) Coral disease; 9) Macroalgae; 10) Recruitment; and 11) Fishing pressure. The abundance of resistant (heat-tolerant) coral species and past temperature variability was perceived to provide the greatest resistance to climate change, while coral recruitment rates, and macroalgae abundance were most influential in the recovery process (McClanahan et al. 2012). The workshop participants agreed that the twenty-two indicators identified were practical and relevant and remained unchanged.

Table 2 Thailand coral reef resilience indicators selected from the Thailand coral resilience assessment workshops (DMCR 2015, based on Maynard et al. 2010, 2015; Omura & Grimsditch, 2009)

	Reef Resilience Indicator	**Resilience Index**					**Influence**	**Method**	**Note**
		1	2	3	4	5			
1.	Live coral cover (% cover)	0-20	21-40	41-60	61-80	81-100	+	Standard method: Line intercept transect	Estimate % cover in the reef area
2.	Abundance of coral recruits (No. of Colony/m^2)	0	1	2-3	4-8	> 8	+	Standard method: Quadrat with Line intercept transect	Coral recruits are juvenile coral the size of 5 cm or less.
3	Class size of the largest coral colonies **(**size in metre**)**	< 0.5	0.5-1.0	>1-2.0	>2-3	> 3	+	Measure the average of the largest three corals, converted into size classes	*Porites* (massive**)**
4.	Abundance of bleaching resistance/tolerant species (No. of Colony or % cover compared to overall live coral cover)	< 2 Colony	2-10 Colony	% cover < 10% or > 10 colony	% Cover 10-30%	% Cover > 30%	+	Standard method: resistance/torelant species are *Porites* (massive), *Goniopara, Pavona decussata, Diploastrea*	If there are few colonies, count the number but if there are many estimate % cover compared to overall live coral cover.
5.	Species richness (No. of coral species)	1-10	11-20	21-30	31-40	> 40	+	Standard method: Estimate species diversity without specify species	Not necessary to identify species

6.	Coral predator (No. of Crown-of-thorn starfish – COT)	> 5	4-5	2-3	1	0	-	Standard method: count the number of COT encounter	Focus on COT: If abundance 30/hectare considered outbreak
7.	Abundance of coral competitors (% cover)	>30	>20-30	>10-20	<10	0	-	Standard method: Line Intercept Transect	Coral competitors in term of space include zooanthids, corallimorph, sponge, bryozoa
8.	Coral disease prevalence (No. of infected colonies)	> 30	16-30	10-15	< 10	0	-	Standard method: search within survey area	Coral health monitoring manual such as Trematodiasis, Pigment response, Focal Bleaching, Non-focal bleaching, white syndrome, pink spot
9.	Herbivore diversity (No. of herbivore species) Andaman Gulf of Thailand	1 1	2-5 2-4	6-10 5-8	11-14 9-12	>15 >12	+	Standard method: Visual assessment (1,000 m^2 for Andaman and 500 m^2 for Gulf of Thailand)	
10.	Abundance of herbivores (No. of herbivores counted) Andaman Gulf of Thailand	<5 <3	5-16 4-9	17-64 10-27	65-256 28-81	>256 > 81	+	Standard method: Visual assessment (1,000 m^2 for Andaman and 500 m^2 for Gulf of Thailand)	Herbivores are herbivorous fish in the family *Scaridae* (Parrotfish), *Acanthuridae* (Surgeonfish) *Siganidae* (Rabbitfish) The different abundance class is based on log number

11.	Abundance of predatory fish (No. of predatory fish counted) Andaman Gulf of Thailand	0 0	<5 1	5-10 2-3	11-15 4-5	>15 >5	+	Standard method: Visual assessment (1,000 m^2 for Andaman and 500 m^2 for Gulf of Thailand)	Focus only on the *Serranidae* (Grouper) (size >30 cm) because they are residential and play important role in keeping balance within coral reef foodchain
12.	Abundance of fisheries target species (No. of fish) Andaman Gulf of Thailand	<5 1-2	5-16 3-4	17-64 5-8	65-256 9-16	>256 >16	+	Standard method: Visual assessment (1,000 m^2 for Andaman and 500 m^2 for Gulf of Thailand)	Common fisheries target species are the family *Serranidae* (Groupder) *Lutjanus* (Snapper) *Lethrinidae* (Emperor) *Haemulidae* (Sweetlip) (Size >20 cm.)
13.	Severity from the latest bleaching event (%)	>75% bleaching	>50-75% bleaching	>25-50% bleaching	>10-25% bleaching	< 10% or none	-	Visual assessment in an area 1,000 m^2	% of bleached coral per area of live coral cover
14	Survival from last bleaching event (%)	None or survive < 10%	Minor survival >10-25%	Low survival >25-50%	Moderate survival >50-75%	Greater survival >75%	-	Visual assessment in an area 1,000 m^2	survived coral per of bleached corals
15.	Proximity of other coastal habitats that enhance ecological connectivity e.g. coral reefs, mangroves, seagrass, rocky outcrop: number of habitat Type within 5-10 km	None	1	2	3	>3	+	GIS or resource database	The number of other habitat types including other coral reefs within 5-10 km but not include artificial reef or estuary. Determine the distance if possible

16.	Cooling factors	None or very low (closed bay setting)	Low (Partially exposed)	Moderate (Moderately expose to wind and wave, reef slopes)	High (Exposed to wave, wind and upwelling, structural enhanced flow)	Very high (channel and regularly impacted by upwelling)	+	General observation and consult local expert who familiar with the site	Consider local physical setting, influence from upwelling, current, wave including channel reef internal wave
17.	Shading factors: topographical features	None		Moderate shading from vertical structure either columns or some erect corals		High shading from overhangs or above water	+	General observation, consult with local expert, GIS database	Light plays an important role in bleaching incident. Consider 1.coral reef structure 2. Island topography And divide into three categories (1, 3, 5)
18.	Fishing pressure	Very high (depletion of fish and clear evidence of destructive fishing gears with clear impact on coral mortality and substrate)	High (frequent use of destructive fishing gears, and clear evidence of moderate mortality and/damage to substrate)	Moderate (frequent use of destructive fishing gear, some evidence of coral mortality and damage to substrate but low compared to natural level.	Some (occur but at too low levels to show any clear impacts)	None	-	General observation	Observe fishing activities evidence such as new discard fishing net not marine debris, cyanide and other destructive method

19.	Anthropogenic impact: physical damage	Very high physical damage and high mortality with damaged area >100 m^2	Physical damage clearly evidenced and some impact on mortality with damaged area >50-100 m^2	Some physical damage and some impact on mortality with damaged area between >25-50 m^2	Some physical damage but no impact on overall mortality with damaged area >1-25 m^2	None	-	General observation within 1,000 m^2	Consider human impact from tourism and community settlement such as plastic waste, anchor sign, discarded fishing net. Try to identify the cause to determine management action
20.	Nutrient and pollution	Very high (Clear evidence of eutrophication, phase-shift, coral mortality, algal, microbial, highly visible pollution		Moderate (Visible impact, some indicators present but no phase shift		None	-	General observation within 1,000 m^2	Pollution indicators such as algal, microbial, Cyanobacteria, sediment or dark layer of soil indication of hydrogen sulfide from waste water

21.	Sediment loading	Very high, near-total covered of sediment on seabed and coral structure due to anthropogenic sources		Some influence on sedimentation but minor effect above natural levels		None, no impact overall	-	General observation	Use 3 categories for assessment if it falls between select the worse category
22	Management	None	Some action/presence, low level of intervention, or awareness	Formally managed with legal framework but lack of enforcement	Formally managed with legal framework, some level of enforcement and compliance, high awareness	Fully effective, well managed and monitored, full compliance	+	Consider management categories and management effectiveness evaluation	

4.3 Sampling sites

To survey and monitor coral reefs, permanent transect sites have been set up throughout the Andaman Sea since 1980s by a team of researchers at Phuket Marine Biological Center under DMCR, formerly a part of the Department of Fisheries (DoF) (Changsang, 1984) although monitoring methods have changed over time (Phongsuwan and Chansang, 1992). Sixty-two sampling sites across the Andaman (**Figure 8**) were selected from over one hundred existing transects in consultation with Mr Niphon Phongsuwan, a coral reef expert and Director of PMBC at that time. The selection was based on the distribution of existing permanent line transects, accessibility and representation of ecoregions including six sites in the Southern Myeik Archipelago to investigate the transboundary aspect.

4.4 Field work assessments

The study received formal research approval from the Department of National Parks, Wildlife and Plant Conservation (DNP) (See **Appendix VI** for notification). Field work was undertaken in Thailand from February 2011 to May 2012 (full-time) and intermittently between June 2012 – March 2018. I conducted preliminary field surveys of all 20 MPAs along the Andaman coast from Ranong to Satun and collaborated with all key research agencies from DNP and DMCR.

Data collection was undertaken by the author in collaboration with researchers from DNP and DMCR at 62 survey stations across the Andaman bioregion. In general, the 100 m line intercept transect method (Dartnall and Jones, 1986) was employed to assess the status of coral communities at each site. The length of living coral species and other organisms (such as sponge, sea anemone, macroalgae etc.) which intersected or underlaid the measuring tape were recorded. Corals intercepted by the transect line were measured and identified to species (or at

least genus or family level) and their appearance (normally coloured live corals or bleaching) recorded. If bleaching occurs, the appearance was recorded at three levels 1) completely bleached (white or very pale); 2) partly bleached (partly white on colony or slightly pale; 3) dead colonies due to bleaching (inferred from standing dead colony which had white skeleton, sometimes slightly covered by filamentous algae. For coral recruits (3-55 mm in diameter), 1x1 m quadrats were used to count the number of coral recruits along the line transect. For fish abundance, visual assessment in an area of 1000 m^2 along each transect (100m x 10 m) was conducted. Sampling was combined with one 20 minute timed swim to maximize sampling of the large mobile fish. For physical factors that influence the resistance and resilience of corals to thermal stress e.g. shading or cooling, indicators were estimated using two approaches, field estimation of key features and review of existing knowledge based on reference material, local knowledge and available data. For anthropogenic impacts, free swims in an area of 1000m^2 were used to observe the current situation regarding fishing activities, pollution and water quality. For other types of data collection, methods are described in **Table 2**.

Teams of 4 or 5 people observed and recorded coral cover and diversity, coral recruitment, fish diversity and abundance, physical characteristics and anthropogenic impacts. One to two persons very familiar with coral and fish identification led the benthic work and assessed fish diversity. Skills for other team members were developed through on-site training. The author was normally responsible for recording physical characters and management-oriented indicators, and also assumed responsibility for other indicators as well such as coral recruit and fish abundance assessment when observers were insufficient. The author compiled the information from other observers and completed all twenty-two indicators after each survey.

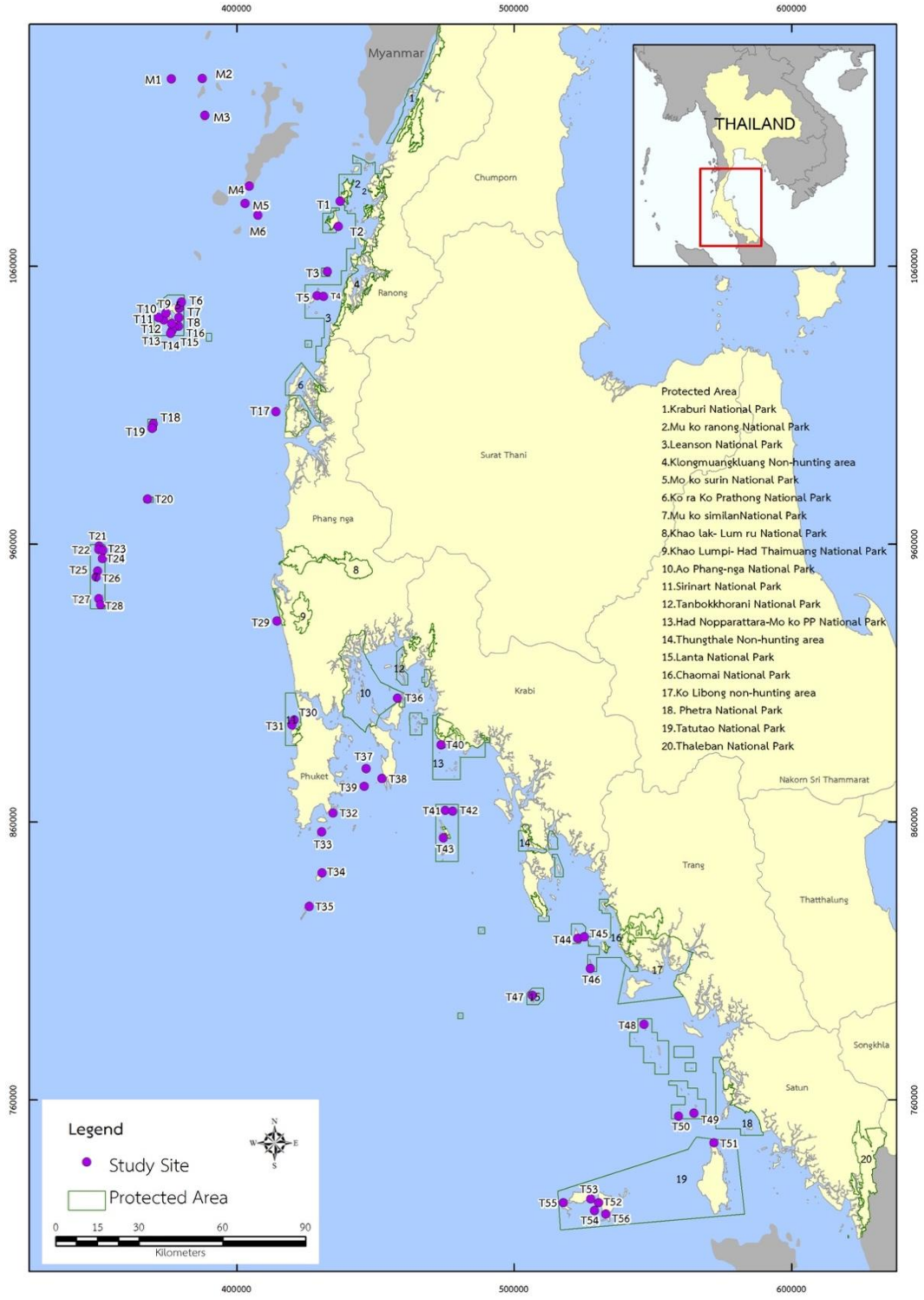


Figure 8. Locations of 62 study sites across the Andaman.

Table 3. Survey station information from North to South

Code	Station	Area	Ecoregion
M1	Nga Khin Nyo	Macleod Island	Myeik Archipelago
M2	Cockburn Islands	Macleod Island	Myeik Archipelago
M3	Nyaung Oo Phee	Macleod Island	Myeik Archipelago
M4	Zadetkyi South	Macleod Island	Myeik Archipelago
M5	Dunkin	Macleod Island	Myeik Archipelago
M6	Cocks Comb	Macleod Island	Myeik Archipelago
T01	Mu Ko Chang	Mu Ko Ranong NP	Northern Mangrove
T02	Ko Payam	non-MPA	Northern Mangrove
T03	Ko Kang Kao	Lameson NP	Northern Mangrove
T04	Ko Kam Yai	Lameson NP	Northern Mangrove
T05	Ko Kam Nui	Lameson NP	Northern Mangrove
T06	Ko Stock	Mu Ko Surin NP	Northern Offshore Islands
T07	Ao Chak	Mu Ko Surin NP	Northern Offshore Islands
T08	Ao Maeyai	Mu Ko Surin NP	Northern Offshore Islands
T09	Ao Mai-ngam	Mu Ko Surin NP	Northern Offshore Islands
T10	Ko Pachumba	Mu Ko Surin NP	Northern Offshore Islands
T11	Ao Suthep	Mu Ko Surin NP	Northern Offshore Islands
T12	Ao Sapparod	Mu Ko Surin NP	Northern Offshore Islands
T13	Ao Tao	Mu Ko Surin NP	Northern Offshore Islands
T14	Ao Phakkad	Mu Ko Surin NP	Northern Offshore Islands
T15	Ko Torinla	Mu Ko Surin NP	Northern Offshore Islands
T16	Hin Pae	Mu Ko Surin NP	Northern Offshore Islands
T17	Ko Phra Thong offshore	Mu Ko Similan NP	Central Beaches and Coastal Gallery Forests
T18	Ko Tachai E	Mu Ko Similan NP	Northern Offshore Islands
T19	Ko Tachai S	Mu Ko Similan NP	Northern Offshore Islands
T20	Ko Bon	Mu Ko Similan NP	Northern Offshore Islands
T21	Ko Ba-ngu	Mu Ko Similan NP	Northern Offshore Islands
T22	Ko Similan N	Mu Ko Similan NP	Northern Offshore Islands
T23	Ko Similan NE	Mu Ko Similan NP	Northern Offshore Islands
T24	Ko Similan SE	Mu Ko Similan NP	Northern Offshore Islands
T25	Ko Payu	Mu Ko Similan NP	Northern Offshore Islands
T26	Ko Miang	Mu Ko Similan NP	Northern Offshore Islands
T27	Ko Payang	Mu Ko Similan NP	Northern Offshore Islands

Code	Station	Area	Ecoregion
T28	Ko Huyong	Mu Ko Similan NP	Northern Offshore Islands
T29	Tai Muang nearshore	Khao Lampi - Had Tai Mueng NP	Central Beaches and Coastal Gallery Forests
T30	Nai Yang	Sirinat NP	Central Beaches and Coastal Gallery Forests
T31	Laem Ao Po	non-MPA	Greater Ao Phang -Nga
T32	Laem Panwa	non-MPA	Greater Ao Phang -Nga
T33	Ko He	non-MPA	Greater Ao Phang -Nga
T34	Ko Racha Yai	non-MPA	Southern Offshore Islands
T35	Ko Racha Noi	non-MPA	Southern Offshore Islands
T36	Ko Yao Noi	non-MPA	Greater Ao Phang -Nga
T37	Ko Lipi	Ao Phang-Nga NP	Greater Ao Phang -Nga
T38	Ko Yao Yai	Ao Phang-Nga NP	Greater Ao Phang -Nga
T39	Ko Khai Nai	non-MPA	Greater Ao Phang -Nga
T40	Laem Hang Nak	Hat Noppharat Thara-Mu Ko Phi Phi NP	Greater Ao Phang -Nga
T41	Ko Yung	Hat Noppharat Thara-Mu Ko Phi Phi NP	Greater Ao Phang -Nga
T42	Ko Pai	Hat Noppharat Thara-Mu Ko Phi Phi NP	Greater Ao Phang -Nga
T43	Ao Ton Sai : Phi Phi Don	Hat Noppharat Thara-Mu Ko Phi Phi NP	Greater Ao Phang -Nga
T44	Ko Ngai (South)	Mu Ko Lanta NP	Southern Coastal Forest
T45	Ko Chueak	Hat Chao Mai NP	Southern Coastal Forest
T46	Ko Kradan	Hat Chao Mai NP	Southern Coastal Forest
T47	Ko Rok (Central)	Mu Ko Lanta NP	Southern Coastal Forest
T48	Ko Liang Nua	Phetra NP	Southern Coastal Forest
T49	Bulon Mai Phai	Phetra NP	Southern Coastal Forest
T50	Bulon Le	Phetra NP	Southern Coastal Forest
T51	Tarutao Station	Tarutao NP	Southern Coastal Forest
T52	Adang West	Tarutao NP	Southern Offshore Islands
T53	Adang South	Tarutao NP	Southern Offshore Islands
T54	Ko Hin Ngam	Tarutao NP	Southern Offshore Islands
T55	Ko Ra Wee	Tarutao NP	Southern Offshore Islands
T56	Ko Batong	Tarutao NP	Southern Offshore Islands

Formerly, coral reef monitoring both inside and outside protected areas was the mandate of the DMCR. However a 2015 agreement transferred monitoring inside protected areas to DNP to ensure data were used in a timely manner for adaptive management. This task is now led by DNP's four MNPOCs. For the Northern Andaman region (Ranong, Phang-nga, Phuket), the monitoring work is covered by MNPOC No.2. For Phuket and the Southern Andaman region (Krabi, Trang, Satun), monitoring is covered by MNPOC No.3 Trang.

From April 2012 until February 2018, I continued to conduct field work with the Marine National Park Operation Center no. 2 (MNPOC Phuket) and no. 3 (MNPOC Trang), and Phuket Marine Biological Center (PMBC) at key study sites of Mu Ko Surin and Mu Ko Similan NP. Based on seascape-wide surveys, I selected Mu Ko Surin National Park as my focal site due to its trajectory of coral recovery and proximity to Myanmar. I also conducted coral reef resilience assessments in the Myeik Archipelago in Myanmar joining IUCN's two-week liveaboard expeditions in February 2014 and January 2015 (See survey summary and itineraries in **Appendix VII**).

4.5 Coral bleaching impact workshop

In October 2013, I co-organized a multi-stakeholder workshop in Phuket, Thailand as part of the project 'Building Capacity for Socio-ecological Resilience to Coral Bleaching Events & Climate Change in Indonesia, Malaysia and Thailand' by an international team of scientists from NOAA and USAID (See agenda and the list of participants in **Appendix VIII**). This workshop invited university researchers, government officials (DMCR, DNP), local dive operators and NGOs to investigate the impacts of the 2010 bleaching event and develop options for responsive actions focusing on the Andaman coast. Background presentations were given on the causes of bleaching

and the temperature stress and ecological impacts of the 2010 bleaching event. Workshop participants then participated in small group discussions to identify the impacts of bleaching in their area and the main questions they had about bleaching. Group discussions were followed by expert presentations on the impacts of the 2010 bleaching event on diver satisfaction, dive operators and the economy, based on data collected in each workshop location during the 2010 event. The morning concluded with a synthesis exercise in which participants confirmed a list of impacts and questions developed during the group discussions; participants then voted on the impact they considered most important, the question they most wanted answered, and the future scenario they thought most likely for the dive industry in their area given projections of increases in the frequency and severity of bleaching.

The afternoon session of each workshop focused on investigating actions that could be taken in response to the short- and longer-term implications of bleaching. Presentations were given on plans for responding during bleaching events, based on existing best-practice models from Malaysia and Bali, Indonesia. Expert presentations then offered ideas for supporting longer-term ecological and social resilience based on the best available science. Following these presentations, workshop participants participated in small-group discussions to identify responsive actions and questions they had about taking action. The afternoon concluded with synthetic exercise in which participants confirmed a list of actions and questions developed during the group discussions and voted on those that they found most important. The findings of these discussions are presented in the results Chapter (Ch 5)

4.6 Management effectiveness evaluation workshop

Management effectiveness evaluation assesses how well protected areas are being managed – primarily the extent to which management is protecting values and achieving goals and objectives (IUCN 2012). Understanding management effectiveness of MPAs in the Andaman is key to determine appropriate conservation strategies in developing MPA networks in the face of climate change. I helped facilitate a series of workshops to evaluate the management effectiveness of Thailand's marine and coastal protected areas from June-August 2011 in Chumporn and Phuket with IUCN and DNP (See agenda and the list of participants in **Appendix IX**). I provided input for system-level assessments as well as site-specific assessments. This mission was supported by World Wide Fund for Nature (WWF)'s 'Strengthening Andaman Marine Protected Areas Network (SAMPAN) project and I became involved with the project again at a later stage providing key recommendations when I joined WWF – Thailand Programme (2012-2014) and subsequently the IUCN Southeast Asia Group (2014-2018) (See key recommendations in **Appendix X**).

A framework for assessing management effectiveness of protected areas was developed by IUCN's World Commission on Protected Areas (WCPA) in 2000 and revised in 2006 (Hockings et al. 2006). The assessment considers elements of the management cycle including; 1) context, 2) planning, 3) inputs, 4) process, 5) outputs and 6) outcomes. This framework forms the basis for over 90% of protected area management effectiveness work carried out around the world (IUCN 2012). The system level assessment was built around a questionnaire, which follows the WCPA framework. Each question was assessed on a four point scale, rated against optimal conditions: 0-25%, 26-50%, 51-75% and 76-100%. In total 44 questions provided an overview of system performance for marine and coastal protected area in Thailand.

The workshop participants were representatives from marine national parks and their respective Protected Areas Advisory Committee (PAC). I was responsible to lead the discussion for the Andaman MPAs and these assessments proved very useful in forming the basis for Chapter 5, discussing improved management activities to enhance the resilience of the field study sites to climate change impacts.

Additionally, I interviewed and consulted with key personnel from several ongoing projects in relation to the marine protected area system namely, the Andaman Sea Nature Reserves Management Plan (Prince Songkla University (PSU)/DNP, 2010), Catalyzing Sustainability of Thailand's Protected Area System (CATSPA) (UNDP/DNP, 2016), Bay of Bengal Large Marine Ecosystem (BOBLME) (Food and Agriculture Organization (FAO)/Department of Fisheries (DoF, 2015)), Preliminary Protected Area Gap Analysis, and Framework for the Protected Area Master Plan (Dearden & Noppawan, 2011), Saving Thailand's Natural Heritage: Preparing a National Protected Areas System (McNeely, 2015), Biodiversity Finance Initiative (BIOFIN) (UNDP, 2017), Mangrove for the Future (MFF) 2014-18 (IUCN, 2018), and Thailand-Myanmar Ecological Connectivity and Transboundary MPAs Preliminary Analysis (DMCR, 2018). A list of key informants can be found in **Appendix XI**).

4.7 Data analysis

Resilience assessment

Primary data and the resilience scores from the twenty-two indicators in sixty-two sites were stored in Microsoft Excel spreadsheets. Based on previous literature (Maynard et al. 2010, Maynard et al. 2015) and discussion at the Thailand coral reef workshop, the difference between the highest resilience score and the lowest score was divided by three to classify sites into three

group; low, moderate and high resilience, relative to the other sites contained within the analysis. The result was presented in the form of a table and map to illustrate the distribution in accordance to resilience scores.

Further analysis was made for resilience scores at Mu Ko Surin National Park. Maynard et al. (2010) weighted resilience indicators into three different categories, i) critically important (score x3) e.g. coral cover, abundance of resistant/tolerant species, connectivity; ii) very important (score x2) e.g. cooling factors, abundance of mature coral colonies, herbivore abundance; and iii) important (score x1) e.g. shading factors, fishing pressure, coral disease. There had been minimal testing of the relative importance of different resilience indicators until McClanahan et al. (2012) identified eleven key factors based on scaling scientific evidence and achievability of quantifying the factors. The evaluation, the first rigorous assessment of factors promoting coral reef resilience, supports the concept that, despite high ecological complexity, relatively few strong variables can be important in influencing ecosystem dynamics (McClanahan et al. 2012).

In the coral reef resilience indicator workshop that I cohosted with DMCR (**section 4.2**), there was no consensus on a standard weighting scale recommendation for Thailand. It was agreed by the meeting that weightings can be justified by each assessor for site-based assessments according to the local situation. For the case study presented here, I weighted the resilience indicators based on the following: (1) the strength of the relationship between the indicator and reef resilience as prioritized in published literature, and (2) the applicability to the case study region. Indicators with strong links to resilience were classified as ‘very important’ and the remainder as ‘important’. Within the results section, the impact of weighting is made clear by comparing the resilience rankings of the highest and lowest-scoring sites with rankings produced when all indicators are unweighted.

Potential MPA network

In a conservation context, gap analysis is a method to identify biodiversity (i.e., species, ecosystems and ecological processes) not conserved adequately within a protected area network (Dudley & Parish 2006). Gap analysis is normally applied to a large area across the whole landscape of an ecologically defined region such as an ecoregion or bioregion (Parish et al. 2003). This allows conservation decisions to be made on the basis of ecological information rather than political boundaries. The Convention on Biological Diversity (CBD) Programme of Work on Protected Areas provides guiding principles for gap analysis to create ecologically representative protected area systems (Dudley & Parish 2006) as follow: 1) Ensure full representation, 2) Aim for redundancy, 3) Design for resilience, 4) Consider representation gaps, ecological gaps and management gaps in the analysis, 5) Employ a participatory approach and 6) Make protected area system design an iterative process. Generally, a gap analysis process consists of mapping three data layers – first step is biophysical inventory mapping, then framework for representation, then existing PAs (USGS 2019). Coral reef ecosystems, seagrass beds and mangroves provide many important ecosystem services including primary production, fisheries and the maintenance of high species diversity (Moberg & Folke 1999; Harborne et al. 2006). This research adopted the gap analysis approach and used three critical habitats namely coral reef, seagrass and mangrove along the Andaman coast as conservation targets because they provide critical ecosystem goods and services both individually and through functional linkages.

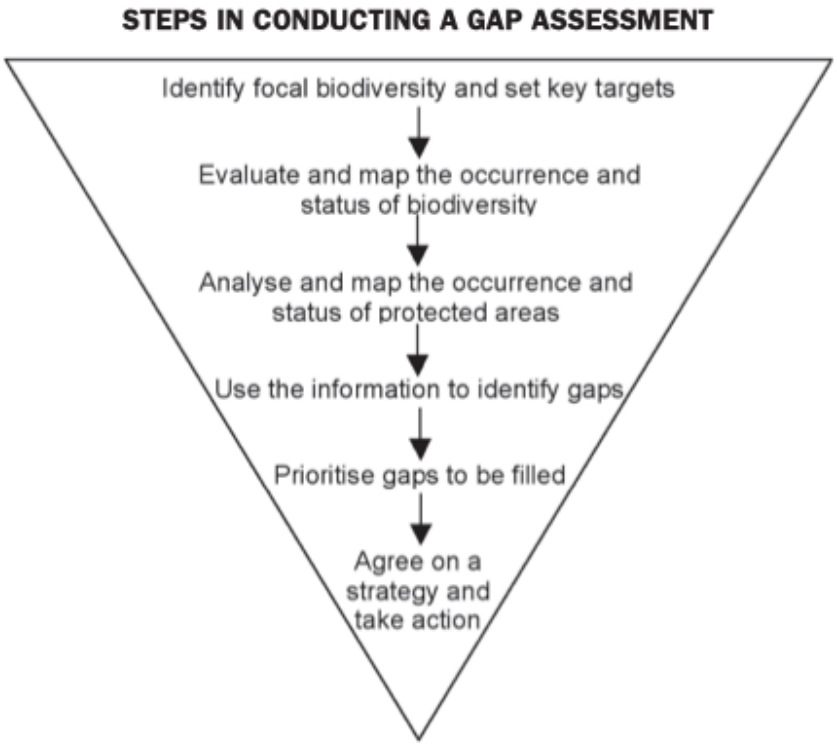
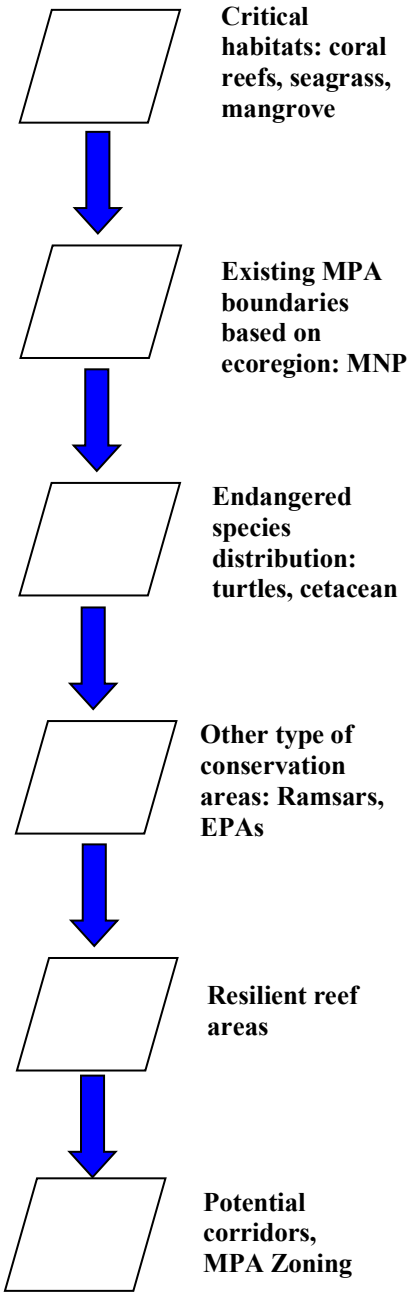


Figure 9. Key steps in a protected area gap analysis (Dudley & Parish 2006).

Existing MPAs on the Andaman coast were assessed according to general recommendation for developing resilient MPA network design (IUCN-WCPA, 2008, McLeod et al. 2009, 2019) including minimum size (10-20 km in diameter), shape (simple), representation (protect at least 20-30% of each habitat type), critical areas (protect biologically or ecologically important), and connectivity (maximum distance of 15-20 km apart). Twenty two MPAs were assessed for average size, shape and spacing. A review of critical habitat (i.e. coral reef, seagrass and mangrove) protection by existing Andaman MPAs for coral reef, seagrass and mangrove was conducted using geometry calculation in geographic information system (GIS) software (ArcGIS 10.1). The analysis focused on the 6 distinct Andaman ecoregions (**Figure 10**) to further understand the gaps and opportunities at a finer scale. Spatial data was prepared based on three

sources 1) the World Heritage Nomination GIS database for ecoregion boundaries), 2) DMCR natural resource GIS database for marine and coastal resources (e.g. coral reef, seagrass, mangrove, marine endangered species, coral bleaching), 3) DNP marine national park GIS database for marine park and non-hunting are boundaries and natural resources inside the park. Spatial data analysis was conducted by overlaying data layers and buffering the area. Area calculations were made through the ArcGIS geometry calculation. Spaces between MPAs were measured with the distance to point tool. The results were visualized and displayed in maps (Chapter 5).

Recommendations for establishing a resilient MPA network in the Andaman were developed based on the results of field resilience assessments, management plan review and management effectiveness evaluation workshops jointly organized with DNP and IUCN (See ten key recommendations in **Appendix X**). Further insight was gained from interviews and consultation with key personnel from several ongoing projects on the Andaman coast (See the list of key personnel in **Appendix XI**). These results are discussed and incorporated in the recommendations for MPA network enhancement in Chapter 5.



Data input	Objectives
Country level -MPA boundary -MPA definition	To verify Thailand's MPA coverage against 10% goal of CBD's Aichi Target by 2020
Andaman bioregion - MPA size - MPA shape	To determine average size and shape of current MPAs against recommended size (at least 10-20 km in diameter and simple shape)
Andaman bioregion - Spaces between MPAs	To calculate spacing to assess connectivity against a goal of maximum space 15-20 km apart
Andaman's six ecoregions --MPA boundary --Coral reefs coverage - Seagrass coverage - Mangrove coverage	To identify gaps and opportunities for marine protection based on critical habitat of each ecoregion against 30% global recommendation
Andaman MPA network -Resilient reef areas - Endangered species feeding ground - Critical habitats - Ramsar sites - Environmental Protection Areas - 3 km buffer area from coast	To identify potential ecological corridor for a resilient Andaman MPA network
Mu Ko Surin N -Resilience scores -Anthropogenic impacts	To recommend management interventions (Zoning) based on resilience assessment result - Protection zone - Recovery zone

Figure 10. Illustration of data input and objectives for analysis

4.8 Social media tracking

I have been writing a personal blog on environmental conservation issues on a Facebook page named ‘Sunshine Sketcher’ (Page ID 119055914810635) since 2010. Currently, there are approximately 20,000 followers with Post Reach of 10,000 to 50,000 people weekly. In 2014, this Facebook page had around 3,000 followers and reached a few thousand people weekly depending on the frequency and content of the posts.

Using this Facebook page, I launched a science communication and education campaign focused on the importance of parrotfish in saving coral reefs using online social media platforms in order to prevent the expansion of the market. I previously posted on parrotfish ecology and its role in maintaining coral reef resilience before parrotfish became widely available in markets. The first content about the sale of parrotfish in Thai supermarkets was posted on June 19, 2014 and reposted again on June 21, 2014. Within 3 days, these two posts reached more than 1 million people and were shared more than 9,500 times. Subsequently, five more parrotfish posts were made on June 24, June 27, July 4, July 5 and July 9.

To mobilize public support, an online petition was planned in cooperation with change.org, one of the internet's leading online platforms for starting campaigns, mobilizing supporters, and working with decision makers to drive solutions. The online petition ‘Save Parrotfish’, demanding the ban of the commercial sale of parrotfish in Thailand, was launched on July 18, 2014, on behalf of a local NGO called Reef Guardian Thailand where I am the group advisor. The petition targeted the CEOs of all five major retailers in Thailand that sell parrotfish. The issue was communicated widely to the public through mainstream media (both print and television). I was interviewed more than ten times including a live news talk show in primetime evening news by the Nation TV.

The number of people and social media engagement for each post throughout the campaign was tracked. Media coverage was documented. The media value, which is an industry measure for giving Public Relations a monetary value for both online and offline coverage was calculated based on the Thailand media tracking report (The Government Public Relations Department).

Chapter 5

Results

This Chapter consists of 4 sections. The first section presents the identification of resilient reef areas after the 2010 mass coral bleaching in Thailand's Andaman Sea. The second section assesses coral reef resilience to help identify management actions at Mu Ko Surin National Park, Phang-Nga. This is followed by the third section presenting options for developing the MPA network on the Andaman coat of Thailand to enhance ecosystem resilience. The final section considers resilience communication based on the findings from the parrotfish social media campaign.

5.1 Identifying resilient reef areas after the 2010 mass coral bleaching in Thailand's Andaman Sea

Thailand's Andaman Sea experienced unprecedented mass coral bleaching in 2010, Approximately, 50-90% of corals suffered bleaching throughout the reef areas in every province along the Andaman coast both inside and outside Marine Protected Areas (MPAs). The results show that the bleaching pattern is not uniform and differs both at regional and local scales. This section presents the results of the coral reef bleaching workshop and the reef resilience assessment framework described in Chapter 4.

5.1.1 Impact of the 2010 coral bleaching

The multi-stakeholder workshop on the 2010 coral bleaching event (section 4.5) aimed to build capacity within key stakeholders, scientific, government, and civic organizations in Thailand to increase the resilience of coral reefs to sudden climate change impacts such as the 2010 coral bleaching event. The workshop helped raise awareness about the impacts of mass bleaching and

climate change on coral reef ecosystems, reef-dependent tourism operators, and local and national economies. It also strengthened interactions among scientists, government decision-makers, and reef-dependent tourism operators to facilitate improved decision-making processes at local to national levels. Results from this workshop (**Table 5-7**) formed the basis for the coral bleaching monitoring and response plan developed by Department of Marine and Coastal Resources (DMCR) that was used during the 2016 mass coral bleaching event and identified management interventions by the Department of National Parks, Wildlife and Plant Conservation (DNP), such as area closures for restoration.

Table 5. Top ten bleaching impacts identified by workshop participants through small group discussions and individual voting (Shuttenberg et al. 2014)

1	There have been decreases in fish and biodiversity
2	Coral reef condition and dive operators are more affected by issues other than bleaching
3	There have been negative impacts on overall coral reef condition
4	Loss of shallow reefs has caused coastal erosion
5	Dive operators did not know what to do
6	Dive operators adapted operations by changing sites or the kinds of trips they offered
7	After the bleaching there are a limited number of good sites and competition for sites has increased, potentially leading to conflict with fishers
8	The local community did not know what was happening and was not affected
9	Some divers were upset or concerned, and some asked for a different site or did not want to return because of the bleaching
10	In many cases, bleaching was extensive

Table 6. Top ten responsive actions identified by workshop participants through small group discussions and individual voting (Shuttenberg et al. 2014)

1	Improve engagement, coordination, and communication between government, businesses, NGOs, and local communities about coral reef management issues
2	Implement education and outreach programs to raise awareness, particularly for snorkelers and divers
3	Enforce existing rules, particularly those related to marine parks and fisheries
4	Improve communication and coordination during bleaching events by developing and/or socializing Bleaching Response Plans and forming Response Committees
5	Close sites and/or reduce the number of divers at certain locations during bleaching events
6	Develop and implement codes of conduct and certification programs for divers, dive operators, snorkel guides, and tourism businesses
7	Create and use alternative dive sites, such as wrecks and artificial reefs
8	Implement restrictions other than site closures during bleaching events
9	Improve water quality
10	Implement reef monitoring by dive operators and scientists

Table 7. Top 20 questions identified by workshop participants through small group discussions and individual voting (Shuttenberg et al. 2014).

1	How to get stakeholders engaged in the sustainable use and conservation of coral reefs?
2	How should we report bleaching, share information, and coordinate during bleaching events?
3	Who has the responsibility to implement the management actions identified at these workshops?
4	Which actions are most effective for helping reefs recover before, during, and after bleaching?
5	What kind of tourism "codes of conduct" work to improve environmental stewardship and do they require a dedicated authority to provide oversight?
6	How much area should be protected to support resilience and for how long? How much extra time to we get for investing in resilience?
7	How to get financial support to implement reef management actions?
8	How to implement site closures, including how to design, communicate, enforce them while protecting dive operators from negative economic impacts?
9	Can restoration, transplantation, or "technical interventions" help corals resist and/or recover from bleaching?
10	What roles and responsibilities do different institutions have during bleaching events?
11	How can we reverse ecological impacts?
12	Why is the bleaching impact different between sites & depths?
13	How can we better increase transparency, reduce corruption, and improve enforcement?
14	Beyond coral bleaching, what are the broader governance arrangements for reef management
15	What are the pros and cons of closing sites to divers and snorkelers during bleaching events
16	What is coral bleaching and what causes it?
17	How does bleaching affect fish, fisheries, and sharks?
18	Which education and outreach strategies are most effective for raising awareness during bleaching events?
19	How much of the reef will recover from bleaching? When?
20	What are the impacts of bleaching on tourism and national & local economies?

5.1.2 Coral reef resilience assessment in the Andaman bioregion

The results of the reef resilience assessment of 62 sites across the Andaman described in section 4.4 are shown in **Table 8** and **Figure 11-12**.

Table 8. Summary of resilience rankings and scores for all indicators for all sites across the Andaman

				ecological-condition												physical- connectivity					management-oriented				
Code	Site	Rank	Total	Live coral cover	Abundance of coral recruits	Class size	Abundance of bleaching resistance species	Species richness	Coral predator	Abundance of coral competitors	Coral diesease prevalence	Herbivore diversity	Herbivore abundance	Abundance of predatory fish	Abundance of fisheries target species	Severity from the latest bleaching event	Survial from last bleaching event	Proximity to other coastal habitats	Cooling factors	Shading factors	Fishing pressure	Physical damage	Nutrient and pollution	Sediment loading	Management
	Resilience conferred: = Least = Some = Most																								
T41	Ko Yung	1	83	2	5	3	3	3	5	5	4	5	5	4	3	2	5	3	4	2	3	4	5	5	3
T28	Ko Huyong	2	82	2	3	4	4	2	5	5	4	5	5	3	3	3	3	2	4	1	4	5	5	5	5
M1	Nga Khin Nyo	3	81	4	4	3	3	4	4	4	4	4	4	3	3	5	4	2	3	3	4	4	4	5	3
T27	Ko Payang	4	80	2	3	3	3	2	5	5	4	5	5	5	4	3	3	2	4	1	4	5	4	4	4
M2	Cockburn Islands	5	79	4	3	4	4	4	4	4	3	4	4	3	3	5	4	2	3	2	4	4	4	4	3
T40	Laem Hang Nak	6	78	2	5	3	3	2	5	5	4	5	5	2	3	2	5	3	4	1	4	4	5	4	2
T17	Ko Phra Thong offshore	7	77	3	3	4	4	4	3	4	4	4	4	3	3	4	4	3	3	4	3	3	4	4	2
T19	Ko Tachai S	8	77	2	4	4	4	3	3	5	3	4	4	4	3	3	3	2	4	2	4	4	4	4	4
T54	Ko Hin Ngam	9	77	4	2	5	5	2	5	5	4	5	4	1	2	1	3	2	4	1	4	5	4	5	4
T56	Ko Batong	10	77	3	2	5	5	3	5	4	3	5	4	2	1	1	4	2	4	1	4	5	5	5	4
T07	Ao Chak	11	76	2	3	5	2	4	4	4	4	4	4	3	3	2	2	2	3	3	3	5	5	5	4
T20	Ko Bon	12	76	3	3	4	3	2	4	5	4	4	4	4	3	3	3	1	4	2	4	4	4	4	4
T22	Ko Similan N	13	76	2	3	4	4	2	5	5	4	5	5	3	2	3	3	2	4	1	4	4	3	4	4
T51	Tarutao Station	14	76	3	2	5	5	1	5	5	4	5	4	1	2	1	3	2	4	1	4	5	5	5	4
T55	Ko Ra Wee	15	76	3	2	5	4	3	5	4	4	5	4	1	1	2	3	2	4	1	4	5	5	5	4
T11	Ao Suthep	16	75	2	4	4	2	4	4	4	4	4	4	2	4	2	2	2	3	3	4	5	4	4	4
T21	Ko Ba-ngu	17	75	1	4	4	2	2	5	5	4	5	5	3	2	3	3	2	4	1	4	4	4	4	4
T47	Ko Rok (Central)	18	75	2	2	5	4	2	5	4	4	5	5	2	2	1	2	2	3	1	5	5	5	5	4
T52	Adang West	19	75	3	2	5	4	2	5	5	4	5	4	1	2	1	3	2	4	1	4	5	4	5	4
T53	Adang South	20	75	3	2	5	5	2	5	4	4	5	4	1	1	1	3	2	4	1	4	5	5	5	4
M3	Nyaung Oo Phee	21	75	4	3	4	3	3	3	3	4	4	3	4	3	4	4	2	3	2	3	4	4	5	3
T24	Ko Similan SE	22	74	2	2	3	4	2	5	5	4	5	4	3	2	3	3	2	4	1	4	4	4	4	4
T35	Ko Racha Noi	23	74	2	2	5	4	2	5	4	5	4	4	2	3	2	4	2	4	1	4	4	4	4	3
T42	Ko Pai	24	74	2	4	3	2	3	5	4	4	2	5	3	4	2	5	2	4	1	4	3	5	4	3
T13	Ao Tao	25	73	2	3	3	5	3	4	4	3	3	3	3	3	3	3	2	3	3	4	4	4	4	4
T37	Ko Lipi	26	73	2	4	4	4	3	5	5	4	4	4	3	3	2	4	2	4	2	2	3	4	4	1
T34	Ko Racha Yai	27	73	2	4	4	4	2	5	4	4	4	4	2	2	2	4	2	4	1	4	3	5	4	3
T48	Ko Liang Nua	28	73	3	2	5	4	2	5	4	4	4	4	2	3	1	2	5	3	2	3	4	4	4	3
T50	Bulon Le	29	72	3	2	5	4	3	4	3	4	4	4	3	4	1	2	4	4	1	3	4	3	4	3
T49	Bulon Mai Phai	30	71	2	2	5	4	3	5	4	4	3	5	3	3	1	2	4	3	1	3	4	3	4	3
M5	Dunkin	31	71	3	3	4	4	3	3	3	4	3	3	3	2	4	4	2	3	2	3	4	4	4	3
T14	Ao Phakkad	32	70	1	2	5	3	3	3	4	4	5	4	1	2	2	3	2	3	3	4	4	4	4	4

Table 8 Summary of resilience rankings and scores for all indicators for all sites across Andaman (cont.)

				ecological-condition												physical- connectivity					management-oriented				
Code	Site	Rank	Total	Live coral cover	Abundance of coral recruits	Class size	Abundance of bleaching resistance species	Species richness	Coral predator	Abundance of coral competitors	Coral diesease prevalence	Herbivore diversity	Herbivore abundance	Abundance of predatory fish	Abundance of fisheries target species	Severity from the latest bleaching event	Survial from last bleaching event	Proximity to other coastal habitats	Cooling factors	Shading factors	Fishing pressure	Physical damage	Nutrient and pollution	Sediment loading	Management
Resilience conferred: = Least, = Some, = Most																									
T23	Ko Similan NE	33	70	1	2	3	3	1	5	5	4	5	5	2	2	3	3	2	4	1	4	3	4	4	4
T26	Ko Miang	34	70	2	2	3	4	3	4	4	3	4	4	3	3	3	3	2	3	1	4	3	4	4	4
T18	Ko Tachai E	35	69	2	2	3	4	1	4	4	4	4	4	1	2	3	3	2	4	2	4	4	4	4	4
T30	Nai Yang	36	68	3	4	4	4	3	4	4	3	3	4	3	2	3	3	2	3	1	3	4	3	3	3
T29	Tai Muang nearshore	37	68	3	3	4	3	3	3	3	4	3	3	3	3	4	4	3	3	2	2	3	3	4	2
T08	Ao Maeyai	38	68	2	2	4	3	3	3	4	2	4	4	2	3	2	2	2	3	3	4	4	4	4	4
T25	Ko Payu	39	68	2	2	3	1	1	5	4	4	4	4	3	3	3	3	2	3	1	4	4	4	4	4
T31	Laem Ao Po	40	68	3	4	4	4	3	4	4	3	3	3	3	2	3	3	2	3	1	3	4	3	3	3
T06	Ko Stock	41	67	1	1	5	2	2	4	1	4	4	4	2	3	2	2	2	4	3	3	4	5	5	4
T10	Ko Pachumba	42	67	1	1	5	3	2	4	4	4	3	3	4	1	2	2	2	4	3	3	4	4	4	4
T09	Ao Mai-ngam	43	67	2	3	3	2	3	4	2	3	4	4	2	3	2	2	2	3	3	4	4	4	4	4
T36	Ko Yao Noi	44	67	2	3	3	4	2	3	3	3	3	3	3	2	3	3	3	4	4	3	3	3	3	4
T39	Ko Khai Nai	45	67	1	4	4	2	2	3	3	4	3	4	3	3	2	4	4	4	1	4	3	3	3	3
M6	Cocks Comb	46	67	2	3	3	3	3	4	3	3	3	2	3	2	3	3	2	3	4	3	3	4	5	3
T38	Ko Yao Yai	47	66	1	3	3	4	3	3	3	3	3	3	3	2	3	3	3	4	4	3	3	3	3	3
M4	Zadetkyi South	48	66	2	3	4	3	3	3	4	3	3	3	3	2	3	3	2	3	2	3	3	4	4	3
T03	Ko Kang Kao	49	64	2	2	3	3	2	3	3	4	3	3	2	2	3	3	3	3	3	3	4	3	4	3
T12	Ao Sapparod	50	64	1	1	3	3	2	4	3	4	3	4	4	1	2	2	2	3	3	3	4	4	4	4
T15	Ko Torinla	51	62	1	1	3	3	2	4	1	4	3	3	3	2	2	2	2	3	3	4	4	4	4	4
T16	Hin Pae	52	61	1	1	3	2	2	4	1	5	1	4	2	2	2	2	2	5	3	3	4	4	4	4
T33	Ko He	53	61	2	4	3	3	2	3	3	2	3	3	2	3	2	4	3	3	1	4	3	3	2	3
T45	Ko Chueak	54	61	2	2	4	3	1	4	3	3	3	3	2	1	1	3	4	4	4	3	3	2	3	3
T46	Ko Kradan	55	61	2	2	4	3	2	3	3	3	3	3	2	1	1	3	4	4	3	3	3	2	4	3
T43	Ao Ton Sai : Phi Phi Don	56	60	1	4	4	2	2	3	3	3	4	4	2	2	2	4	2	3	1	3	3	3	2	3
T44	Ko Ngai (South)	57	60	3	1	3	4	2	3	3	4	3	3	2	2	1	2	2	3	1	3	3	4	4	4
T01	Mu Ko Chang	58	59	1	2	3	3	2	4	3	3	2	2	2	2	3	3	4	3	3	2	3	3	3	3
T05	Ko Kam Nui	59	59	1	2	3	3	3	3	3	3	3	3	2	2	2	3	2	3	3	3	3	3	3	3
T32	Laem Panwa	60	59	1	4	3	3	3	3	3	3	3	3	2	2	2	4	4	3	1	2	3	3	1	3
T04	Ko Kam Yai	61	58	1	2	3	3	2	3	3	3	3	2	2	2	3	3	2	3	3	3	3	3	3	3
T02	Ko Payam	62	51	1	2	2	3	2	3	2	3	2	2	1	1	3	3	4	3	3	1	2	3	3	2

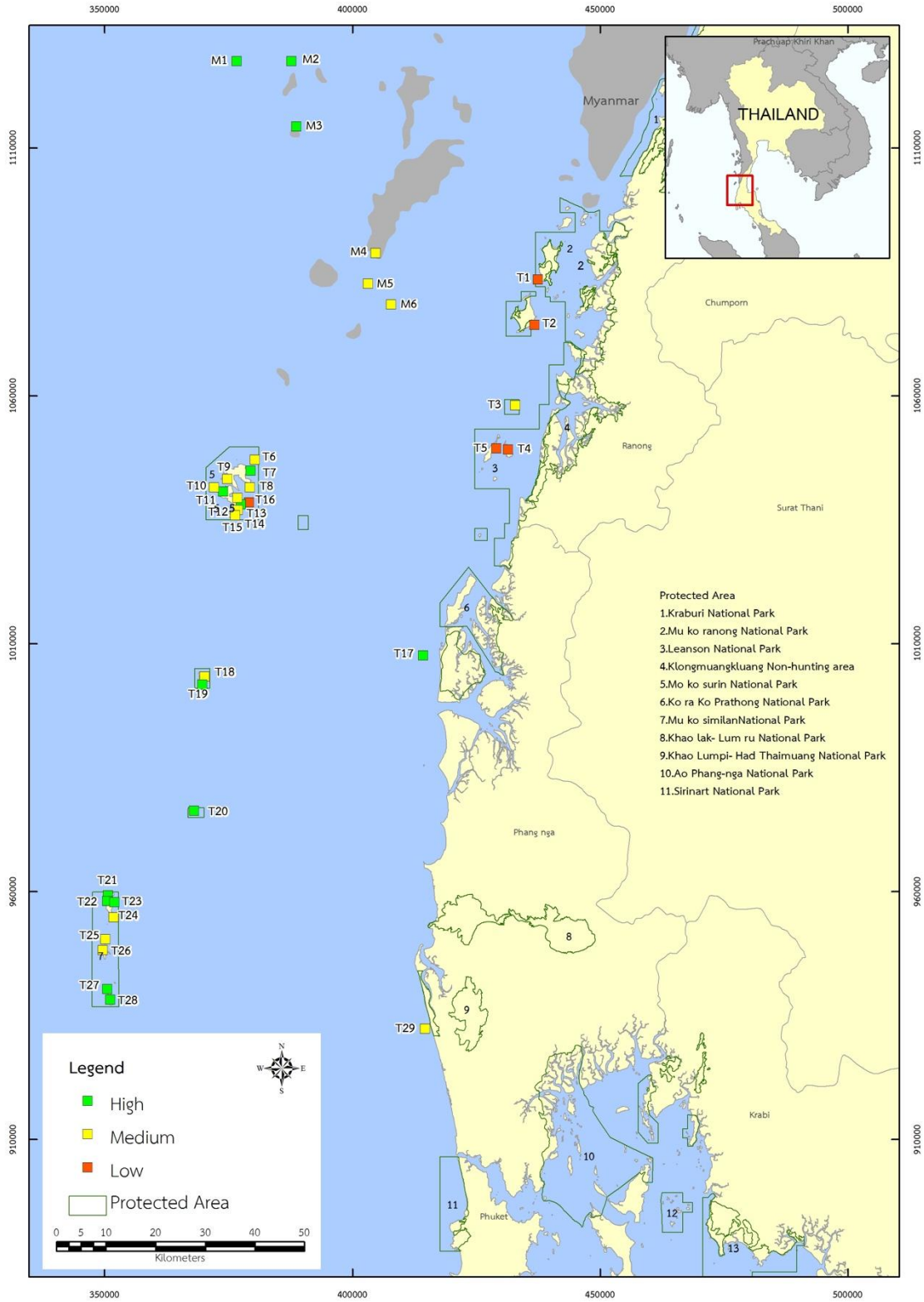


Figure 11. Study sites along the Northern Andaman coast with their resilience rankings.

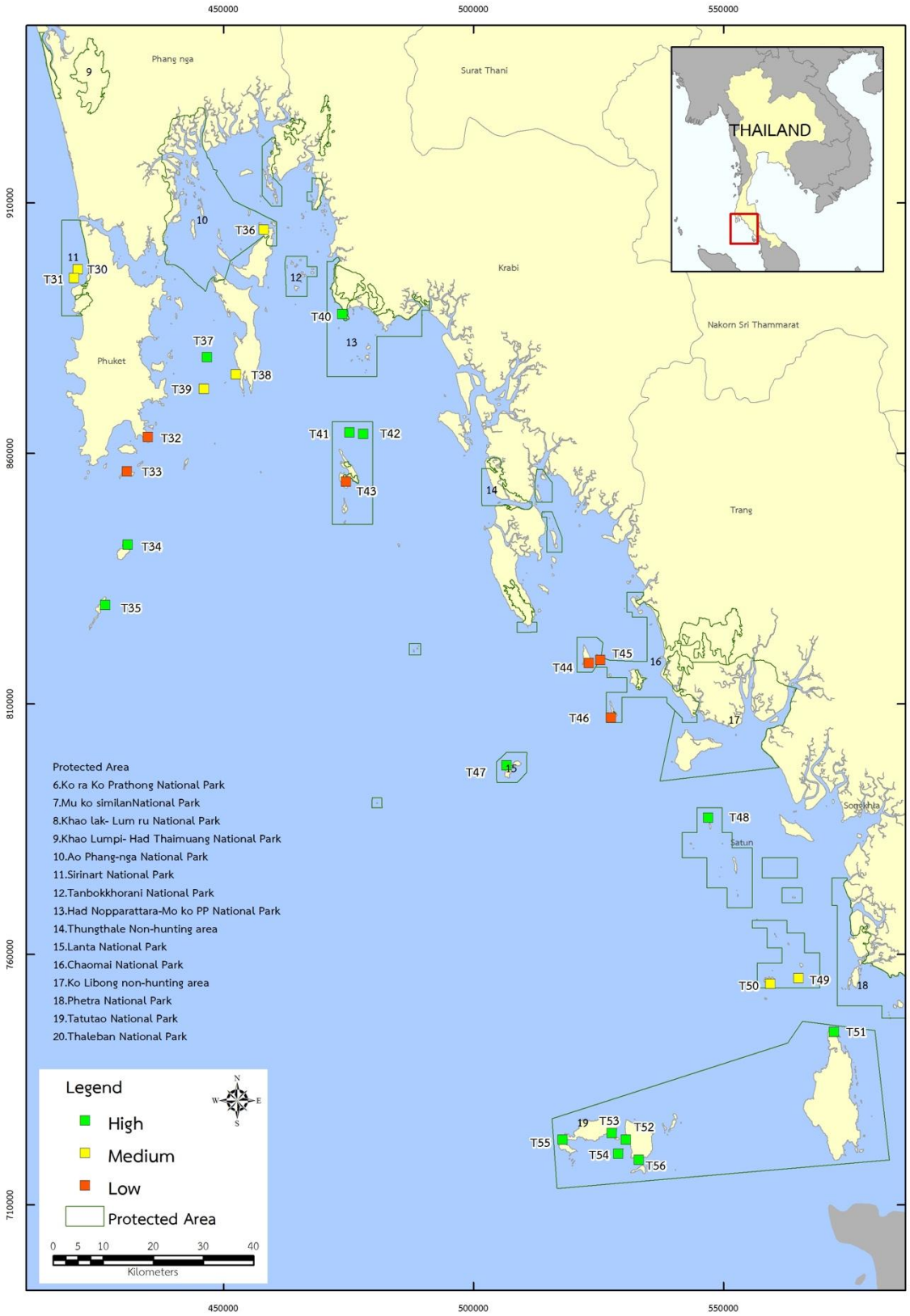


Figure 12. Study sites along Southern Andaman Coast with their resilience rankings.

Identification of resilient reefs based on resilience scores

Resilience scores ranged from 51 for the lowest-scoring site at Ko Payam (T02) to 83 for the highest-scoring site at Ko Yung (T41) in Hat Noppharat Thara-Mu Ko Phi Phi NP (**Table 8**). Twenty-eight sites were classified as high resilience. They were mainly located far off shore (**Figure 11 &12)** from Nha Khin Yo (M1), Cockburn Islands (M2) and Nyaung Oo Phee (M3) in Myanmar to Mu Ko Surin and Similan all the way to Mu Ko Adang-Rawee in the Southern Andaman. Twenty-three sites were classified as moderate and eleven sites were grouped as low resilience. It is notable that the majority of low-scoring resilience sites are located near major human settlements (**Figure 11&12**).

The northern Andaman sites suffered very high mortality from the 2010 mass coral bleaching event but the recovery differed markedly from site to site even within the same island group (e.g. Mu Ko Surin or Mu Ku Similan). Interestingly, coral reefs in offshore island groups in the southern Myeik Archipelago were not affected by the 2010 bleaching event as evident by very high live coral cover (61-80%) in all three sites.

5.2. Assessing coral reef resilience to help identify management actions at Mu Ko Surin National Park, Phang-nga, Thailand

The topography of Mu Ko Surin (see **Figure 13**) is suitable for the development of coral reefs with large bay areas providing good wave protection, clear water and optimum temperatures. Most reefs around Mu Ko Surin are fringing reefs on sandy bottoms and were originally dominated by branching coral species (*Acropora* spp.).

Eleven monitoring stations were selected for resilience assessment. Most of these transects are permanent monitoring stations used by the Marine National Park Operation Center (MNPOC) of the Department of National Parks, Wildlife and Plant Conservation (DNP). One hundred meter permanent transects have been developed by researchers at Phuket Marine Biological Center (PMBC) since 1986 using the line intercept methodology as described in Chapter 4. Some transects were adapted over time but the majority remain unchanged. Ao Sapparos was not a long-term site but was added because of the proximity to human settlement (Moken village). These 11 study sites are fringing reefs dominated by branching, laminar and encrusting of *Acropora, Porites* and *Montipora* – most of which were severely affected by the 2010 bleaching event **(Figure 5**)

Twenty-two resilience indicators (**Table 3**) were used to assess the 11 selected stations at Mu Ko Surin . A system of resilience indicator weighting was devised and tested to differentiate the results at finer scale based on different contribution to the nature and magnitude of ecosystem resilience. This process is described in the next section.

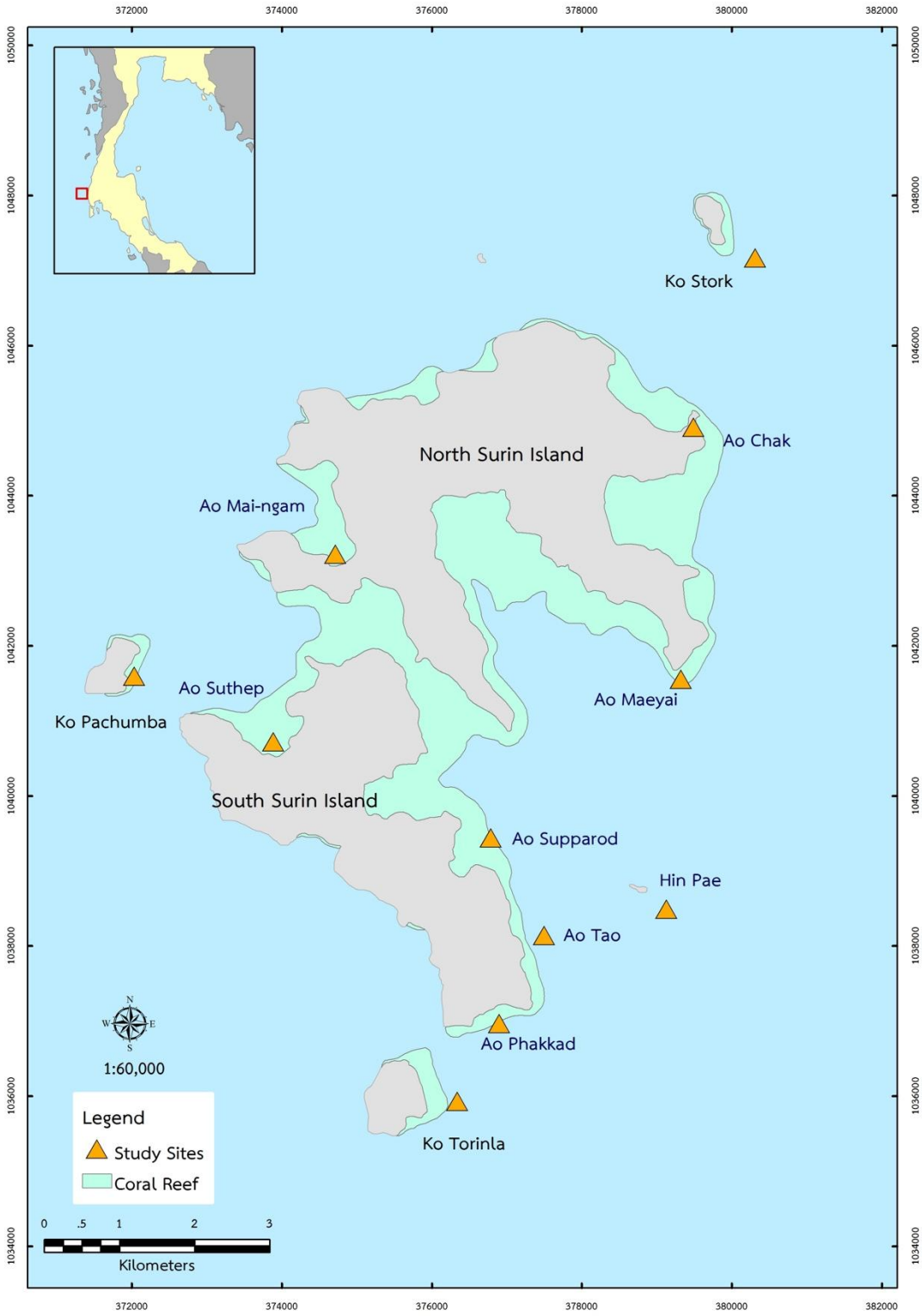


Figure 13. Mu Ko Surin National Park and survey stations.

Table 9. Study sites and physical characteristic of Mu Ko Surin National Park

No	Station	Site Description	Coordinate
10	Ao Chak	An exposed bay, located northeast of Ko Surin Nua. Coral reef occurred at 1 to 17 m in depth, 250 m in width from the coast.	9°27'17.65''N, 97°53'50.53''E
2	Ao Mae Yai	An exposed bay, located southeast of Ko Surin Nua. Coral reef occurred at 0.5 to 21 m in depth, 120 m in width from the coast.	9°25'27.55''N, 97°53'50.80''E
3	Ao Mai Ngam	A sheltered bay, located east of Ko Surin Nua. Coral reef occurred at 1 to 13 m in depth, 120 m in width from the coast	9°26'12.30''N, 97°51'24.56''E
4	Ao Suthep	A sheltered bay, located north of Ko Surin Tai. Coral reef occurred at 1 to 14 m in depth, 250 m in width from the coast	9°24'48.46''N, 97°50'56.70''E
5	Ao Phak Kat	An exposed bay, located south of Ko Surin Tai. Coral reef occurred at 0.5 to 18 m in depth, 90 m in width from the coast.	9°22'48.23''N, 97°52'53.79''E
6	Ao Tao	An exposed bay, located west of Ko Surin Tai. Coral reef occurred at 1 to 22 m in depth, 85 m in width from the coast.	9°23'32.99''N, 97°52'52.71''E
7	Ko Stork	An exposed bay, located north of Mu Ko Surin. Coral reef occurred at 1.5 to 20 m in depth, 150 m in width from the coast.	9°28'20.46''N, 97°54'20.77''E
8	Ko Pachumba	An exposed bay, located west of Mu Ko Surin. Coral reef occurred at 0.5 to 20 m in depth, 200 m in width from the coast	9°25'17.11''N, 97°50'09.20''E
9	Ko Torinla	An exposed bay, located south of Mu Ko Surin. Coral reef occurred at 1 to 18 m in depth, 100 m in width from the coast.	9°22'30.17''N, 97°52'13.17''E
10	Hin Pae	A pinnacle, located east of Ko Surin Tai. Coral reef occurred at 2 to 16 m in depth, 70 m in width from the coast.	9°23'45.37''N, 97°53'44.65''E
11	Ao Sapparos	is a sheltered bay, located west of Ko Surin Tai near Park arranged Moken settlement. Coral reef occurred at 1 to 16 m in depth, 55 m in width from the coast	9°23'32.55''N, 97°52'52.24''E

5.2.1 Resilience scores and indicator ranking

In general, Thailand resilience indicators are semi-quantitative but the score for ecological data (Indicators 1-12, **Table 3**) is quantitative based on actual data collected that translates into Likert scale (1-5 categories). For the rest (Indicators 13-22) scores are based on historical data and field assessments. Weightings are then assigned for Mu Ko Surin study sites, with scores of 'very important' indicators multiplied by 2 and 'important' factors multiplied by 1 or being unweighted. The higher score means that more resilience is conferred upon the site as a result of that indicator. The final resilience score for each site is the sum of the scores for all of the indicators combined following weighting. Sites are then ranked from most resilient (highest resilience score) to least resilient (lowest resilience score). The difference between the highest resilience score and the lowest score was divided by three, resulting in a score range used to classify sites as being of low, moderate or high resilience, relative to the other sites contained within the analysis.

5.2.2 Resilience assessment result

Resilience scores for Mu Ko Surin National Park ranged from 92 for the lowest-scoring sites (Ao Sapparos) to 117 for the highest-scoring site (Ao Chak and Ao Suthep). The top four sites that classified as high resilience were Ao Chak, Ao Suthep, Ao Tao and Ao Phakkhad (**Table 10, Figure 14)**. The three lowest-scoring sites were Ao Sapparos, Hinpae and Ko Torinla. Three sites were classified as having moderate resilience (Ao Maeyai, Ao Mai-ngam and Ko Pachumba). The weighting of resilience indicators did not change the order of the most and least resilient sites but helped to differentiate sites by increasing the score spread among them.

Table 10. Summary of resilience rankings and scores for all indicators for all sites. **Bold** is used for indicators with weightings: very important (x2).

			ecological-condition												physical and connectivity					management-oriented				
Resilience conferred: = Least; = Some; = Most			Live coral cover	**Abundance of coral recruits**	Class size	**Abundance of bleaching resistance species**	**Species richness**	Coral predator	**Abundance of coral competitors**	**Coral diesease prevalence**	Herbivore diversity	**Herbivore abundance**	Abundance of predatory fish	Abundance of fisheries target species	Severity from the latest bleaching event	Survial from last bleaching event	Proximity to other coastal habitats	Cooling factors	Shading factors	**Fishing pressure**	**Physical damage**	**Nutrient and pollution**	**Sediment loading**	Management
Site	Rank	Total																						
Ao Chak	1	117	2	6	5	4	8	4	8	8	4	8	3	3	2	2	4	3	3	6	10	10	10	4
Ao Suthep	2	117	2	8	4	4	8	4	8	8	4	8	2	4	2	3	4	3	3	8	10	8	8	4
Ao Tao	3	112	2	6	3	10	6	4	8	6	3	6	3	3	3	3	4	3	3	8	8	8	8	4
Ao Phakkad	4	110	1	6	5	6	6	3	8	8	5	8	1	2	2	3	4	3	3	8	8	8	8	4
Ao Maeyai	5	102	2	4	4	6	6	3	8	4	4	8	2	3	2	2	4	3	3	8	6	8	8	4
Ao Mai-ngam	6	102	2	6	3	4	6	4	6	6	4	8	2	3	2	2	4	3	3	8	8	6	8	4
Ko Pachumba	7	101	1	2	5	6	4	4	8	8	3	6	4	1	2	2	4	4	3	6	8	8	8	4
Ko Stock	8	96	1	2	5	4	4	4	2	8	4	8	2	3	2	2	4	4	3	4	6	10	10	4
Ko Torinla	9	94	1	2	3	6	4	4	2	8	3	6	3	2	2	2	4	3	3	8	8	8	8	4
Hin Pae	10	93	1	2	3	4	4	4	2	10	1	8	2	2	2	2	4	5	3	6	6	8	10	4
Ao Sapparod	11	92	1	2	3	6	4	4	6	8	3	8	4	1	2	2	4	3	3	6	8	4	6	4
	Average score		1.5	4.2	3.9	5.5	5.5	3.8	6.0	7.5	3.5	7.5	2.5	2.5	2.1	2.3	4.0	3.4	3.0	6.9	7.8	7.8	8.4	4.0
	Standard Error		0.2	0.7	0.3	0.5	0.5	0.1	0.8	0.5	0.3	0.3	0.3	0.3	0.1	0.1	0.0	0.2	0.0	0.4	0.4	0.5	0.4	0.0

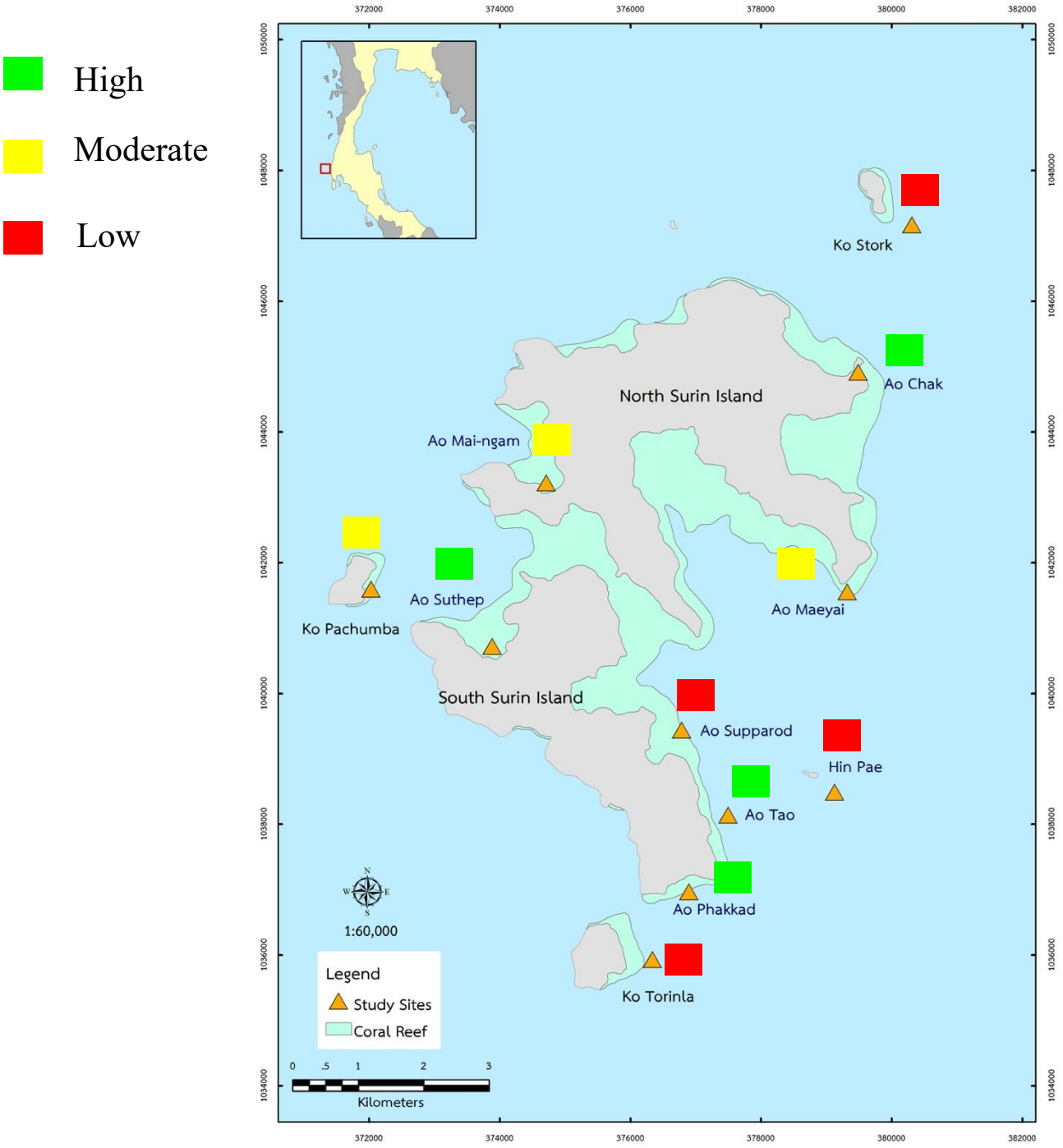


Figure 14. Resilience assessment result of Mu Ko Surin National Park from High (Green), Moderate (Yellow) and Low (Red)

All sites suffered heavily and almost equally from the 2010 mass coral bleaching event but the recovery has varied markedly. Ao Suthep, Ao Chak and Ao Phakkad showed promising sign of recovery and within 7 years, coral cover almost recovered to the previous coverage before the 2010 bleaching (**Figure 15-16**).

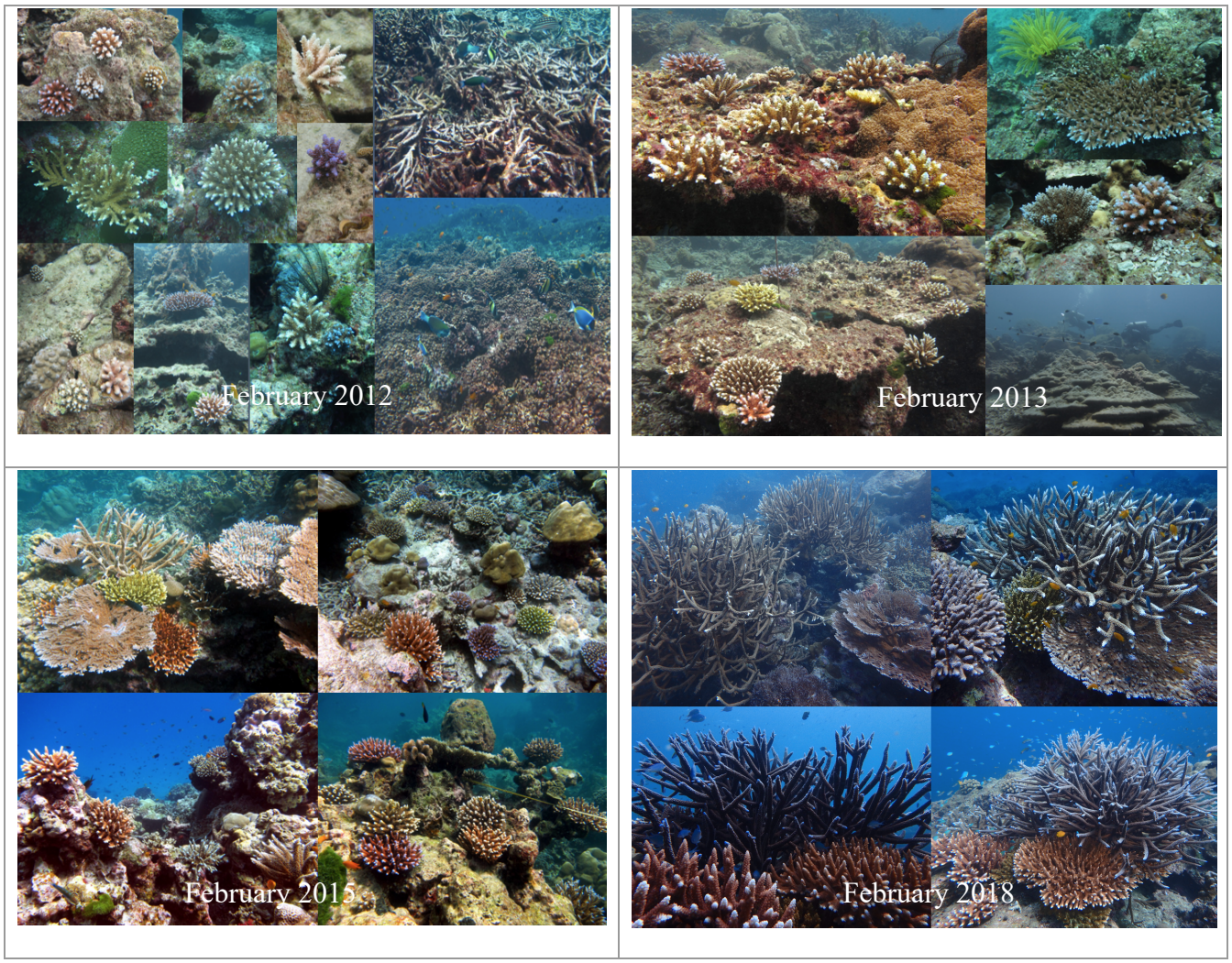


Figure 15. Coral recovery along line transect at Ao Suthep recorded in February 2012, 2013, 2015 and 2018 (Photo: P. Manopawitr)

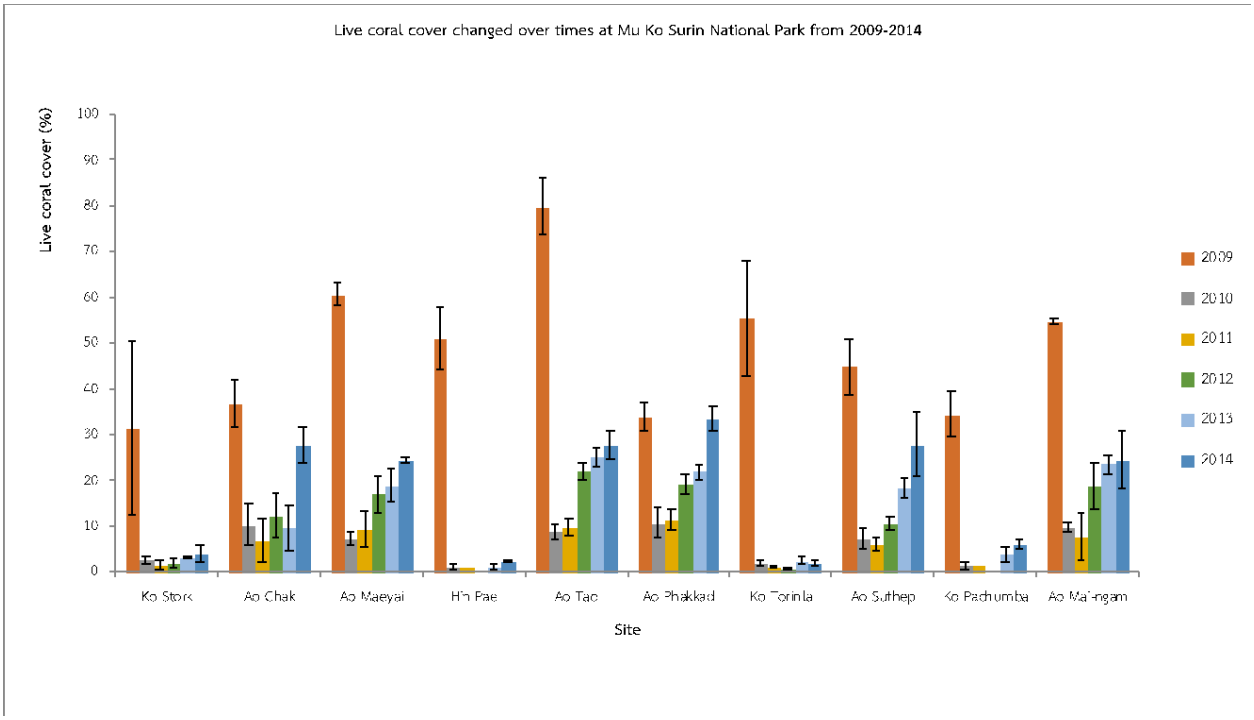


Figure 16. Live coral cover change over time at Mu Ko Surin National Park from 2009-2014 (Chanmethakul (2015) Phuket Rajabhat University Unpublished Data).

Although there are several resilience parameters, the four most resilient sites corresponded strongly with abundant recruitment while the least resilient sites reflect much slower recovery and very low recruitment. Three of the most resilient sites are located on the eastern side exposed to the northeastern current but well protected within the bay. The three least resilient sites share reef patch characteristics located near smaller islands or rocky outcrops with little protection.

While physical characteristics such as cooling and shading factors, proximity to other coastal habitats did not differ much across sites, the ecological conditions (especially abundance of coral recruits, coral species richness and abundance of coral competitors) and management-oriented

factors (fishing pressure, physical damage, nutrient and pollution and sediment loading) were quite revealing to understand variations in resilience at a finer scale.

Although, all sites supposedly received the same protection under the National Park Act, the result from this assessment show that each site face different degrees of human stress. The scores resulting from the assessment provide a guide for practical interventions to implement resilience-based management by reducing specific stressors.

Since not all resilience factors can be influenced by management interventions, rankings of 'management influence potential' were produced following the summary of the scores for eight indicators that managers can influence for each of the study sites. In theory, the sites with the lowest scores would benefit the most, in terms of percent increase in resilience score from local intervention (**see Table 11**).

Table 11. Management influence potentials rankings calculated as the sum scores at each site for the resilience indicators that managers can influence.

Resilience conferred:
= Least
= Some
= Most

Site	Rank	Total	Herbivore abundance	Abundance of predatory fish	Abundance of fisheries target species	Fishing pressure	Physical damage	Nutrient and pollution	Sediment loading	Management
Ao Sapparos	1	41	8	4	1	6	8	4	6	4
Ko Pachumba	2	45	6	4	1	6	8	8	8	4
Hin Pae	3	46	8	2	2	6	6	8	10	4
Ao Phakkad	4	47	8	1	2	8	8	8	8	4
Ao Maeyai	5	47	8	2	3	8	6	8	8	4
Ao Mai-ngam	6	47	8	2	3	8	8	6	8	4
Ko Stork	7	47	8	2	3	4	6	10	10	4
Ko Torinla	8	47	6	3	2	8	8	8	8	4
Ao Tao	9	48	6	3	3	8	8	8	8	4
Ao Suthep	10	52	8	2	4	8	10	8	8	4
Ao Chak	11	54	8	3	3	6	10	10	10	4
	Average score		7.5	2.5	2.5	6.9	7.8	7.8	8.4	4.0
	Standard Error		0.3	0.3	0.3	0.4	0.4	0.5	0.4	0.0

Ao Sapparos received the lowest scores for abundance of fisheries target species, nutrient and pollution, and sediment loading. Ko Pachumba received the lowest scores for abundance of fisheries target species and Hin Pae received the lowest score for physical damage. In term of physical damage, Ao Mae Yai and Ko Stork also received the lowest score. Ko Stork also received the lowest score for fishing pressure and local action should be taken. Ao Phakkad which has a high resilience score overall received a noticeably low score on abundance of predatory fish. Further investigation may be needed because overall recovery of the reef at Ao Phakkad is among the highest sites.

5.3 Designing Marine Protected Area network on the Andaman Coast of Thailand to build ecosystem resilience and improve coral reef conservation

Post-bleaching surveys in Thailand revealed the areas that harbor resilient reefs. Although the bleaching impact was not uniform and differed both at regional and local scales, the recovery processes are taking places across local sites. This section reports the result of the mapping of critical habitats along the Andaman coast and resulting gap analysis of unprotected sites. The results serve as a basis for designing a resilient MPA network to improve coral reef conservation.

5.3.1 Overall MPA Coverage for Thailand

To verify overall figures on levels of existing marine protection for Thailand, I recalculated MPA coverage by deducting the fisheries management areas, the overlapped jurisdiction among different entitles such as Ramsar sites, ASEAN Heritage site and Biosphere reserve and those critical marine habitats that are already included in marine national parks.

Excluding all fishery management zones, the latest coverage and the gap towards the 10% CBD target are shown in **Table 12.** The analysis showed that Thailand has 18,136 km^2 of coastal and marine areas protected or about 5.6% of the total marine area. Of the total MPA area, about 31% would be classified as no-take area (IUCN Category II) by law i.e. marine national parks and this area accounts for only 1.76% of the total marine area. In fact, many marine national parks allow fishing activity and do not act as no-take areas (Lunn & Dearden 2006). The country still needs an additional marine and coastal area of 14,212 km^2 to be protected in order to reach the CBD target of at least 10% of coastal and marine areas by 2020.

Table 12. Revised Thailand MPA coverage* and the gap towards 10% Aichi Target

Type	**No.**	**Area (km^2)**	**Coastal and Marine Areas**	**IUCN Categories**
National Park	22	6,440	5,716	II
Non-hunting Area	6	1,536	1,138	IV
Mangrove Conservation Area (DMCR)	160	2,304	2,304	IV
Biosphere Reserve	1	246	246	IV
Species Conservation Area (DoF)	56	167	167	IV
Environmental Protection Area	6	14,974	9,530	VI
Total Area			19,101	
Actual area excluding overlapped jurisdiction			**18,136**	
Thailand's Exclusive Economic Zone (EEZ)			323,488	
Current MPA coverage			**5.6%**	
Target of 10% MPA			32,348	
Additional Area needed to reach 10%			14,212	

*This classification excluded 25 Fisheries Management Areas with total area of 50,814.94 km^2

There are a lot of opportunities with the new DMCR Act (2015) to create additional MPAs. DMCR's 10 year MPA target (2016-2025) listed 35 MPAs with a total area of 14,330 km^2 to be established. One of the largest proposed areas is Shelf Break Front in the Andaman Sea near the continental shelf with an area of 6,750 km^2 (See **Figure 22**). Around 3,416 km^2 of proposed DMCR MPA areas based on ecological characteristics are already protected in some form of existing MPAs (national parks and non-hunting area). These areas will need to be clarified in term of jurisdiction among the agencies. Nevertheless, 10,913 km^2 would be added in terms of MPA coverage if DMCR can proceed as planned. That would bring Thailand's total MPA

coverage to 9% by the year 2025. This is still very far from international policy recommendation that encourages government to expand MPA network to at least 30% of marine protection to ensure integrity of biodiversity and ecosystem services (IUCN-WCPA, 2014). There is a need for Thailand to scale up its MPA coverage as well as increase strict protection areas throughout the country.

5.3.2 Representation and design analysis for Andaman region

Individual MPA design in Thailand is variable and developed largely in an *ad hoc* basis with little systematic planning. Nevertheless, there are 20 MPAs distributed throughout the Andaman coast with the distance between them ranging from 0 km to 63 km with an average spacing between MPAs of 22.05 km (See **Table 13**). The average spacing is slightly more than the recommended 15-20 km apart (Salm et al. 2006; Green et al. 2007) to allow for replenishment via larval dispersal. The obvious gap for the distance between MPAs is the offshore island groups for example Mu Ko Surin to Ko Ra – Ko Prathong is 41 km and Mu Ko Similan to Khao Lak - Lum Ru is 63 km.

The size of Andaman MPAs ranges from 72-1,490 km^2 with average size of 282 km^2, notably larger than the country average MPA size of 178.3 km^2 (See **Table 14**). The diameter of Andaman MPAs ranges from 7.15 – 66. 35 km with an average diameter of 30.17 km (See **Table 14**), larger than the minimum of 10-20 km diameter guideline. In general, the size of Andaman MPAs are large enough to protect the full range of marine habitat types and ecological processes on which they depend and to accommodate self-seeding by short distance dispersers (Fernandes et al. 2005; Mora et al. 2006; McLeod et al. 2019).

However, a number of the sites are relatively small thus hampering their capacity to protect functioning ecosystems. For example, Sirinat, Khao Lampi-Hat Thai Mueang and Thung Thale

all have areas of less than100 km^2 and Mu Ko Lanta and Thung Thale have diameters of only 7.15 km and 11 km respectively. Connecting these parks within larger conservation areas is an important step to developing an MPA network.

Table 13. Distance between MPAs from North to South direction

From MPA	**To MPA**	**Distance (km)**
Kraburi NP	Mu Ko Ranong NP	8.3
Mu Ko Ranong NP	Laemson NP	0
Lameson NP	Klongmuangkluang NHA	0
Laemson NP	Mu Ko Surin NP	43.7
Klongmuangkluang NHA	Mu Ko Surin NP	58
Mu Ko Surin NP	Ko ra Ko Prathong NP	41
Mu Ko Surin NP	Mu Ko Similan NP (Tachai Is.)	34
Mu Ko Similan NP	Khao Lak-Lum Ru NP	63
Khao Lak-Lum Ru NP	Khao Lumpi-Had Thaimuang NP	9.1
Khao Lumpi-Had Thaimuang NP	Sirinat NP	23.65
Sirinat NP	Ao Phang-Nga NP	17
Ao Phang-Nga NP	Tanbokkorani	6.5
Tanbokkhorani NP	Had Nopparattara-Mu Ko Phi Phi NP	36.8
Had Nopparattara – Mu Ko PhiPhi NP	Thung Thale NHA	8.9
ThungThale NHA	Lanta NP	24
Lanta NP	Hat Chaomai NP	17
Hat Chaomai NP	Ko Libong NP	0
Ko Libong NP	Phetra NP	6.5
Phetra NP	Tarutao NP	3.8
Tarutao NP	Thaleban NP	39.9
	Average:	22.05

Table 14. Andaman MPAs in size and diameter

Protected Areas	**Area (km^2)**	**Diameter (km)**
Lam Nam Kraburi NP	166.1	45
Mu Ko Ranong NP	356.7	32.6
Laem Son NP	315	47.18
Klong Muang Kluang Non-Hunting Area	131.04	28.4
Mu Ko Ra-Ko Phra Thong NP*	166.1	26.76
Khao Lak-Lam Ru NP	125	33.8
Khao Lampi-Hat Thai Mueang NP	72	15
Sirinat NP	90	19.04
Mu Ko Surin NP	141.2	15
Mu Ko Similan NP	140	23.16
Ao Phang-nga NP	400	36.48
Than Bok Khorani NP	104	13.7
Hat Noppharat Thara-Mu Ko Phi Phi NP	387.9	20.5
Mu Ko Lanta NP	134	7.15
Thung Thale Non-Hunting Area	53.18	11
Hat Chao Mai NP	230.8	29
Mu Ko Li Bong Non-Hunting Area	447.5	32.24
Mu Ko Phetra NP	494.4	60
Tarutao NP	1490	66.35
Thale Ban NP	196	41.1
Average	282.05	30.17

Most Andaman MPAs especially the island group MPAs e.g. Mu Ko Surin, Mu Ko Similan, Mu Ko Phi Phi have a rectangular shape. This offers an effective way to locate them on the ground and communicate the area to resource users as well as for surveillance and law enforcement purposes. One of the obvious design shortcomings is the limited marine areas (less than 10% of their total area) of the three MPAs, Khao Lampi-Hat Thai Mueng, Khao Lak-Lam Ru and Thaleban NP. In the case of Hat Thai Mueng, an important nesting site for endangered leatherback turtles, the park boundary ends at the low tide mark only, thereby giving no protection for the turtles' feeding ground and the extensive coral reefs in front of the park. Expanding the marine areas of these three MPAs is a high priority to protect key habitats and improve the design of the overall MPA network.

On average the Andaman MPAs are 90% marine; 10% terrestrial. The limited protection of terrestrial areas greatly restricts the ability to protect the parks from land-based threats such as pollution and coastal over-development. This can be amended by other forms of management. Three out of six provinces namely Phang-nga, Phuket and Krabi, are EPAs which have control over pollution and coastal development. However, weak law enforcement results in continued degradation of nearshore habitats from sewage and sedimentation. EPAs need to be managed effectively as part of the MPA network. This will help prioritize the coastal areas that need better protection from land-based pollution under limited resources.

5.3.3 Andaman MPA gap analysis

Gap analysis is used to identify conservation targets and whether or not they are adequately conserved within a protected area network. Average size, shape and spacing were calculated for twenty-two MPAs against general recommendations for developing resilient MPA network

design (IUCN-WCPA, 2008 and McLeod et al. 2009). A review of critical habitat (i.e. coral reef, seagrass and mangrove) protection by existing Andaman MPAs for coral reef, seagrass and mangrove was conducted following methods in Chapter 4.

Generally, mangrove, seagrass and coral reefs are well represented in MPAs across Andaman bioregion; 62% of coral reefs, 40% of seagrass and 20% of mangrove (**Table 15**) are protected within the Andaman MPAs. These proportions would be considered quite high, given the general rule of thumb for developing MPA network to have about 30% of the area of each habitat type (Anthony et al. 2015, Green et al. 2009, McLeod et al. 2019). I conducted critical habitat mapping using GIS software and ground checking against existing MPAs on the Andaman coast to better understand the gaps and opportunities. When this information is mapped and analyzed for each of the six ecoregions, it shows where the gaps and opportunities are for expanding the MPA network in the Andaman sea.

Table 15. Critical habitats inside and outside MPAs for each Andaman ecoregion

Andaman Ecoregion	Coral Reefs								
	Outside MPAs			Inside MPAs			Total		
	Rai	sqkm	%	Rai	sqkm	%	Rai	sqkm	%
The Northern Mangroves and Inshore Islands	872.01	1.40	33.18	1,755.81	2.81	66.82	2,627.82	4.20	4.18
The Centrall Beaches and Coastal Gallery Forests	6,663.02	10.66	83.06	1,358.61	2.17	16.94	8,021.63	12.83	12.76
The Northern Offshore Islands	42.01	0.07	0.40	10,523.53	16.84	99.60	10,565.54	16.90	16.81
The Greater Ao Phang – nga	14,689.08	23.50	62.40	8,852.04	14.16	37.60	23,541.11	37.67	37.46
The Southern Coastal Forests	842.72	1.35	9.24	8,275.41	13.24	90.76	9,118.13	14.59	14.51
The Southern Offshore Islands	598.84	0.96	6.67	8,374.34	13.40	93.33	8,973.19	14.36	14.28
รวม	**23,707.69**	**37.93**	**37.72**	**39,139.73**	**62.62**	**62.28**	**62,847.42**	**100.56**	**100.00**

Andaman Ecoregion	Seagrass								
	Outside MPAs			Inside MPAs			Total		
	Rai	sqkm	%	Rai	sqkm	%	Rai	sqkm	%
The Northern Mangroves and Inshore Islands	679.33	1.09	72.25	260.97	0.42	27.75	940.30	1.50	1.50
The Central Beaches and Coastal Gallery Forests	6,527.45	10.44	69.46	2,869.64	4.59	30.54	9,397.09	15.04	14.95
The Northern Offshore Islands	-	-	-	136.34	0.22	100.00	136.34	0.22	0.22
The Greater Ao Phang-nga	26,188.53	41.90	93.87	1,710.98	2.74	6.13	27,899.51	44.64	44.39
The Southern Coastal Forests	1,862.36	2.98	8.73	19,462.00	31.14	91.27	21,324.37	34.12	33.93
The Southern Offshore Islands	-	-	-	-	-	-	-	-	-
Total	**35,257.68**	**56.41**	**59.06**	**24,439.93**	**39.10**	**40.94**	**59,697.61**	**95.52**	**94.99**

Andaman Ecoregion	Mangrove								
	Outside MPAs			Inside MPAs			Total		
	Rai	sqkm	%	Rai	sqkm	%	Rai	sqkm	%
The Northern Mangroves and Inshore Islands	92998.93	148.80	55.34	75041.97	120.07	44.66	168040.89	268.87	267.38
The Central Beaches and Coastal Gallery Forests	129892.33	207.83	67.88	61469.86	98.35	32.12	191362.20	306.18	304.49
The Northern Offshore Islands	-	-	-	-	-	-	-	-	-
The Greater Ao Phang-nga	379450.09	607.12	87.93	52092.05	83.35	12.07	431542.14	690.47	686.65
The Southern Coastal Forests	417508.51	668.01	85.47	70984.91	113.58	14.53	488493.42	781.59	777.27
The Southern Offshore Islands	-	-	-	-	-	-	-	-	-
Total	**1019849.86**	**1631.76**	**79.71**	**259588.79**	**415.34**	**20.29**	**1279438.65**	**2047.10**	**2035.79**

Coral reefs and mangrove are very well covered in *the Northern Mangrove and Inshore Islands* ecoregion with an area coverage of 66% and 44% respectively (**Figure 17**). However, 72% of seagrass of this ecoregion still lies outside MPAs. Although seagrass beds here are very small compared to other ecoregions the Bangbaen seagrass is recognized nationally as an important seagrass area and should be strictly protected (**Figure 18**). Coral reefs in *the Central Beaches and Coastal Gallery Forests* are not well represented in the MPAs with only 17% of corals protected compared to 62% on average within Andaman MPAs (**Figure 19**). An additional 10.6 km^2 of coral reefs (83% of corals in this ecoregion) need to be protected because of their significance as stepping-stones between near-shore and offshore reefs.

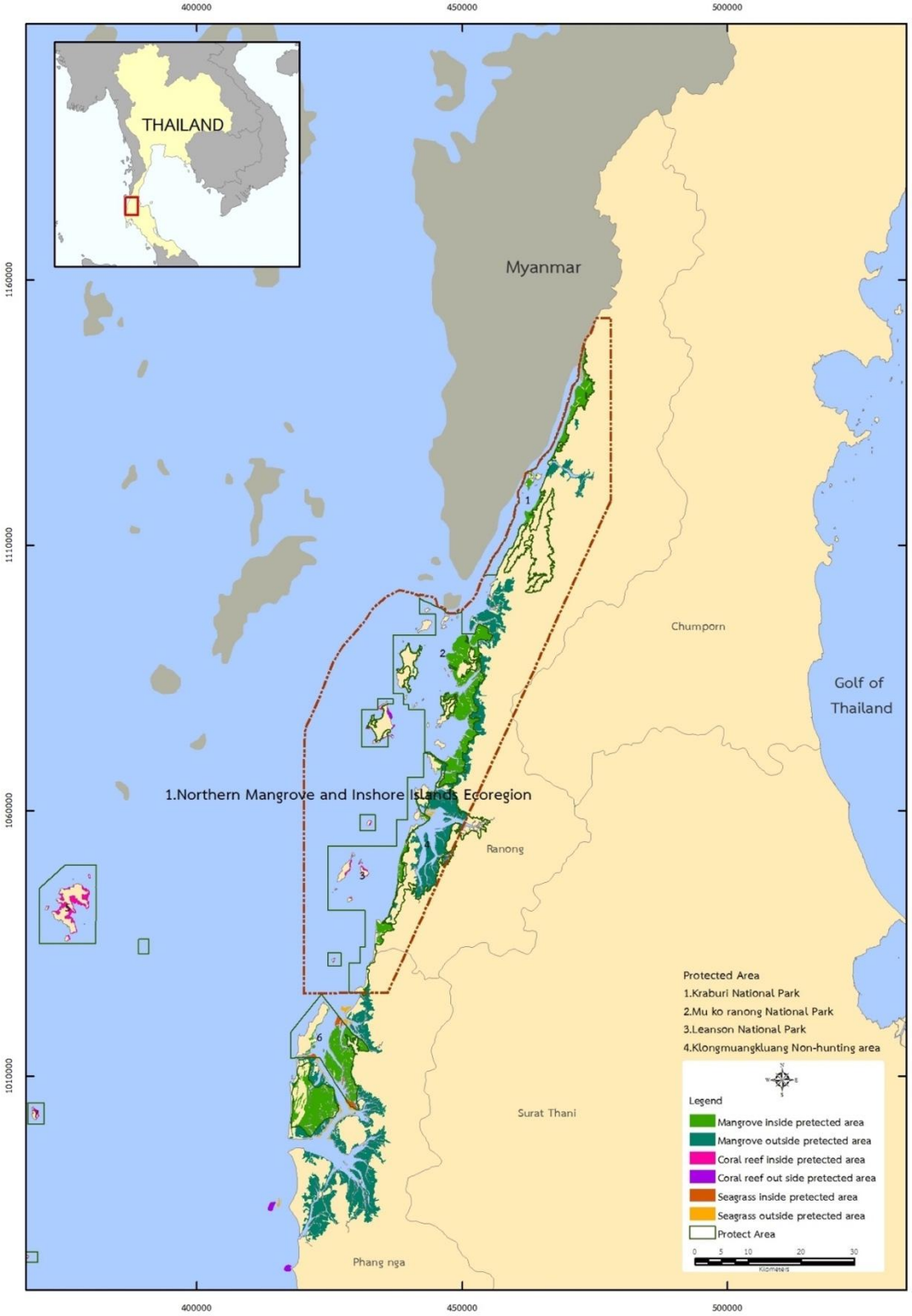


Figure 17. The Northern Mangrove and Inshore Islands ecoregion

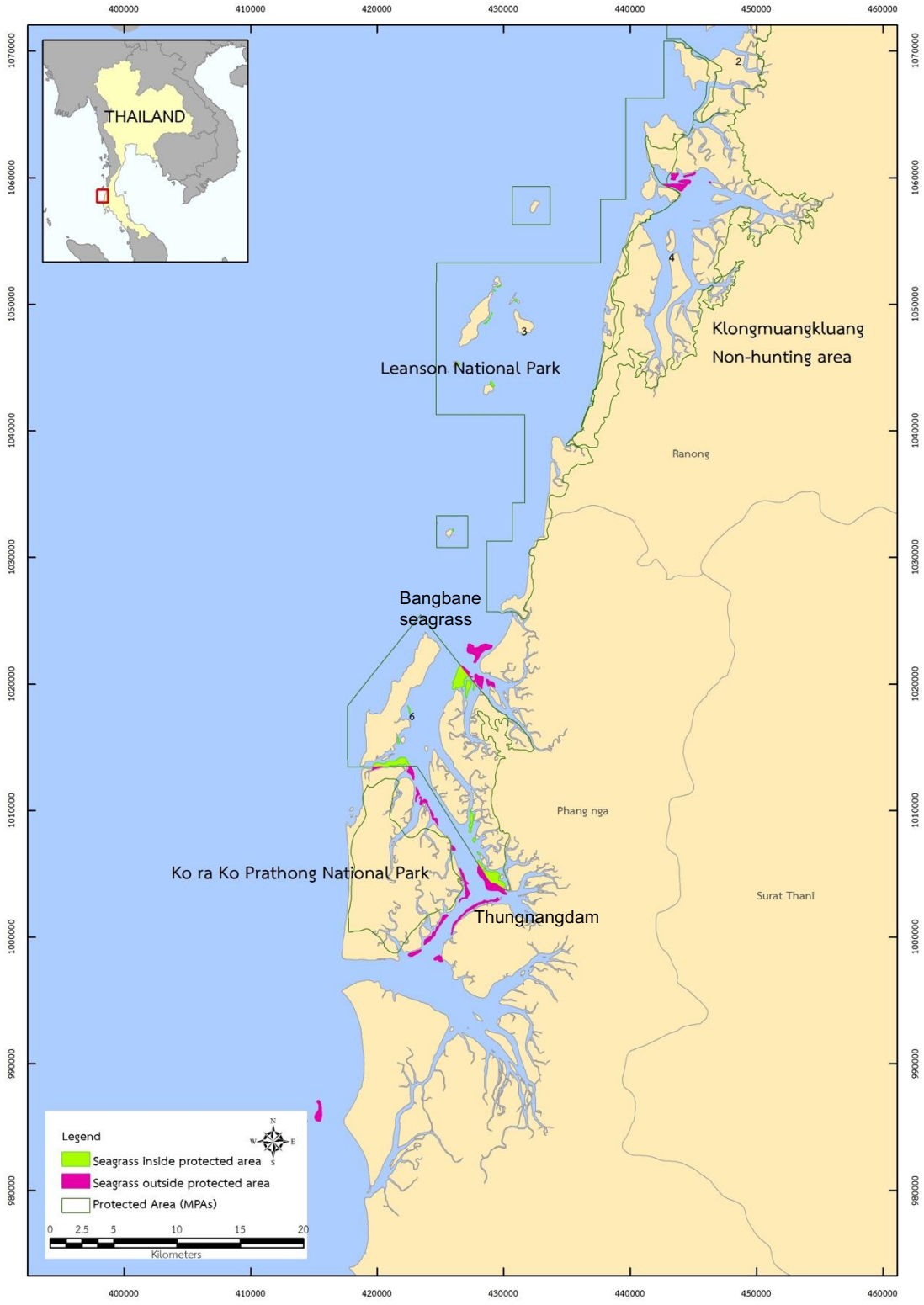


Figure 18. Seagrass outside protected area on the Northern Andaman region

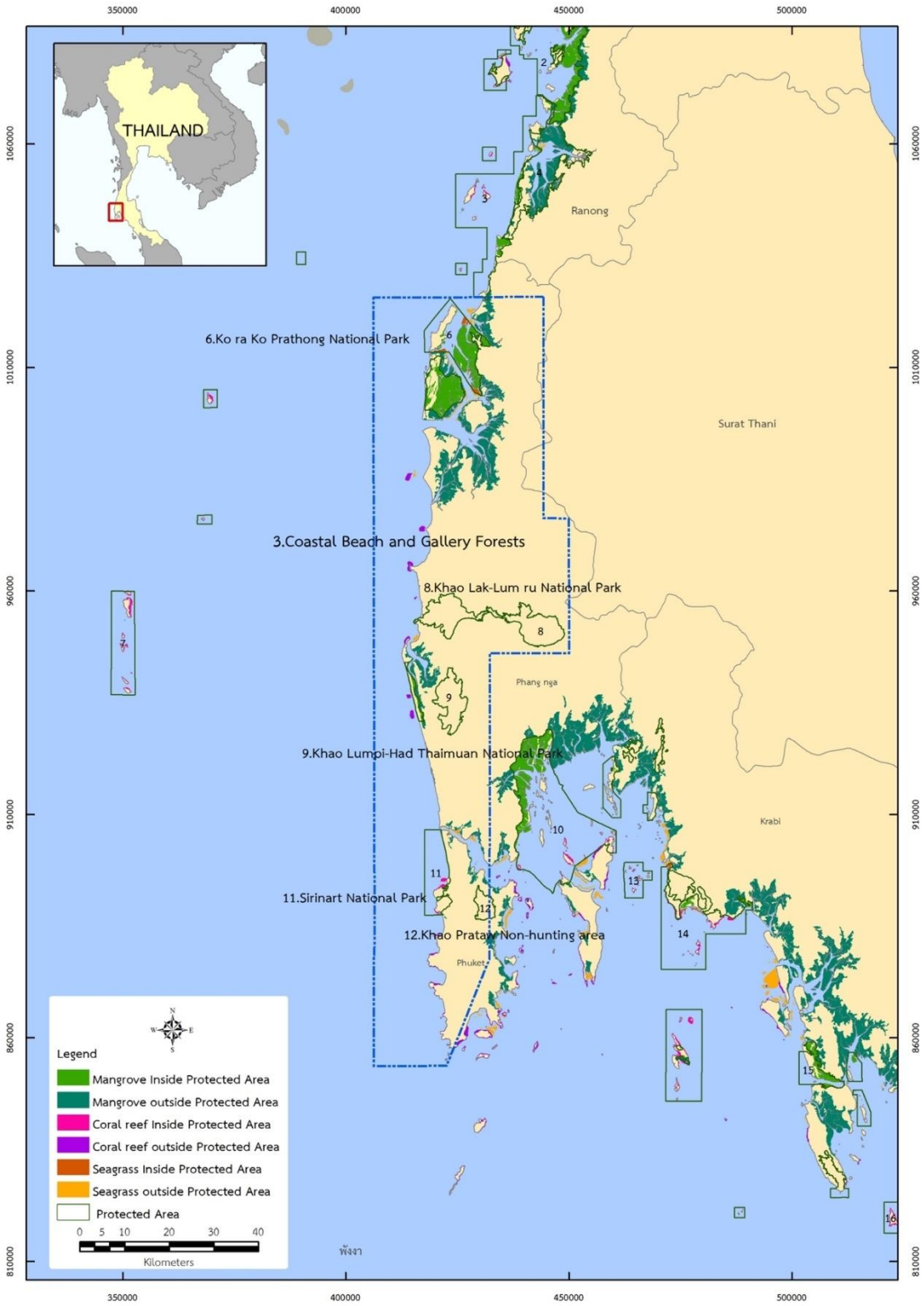


Figure 19. The Central Beaches and Coastal Gallery Forests ecoregion

A number of nationally important seagrass beds in the *Central Beaches and Coastal Gallery Forests* lie outside MPAs for example Thung Nang Dam near Kuraburi, and the Phuket channel, making them vulnerable to degradation from human activities (See **Figure 19**). In total, 70% of seagrass (10.4 km^2) in this ecoregion are outside MPAs and need to be protected to ensure ecological connectivity with other coastal habitats.

In the *Northern Offshore Islands*, almost all coral reefs (99.6%) and seagrass (100%) are already inside the MPAs namely Mu Ko Surin and Mu Ko Similan National Park (**Figure 20**). However, critical habitats in this ecoregion are not isolated. Their replenishment and ecological connectivity are tied with the Myeik Archipelago to the north in Myanmar and the Shelf Break Front area to the west. The potential connectivity with the Myeik Archipelago will be discussed later in the resilience assessment section. At the Shelf Break Front and its surrounding areas near the Andaman continental shelf, the phytoplankton biomass and production are three times greater than in shelf flat water, and fish larvae abundance is two times greater (Nielsen et al. 2004). The high biological productivity of the "Shelf Break Front" provides substantial spawning and feeding grounds, supporting fishing grounds and potentially feeding ground for marine endangered species (CBD 2016). This very large marine area covering 13,176 km^2, located between 9.683ºN, 97.364ºE and 6.089ºN and 98.073ºE southwest of *the Northern Offshore Islands*, has been adopted as an Ecologically or Biologically Significant Marine Area (EBSAs) in the North-East Indian Ocean in 2016 (CBD 2016) (**Figure 21**). Part of the Shelf Break Front (6,750 km^2) is one of the target areas for MPA development by DMCR (2016-2025). This area could be integrated into the Andaman MPA network and potentially increase the MPA coverage for Thailand substantially.

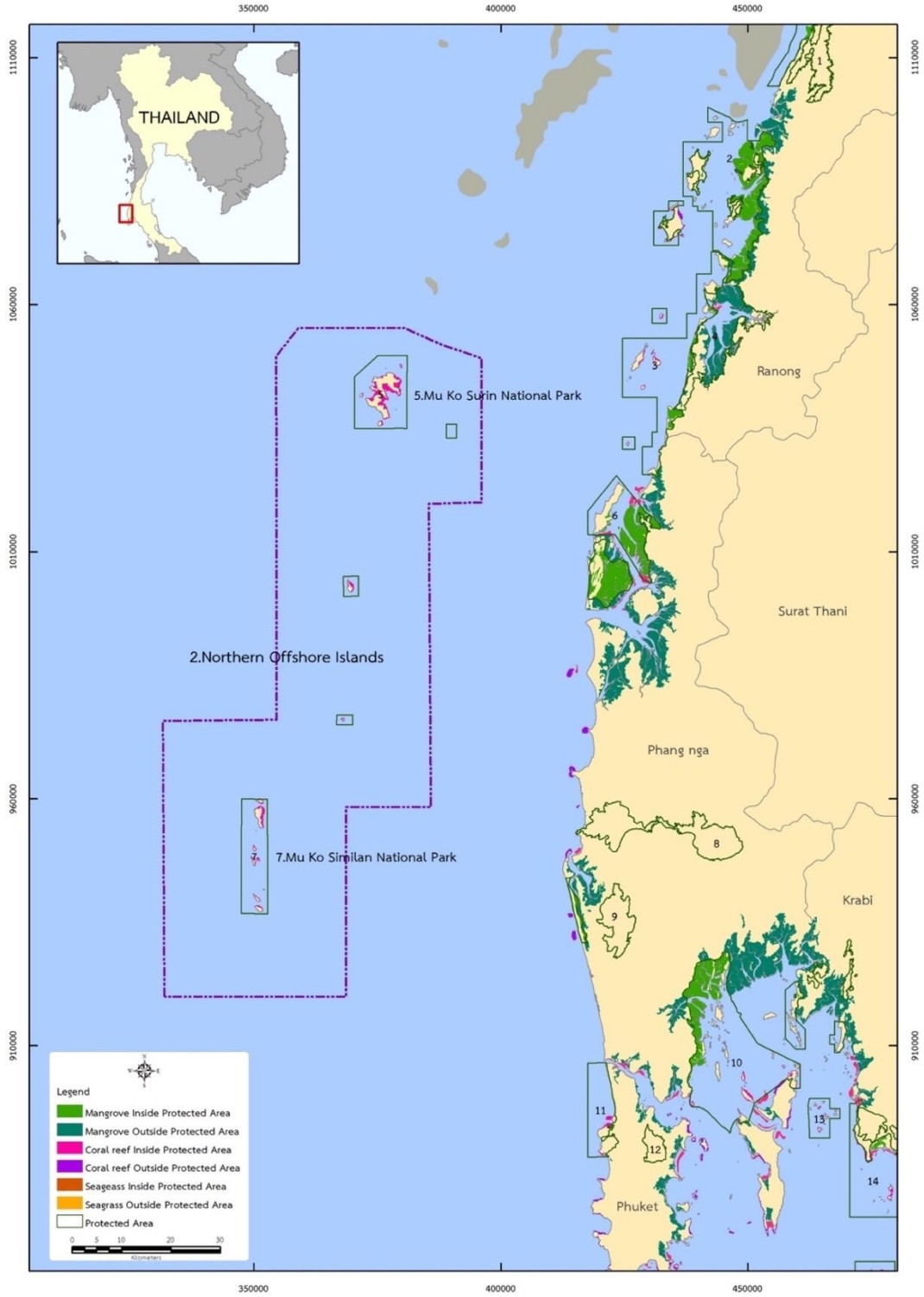


Figure 20. The Northern Offshore Islands ecoregion

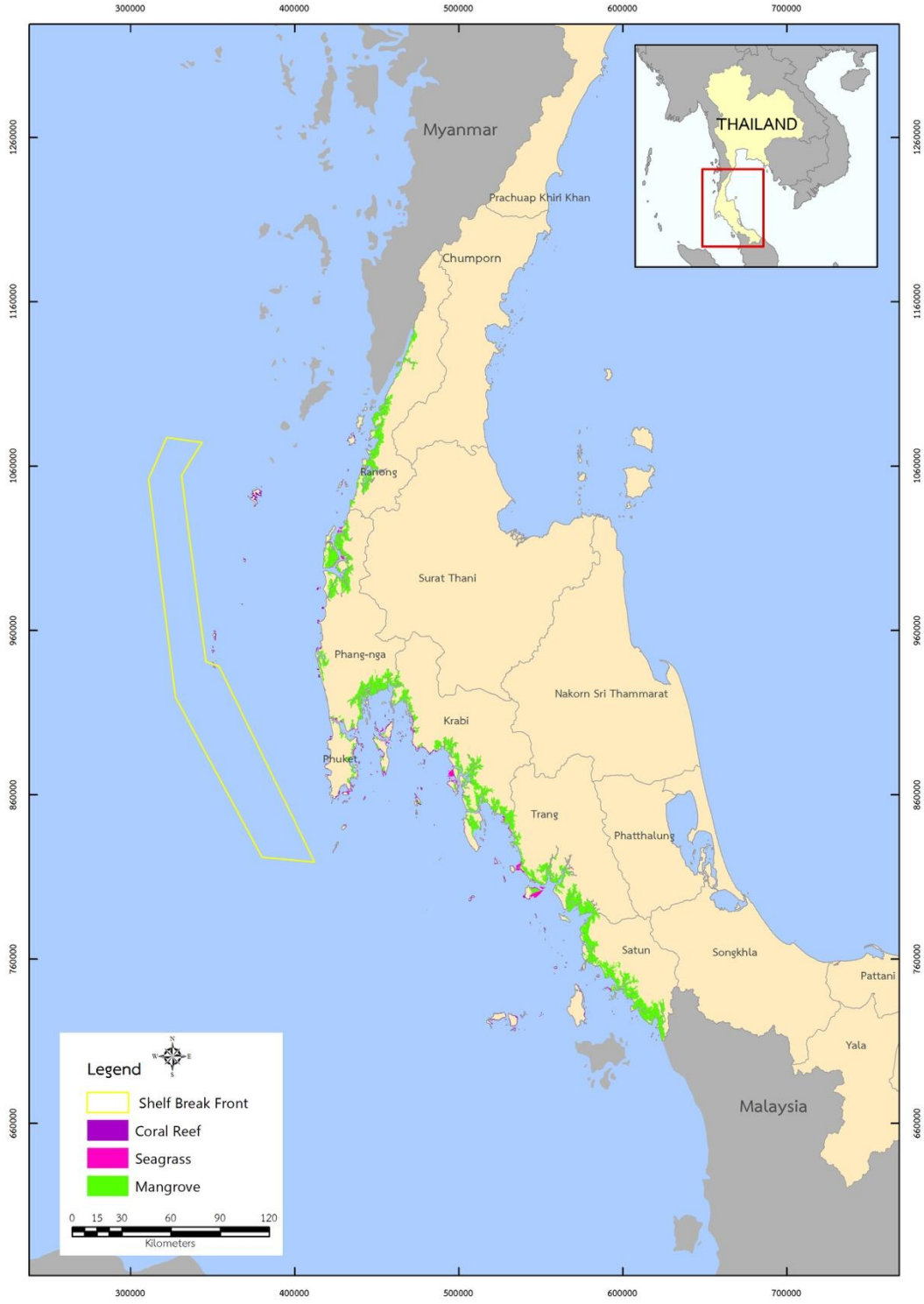


Figure 21. The Shelf Break, an Ecologically or Biologically Significant Marine Area

In the *Greater Ao Phang-nga* bioregion, 94% of seagrass (41 km^2), 88% of mangroves (607 km^2) and 62% (23.5 km^2) are outside MPAs **(Figure 22)**. This is the largest gap as well as the greatest opportunity to expand the MPA network. One practical approach is to create biological corridors between the two Ramsar sites, Ao Phang-nga and the Krabi Estuary (**Figure 23**). This corridor, using a three km from shore buffer, would capture large tracts of mangrove, seagrass and nearshore coral reefs that are currently not effectively protected.

The large seagrass bed at the Sriboya islands north of Mu Ko Lanta National Park is currently not protected. This is also an important feeding ground of the endangered dugong (**Figure 23**). This significant gap has been discussed with DMCR and a 450 km^2 MPA of Mu Ko Sriboya has been included in DMCR MPA development plan (2016-2025).

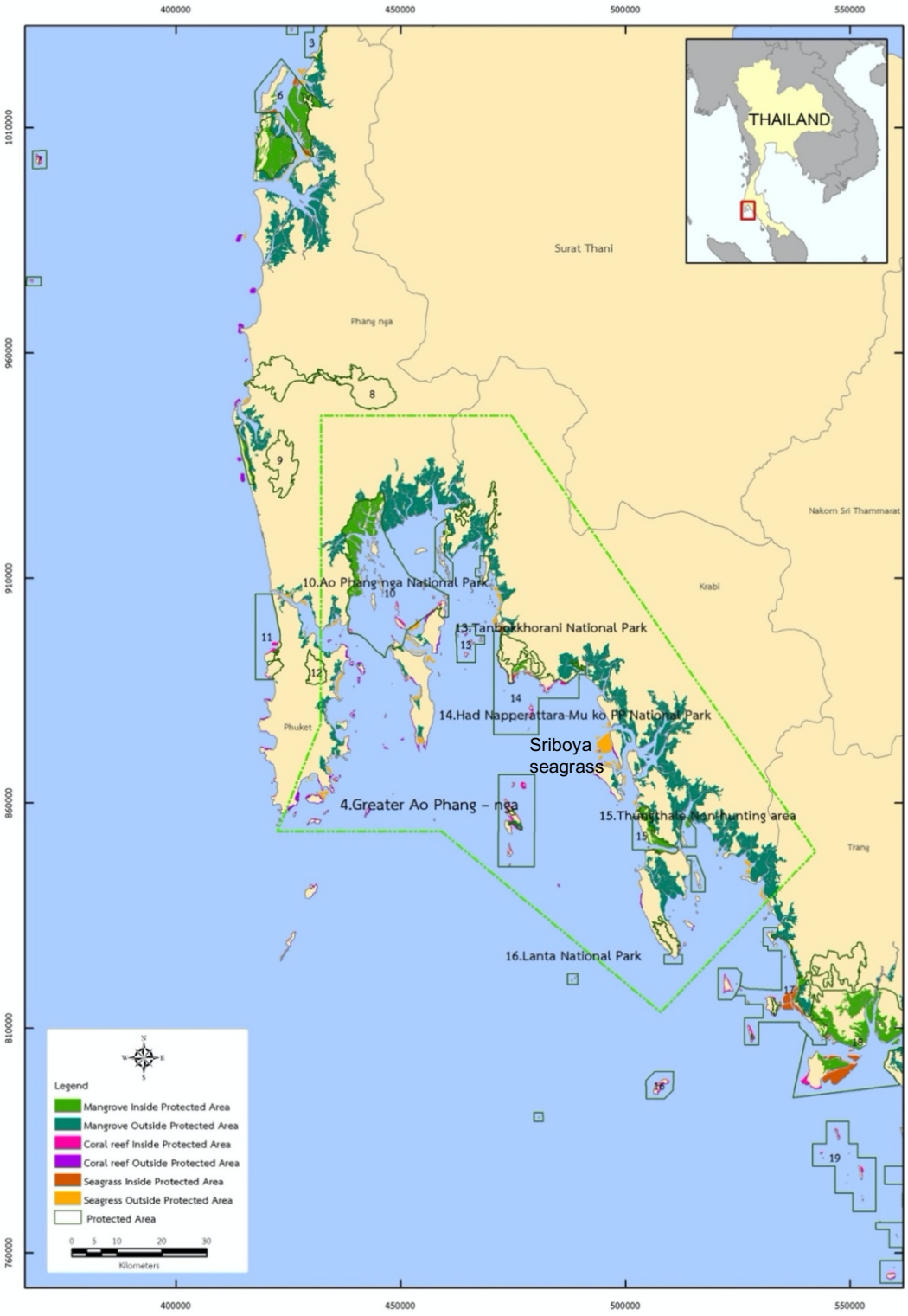


Figure 22 The Greater Ao Phang-nga ecoregion

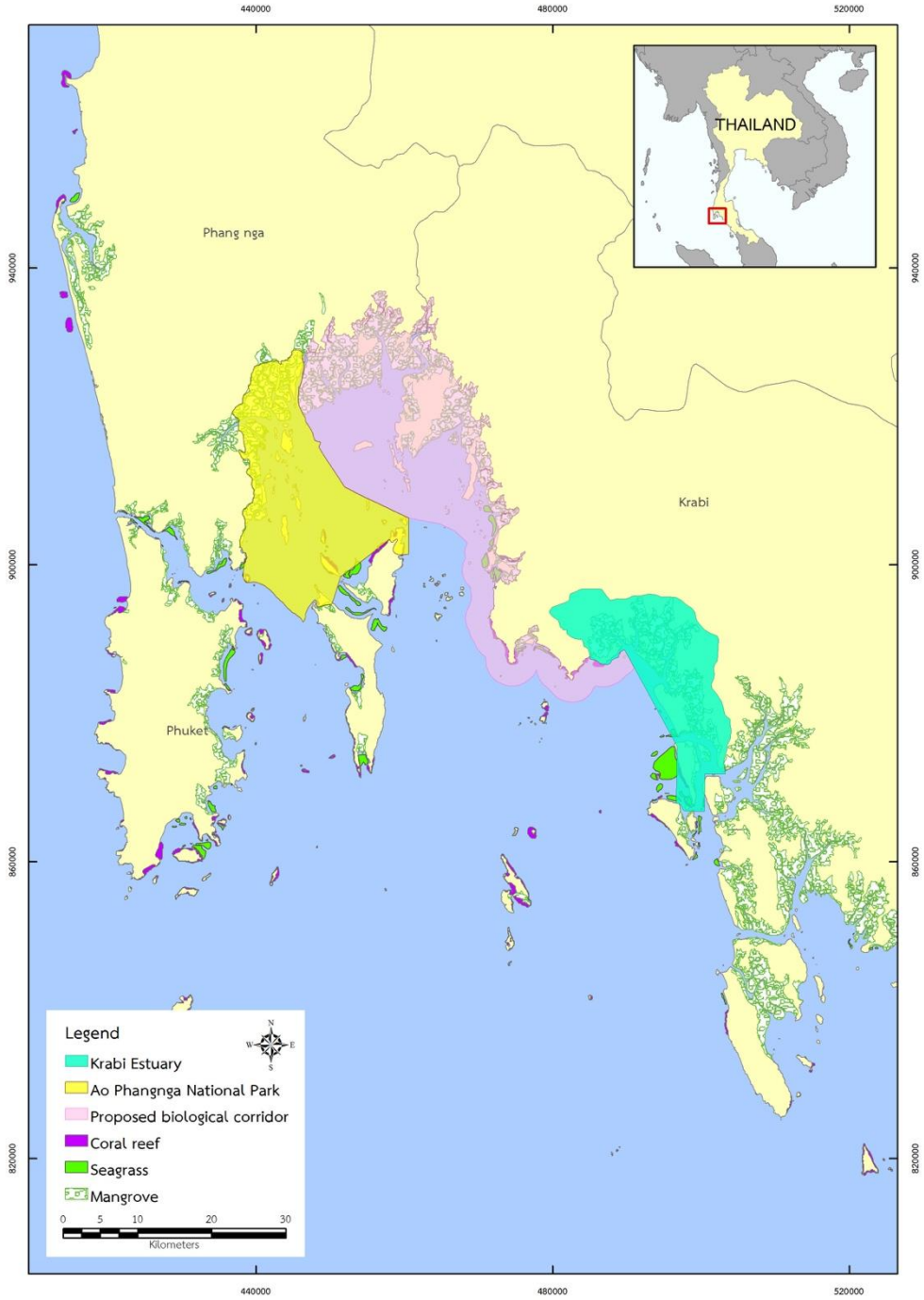


Figure 23. Proposed biological corridor between Ao Phang-Nga Ramsar site and Laem Son National Park.

In the *Southern Coastal Forests,* 90% of coral reefs (13.24 km^2) and 91% of seagrass (31.14 km^2) are already under protection inside MPAs (**Figure 24**). The remaining gap is 85% of mangrove (668 km^2) currently not managed effectively. The large mangrove tract south of Had Chao Mai National Park and Mu Ko Libong Non-hunting Area to the north of Mu Ko Phetra National Park should be set up as biological corridor. Similarly, the large mangrove tract in southern Satun south of Mu Ko Phetra to Malaysian border should be managed as functional nearshore habitat linking seagrass beds and coral reefs of Mu Ko Phetra and nearby Tarutao island.

In the *Southern Offshore Islands*, 93% of coral reefs (13.4 km^2) is already covered in two marine national parks, Tarutao and Mu Ko Lanta (**Figure 25**). There is no mangrove or seagrass present offshore. The remaining gap is the offshore reefs in Mu Ko Racha south of Phuket which has no formal protection. These offshore areas have been included in the DMCR MPA development plan (2016-2025) and will cover 375 km^2 of Racha islands.

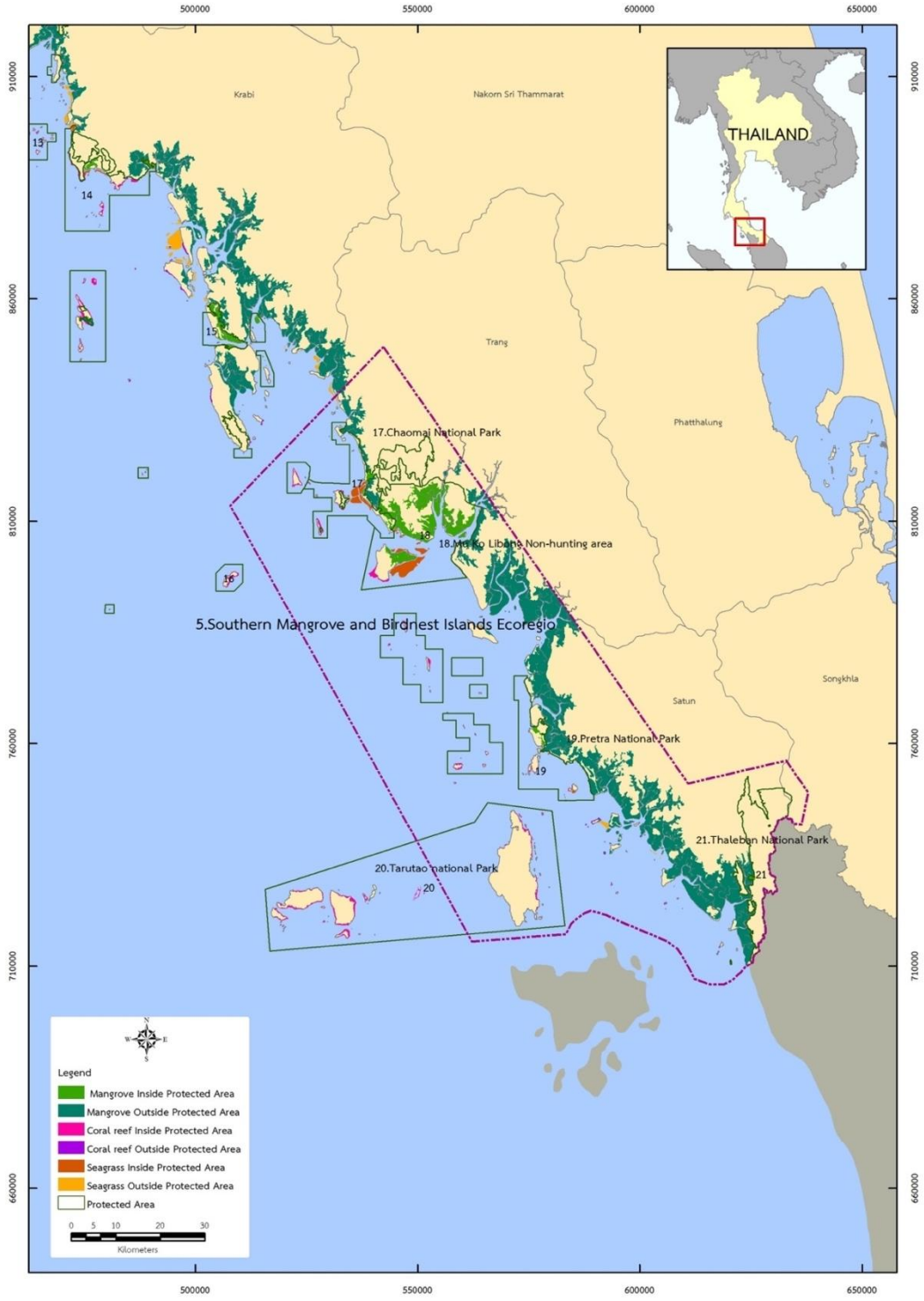


Figure 24. The Southern Coastal Forests ecoregion

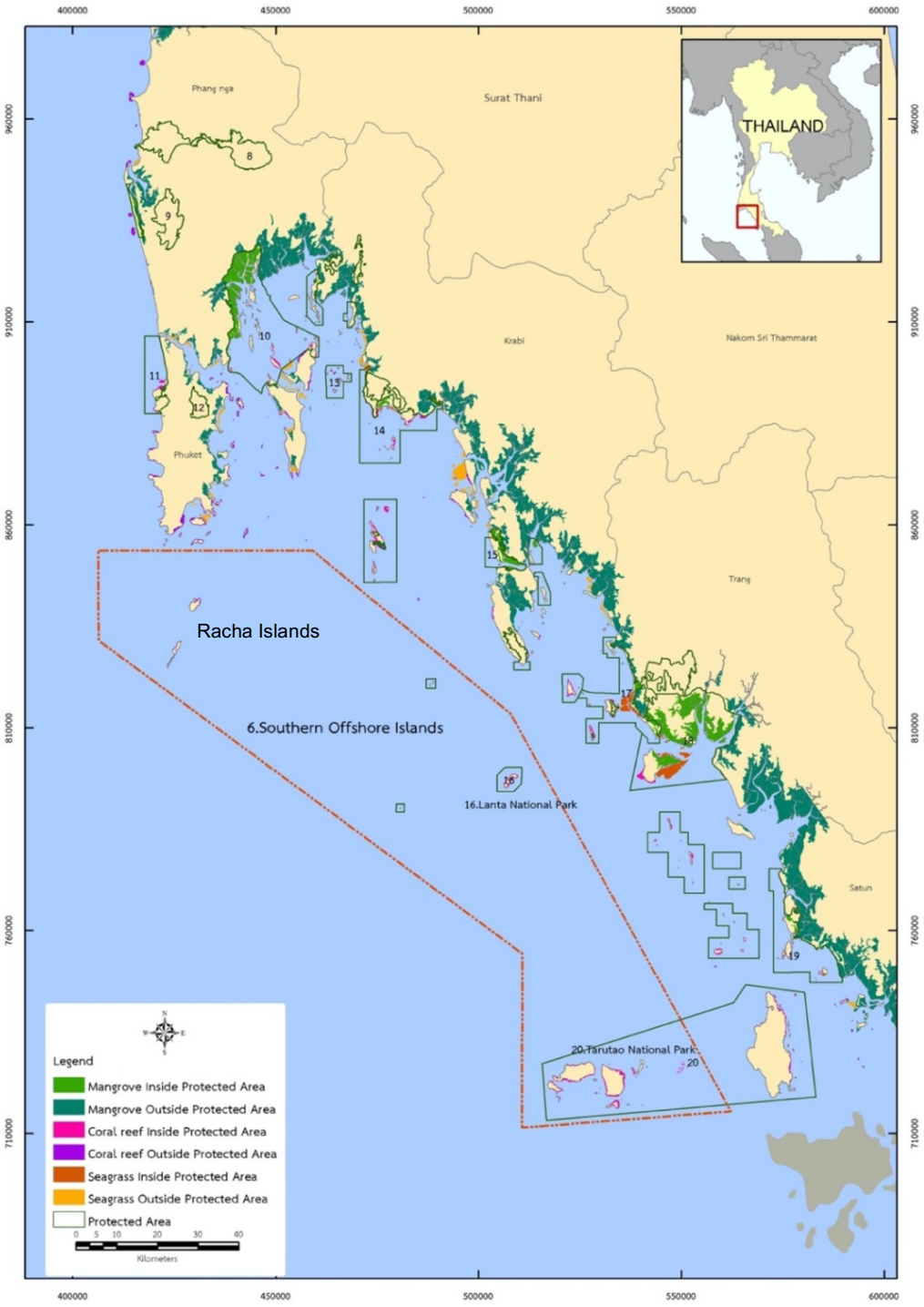


Figure 25. The Southern Offshore Islands ecoregion

Dugong distribution and potential feeding grounds were also mapped and updated (**Figure 26**). Although the largest population of dugong of around 200 individuals is mostly found in Trang the animals are not restricted to living inside the park. It is important to incorporate adjacent seagrass areas into the MPA network. Elsewhere, remnant dugong populations can be found in two significant seagrass areas of Sriboya island in Krabi and Kuraburi in Phang-nga.

Sea turtle distribution and nesting sites were also mapped and updated (**Figure 27-28**). One prime turtle nesting site especially for leatherback turtles on the mainland can be found between Taimueang Beach in Nam Tok Lampi-Had Taimueang National Park in Phang-nga and Mai Khao Beach in Sirinat National Park in Phuket. All nesting beaches outside MPAs should be considered for special measures such as public agreements to ensure minimal disturbance during the nesting season. An example of such a measure is the Mai Khao Marine Turtle Conservation Declaration signed by 10 hospitality operators and three government agencies (Sirinat National Park, Phuket Marine Biological Center and Mai Khao Subdistrict Administrative Organisation) with support from Mai Khao Marine Turtle Foundation in 2016. The declaration aims to promote strategic partnerships between the private sector and government to ensure best practices (limited lighting and night activities) for beach management in front of the hotels. Hospitality operators will also create financial mechanism to support local people who find the turtle nest to reduce nest poaching. This kind of arrangement promotes multi-agency and public-private cooperation in biologically important areas that have no effective mechanism. It is essential to ensure that the MPA network protect critical habitats for endangered species comprehensively.

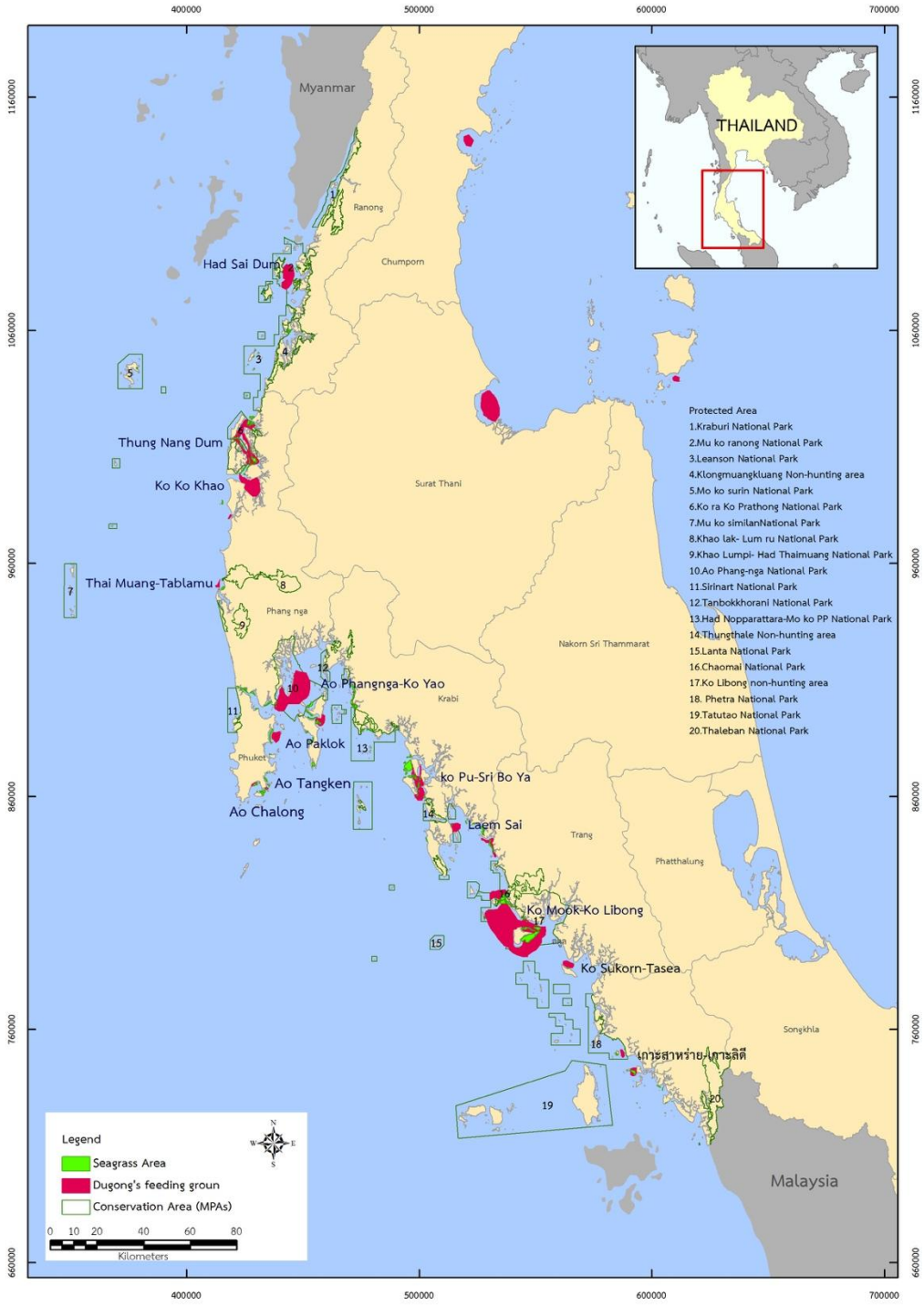


Figure 26. Dugong distribution and feeding ground (DMCR 2018)

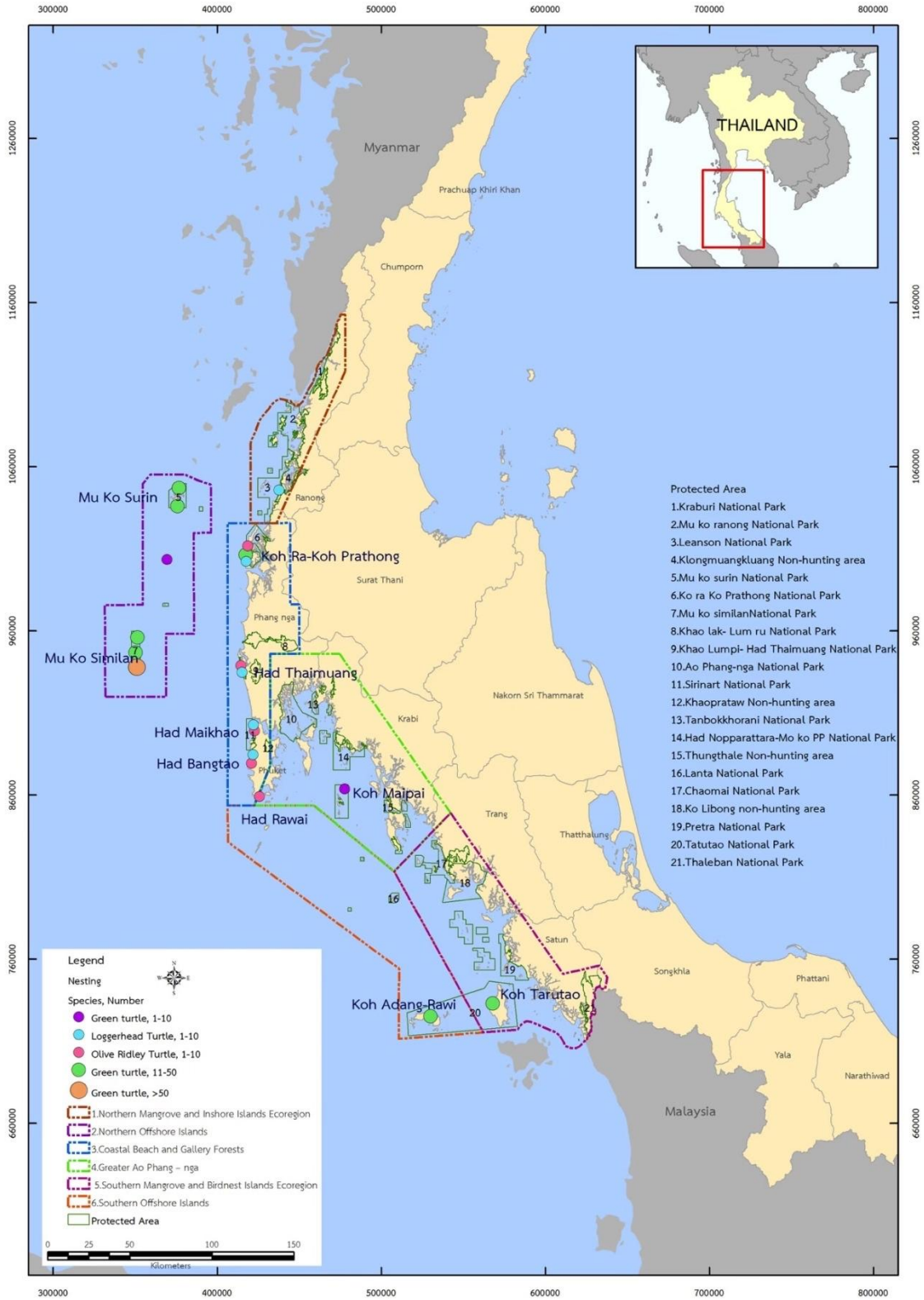


Figure 27 Sea turtle frequent sighting and distribution (DMCR 2018)

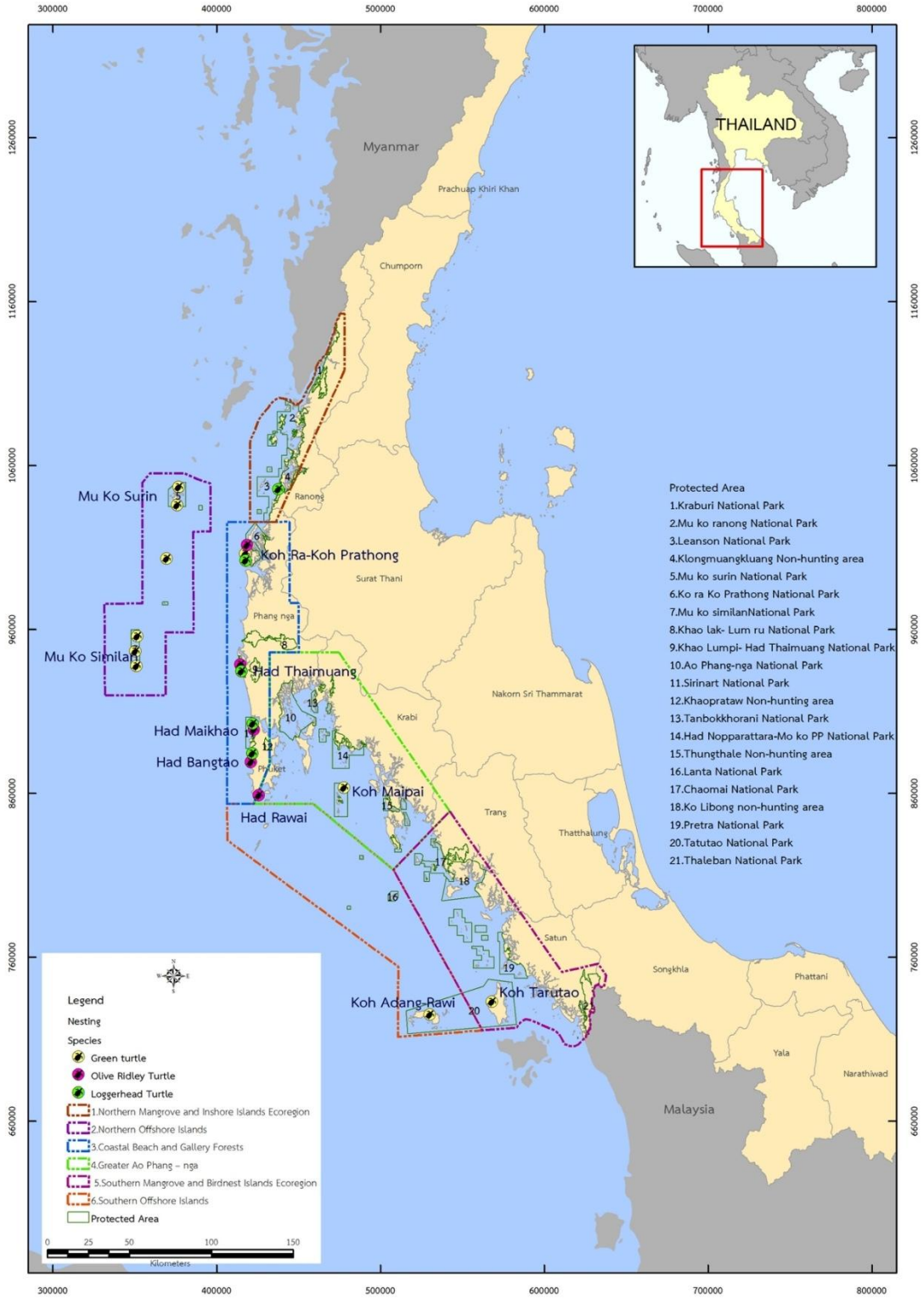


Figure 28. Sea turtle nesting occurrence (DMCR 2018)

5.3.4 Developing a resilient MPA network

In order to develop a well-represented, well-connect and resilient MPA network on the Andaman coast, I incorporate the current MPAs with other critical habitat areas i.e. endangered species feeding ground, other type of conservation areas namely Environmental Protection Area (EPA), DoF's Species Conservation Area, Ramsar sites and proposed marine biological corridors.

I have identified four main marine biological corridors along the Andaman coast using a three km from shore buffer that cover resilient reef areas and capture large tracts of mangrove, seagrass and nearshore coral reefs. The three km boundary is easily recognised and is part of no-trawl area set by DoF. However, these nearshore areas are currently not effectively protected. By establishing these areas as biological corridor would prioritise conservation management and enhance ecological connectivity among existing MPAs.

Four biological corridors with total area of 1,986.77 km^2 are 1) Proposed biological corridor between Ao Phang-Nga Ramsar site and Krabi Estuary Ramsar site (65.6 km^2) (**Figure 29**), 2) Proposed biological corridor between Ko Ra-Ko Phrathong – Sirinat National Park (694.47 km^2) (**Figure 30**), 3) Proposed biological corridor between Ao Phang-Nga Ramsar site and Laem Son National Park (702 km^2) (**Figure 23**) and 4) Proposed biological corridor between Mu Ko Phetra National Park and Thaleban National Park (524.7 km^2) (**Figure 31**). The proposed resilient MPA network on the Andaman coast of Thailand is shown in **Figure 32**.

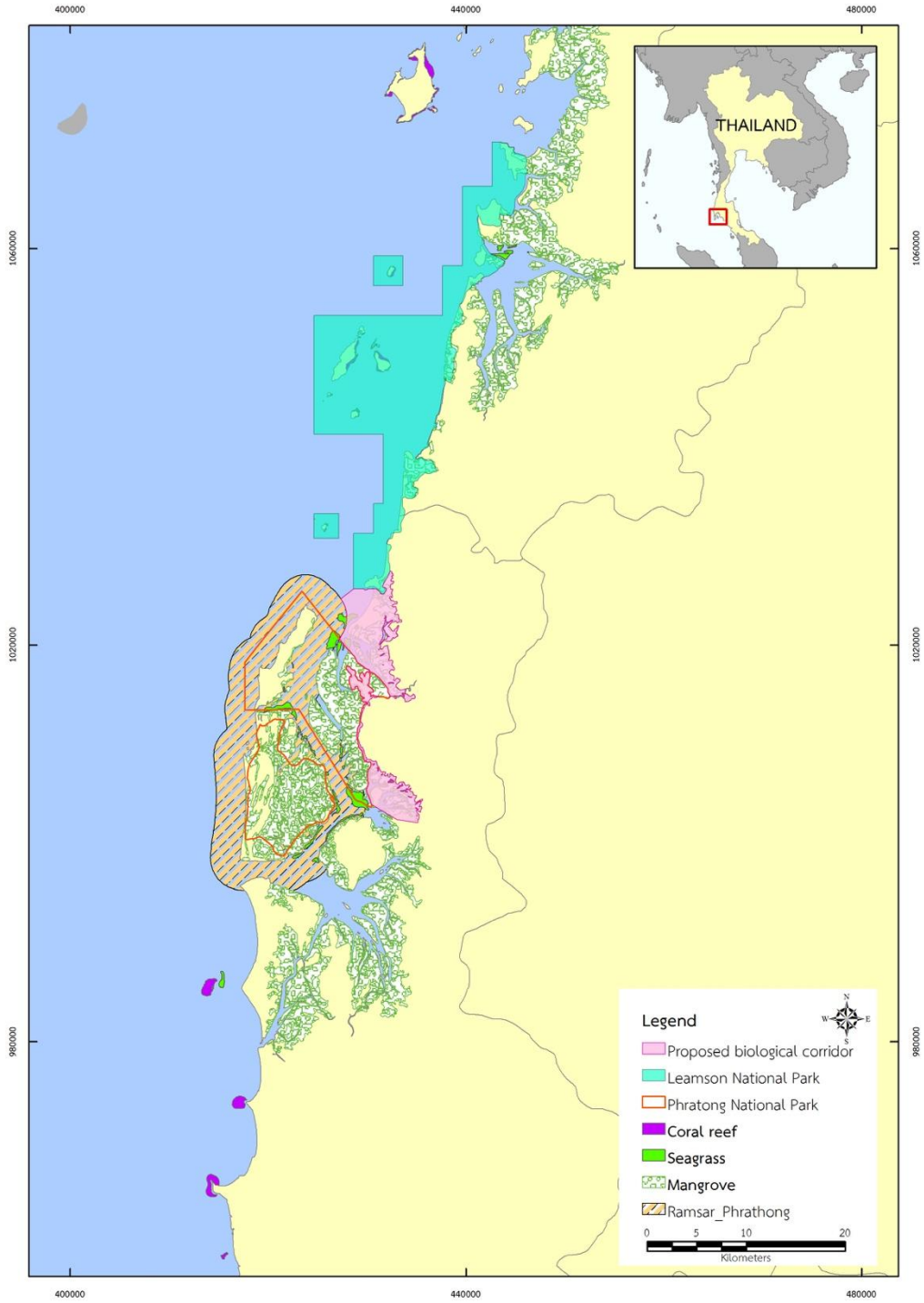


Figure 29. Proposed biological corridor between Lameson and Mu Ko Ra- Ko Phra Thong National Park

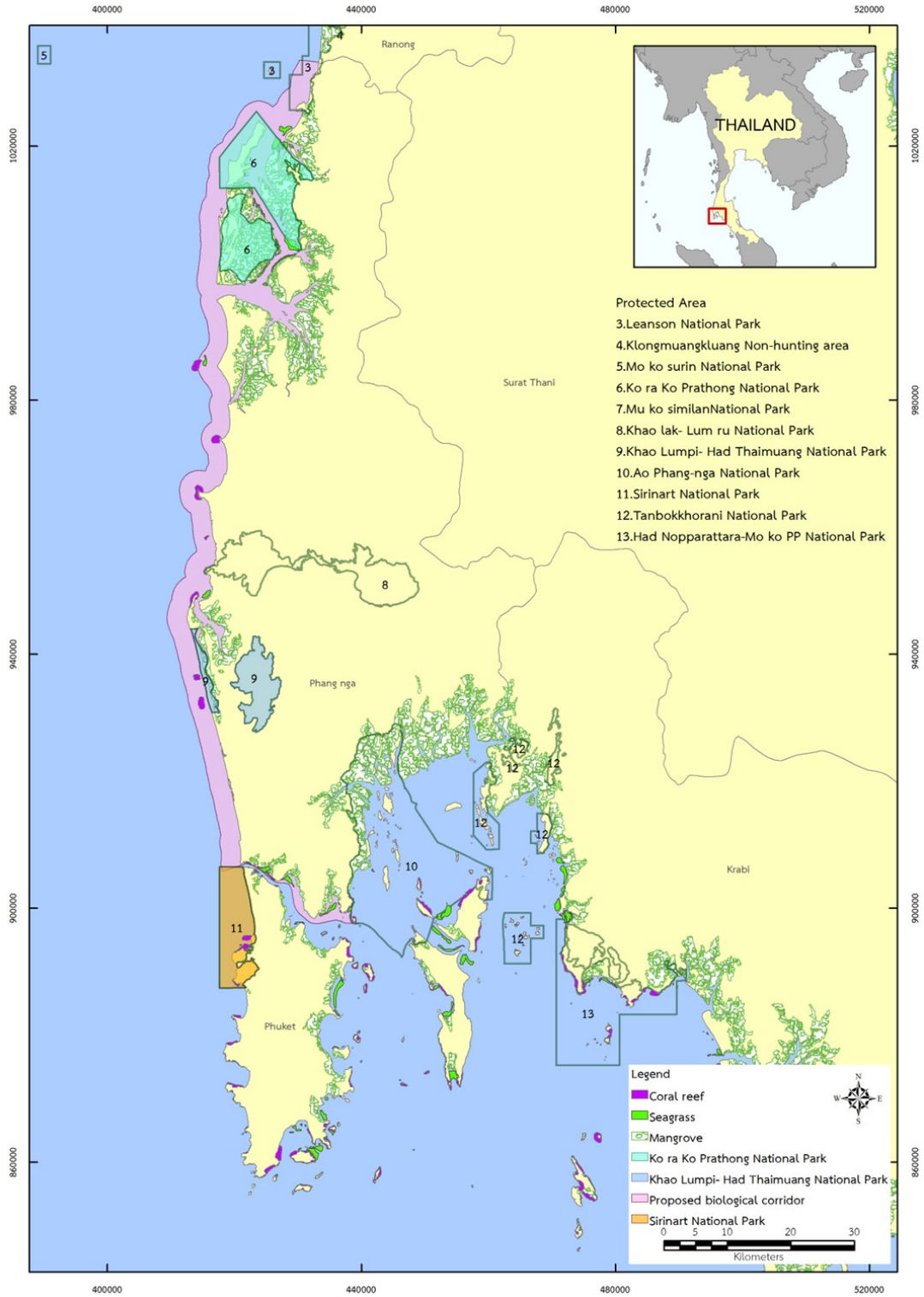


Figure 30. Proposed biological corridor between Ko Ra-Ko Phrathong and Sirinat National Park

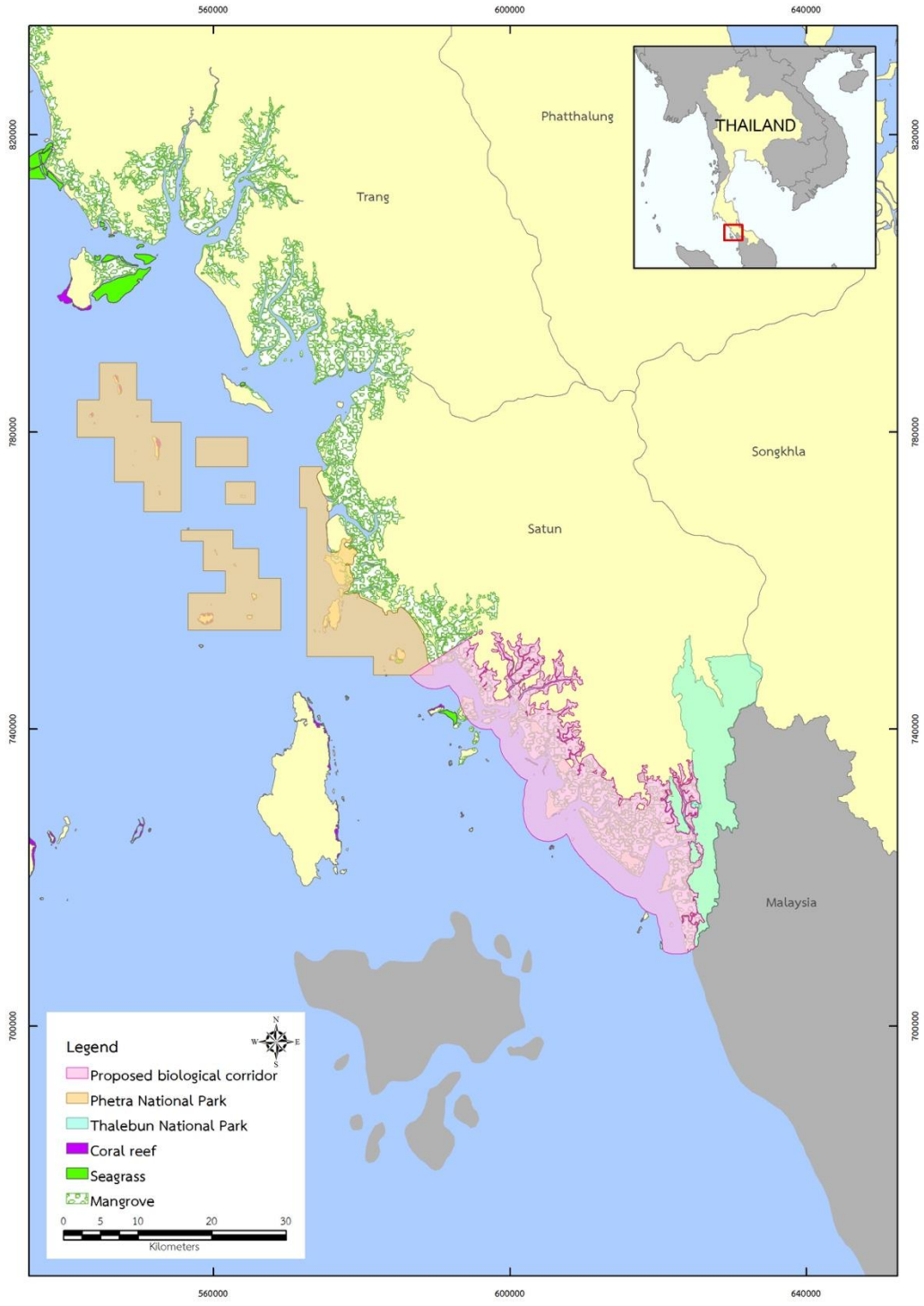


Figure 31. Proposed biological corridor between Mu Ko Phetra and Thaleban National Park

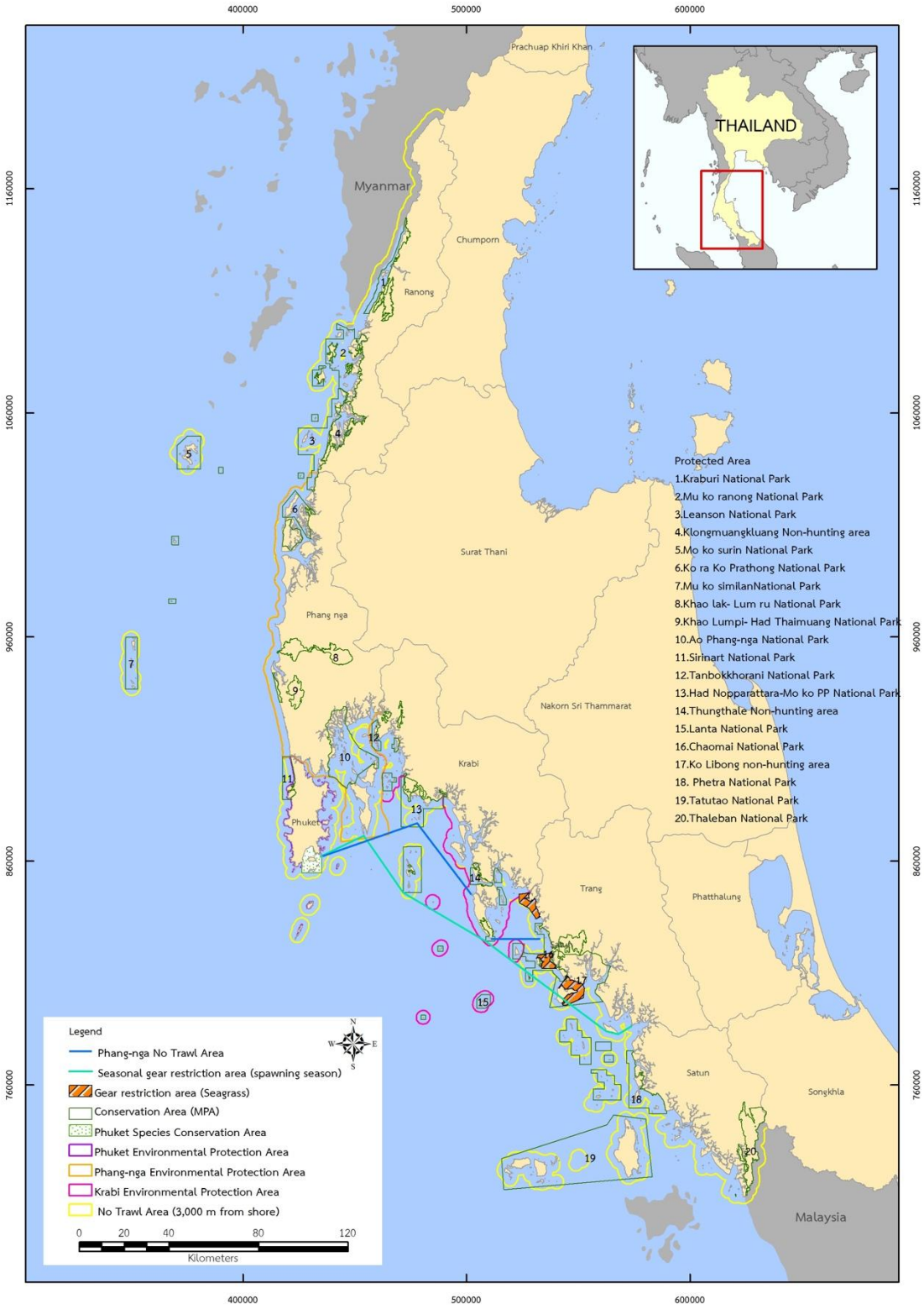


Figure 32. Proposed Andaman MPA network

5.4 Communicating resilience for change: Using social media to ban the commercial sale of parrotfish in Thailand

In 2014, there was an emerging problem of the commercial sale of parrotfish in major retailers in Thailand. Well-known supermarkets in the country started to sell parrotfish. Since the species is not protected and it is not illegal to sell or buy parrotfish, a public campaign using Facebook page 'Sunshine Sketcher' (**Figure 33**) was launched to counter this potential problem and help maintain coral reef resilience. This section describes the results of the campaign and is an example of how social media can be used to further public engagement in enhancing reef protection in Thailand.

5.4.1 Nature of the campaign

During the first phase, the goal was to bring public attention to the issue of commercial sale of parrotfish which is a new situation in Thailand. I employed a role-play technique, writing on behalf of parrotfish to make it succinct and more relatable to the target audience i.e. the diving community. The accompanying pictures taken from the supermarket on the same day helped convey the urgency of the situation that just happened. This encouraged the audience to pay attention, collaborate and support action because it was a "new" problem on which they could potentially have an influence. Following posts reinforced the message by providing scientific references and case studies from elsewhere e.g. in the Caribbean and the Great Barrier Reef, outlining the importance of parrotfish in maintaining reef resilience.

The second phase of the communication involved an online petition that targeted CEOs of the retailers. The campaign took advantage of the fact that modern trade companies are highly sensitive to their reputation and image.

5.4.2 Impact of social media campaign

The online campaign (**Figure 34**) through the facebook page reached over 2.2 million people during the 6 weeks period and led to the launch of the'Save Parrotfish' online petition on July 18, 2014 (See **Figure 35**). Just three days later, Tesco LOTUS announced a ban on parrotfish sales Subsequently, Central Food, Makro, Thammachart Seafood, The Mall Group and Villa Market all announced bans on the sale of parrotfish within 10 days of the campaign launch (**Table 16**). In total 23,037 people signed the petition and the campaign proclaimed victory on August 5, 2014.

During the online campaign, many different types of media covered the parrotfish and coral reef resilience issue (See **Tables 16-19**). The important role of parrotfish and impact of overfishing of herbivorous fish was widely communicated in mainstream media with estimated PR Value around USD360,758 in total from television (USD289,636), print media (USD61,879) and online media (USD9,242) (See **Table 17-19**). This calculation is based on the market value of different media e.g. Air time: how much it cost to feature this news for certain period of time for particular channel, space in newspaper and online media. Each major media outlet/brand can be estimated PR Value based on reference distributed by Department of Public Relation (DPR 2014). The outreach of these media ultimately exceeded the 2 million people from the original facebook channel and could be in the range of 5-10 million people based on mainstream media rating.

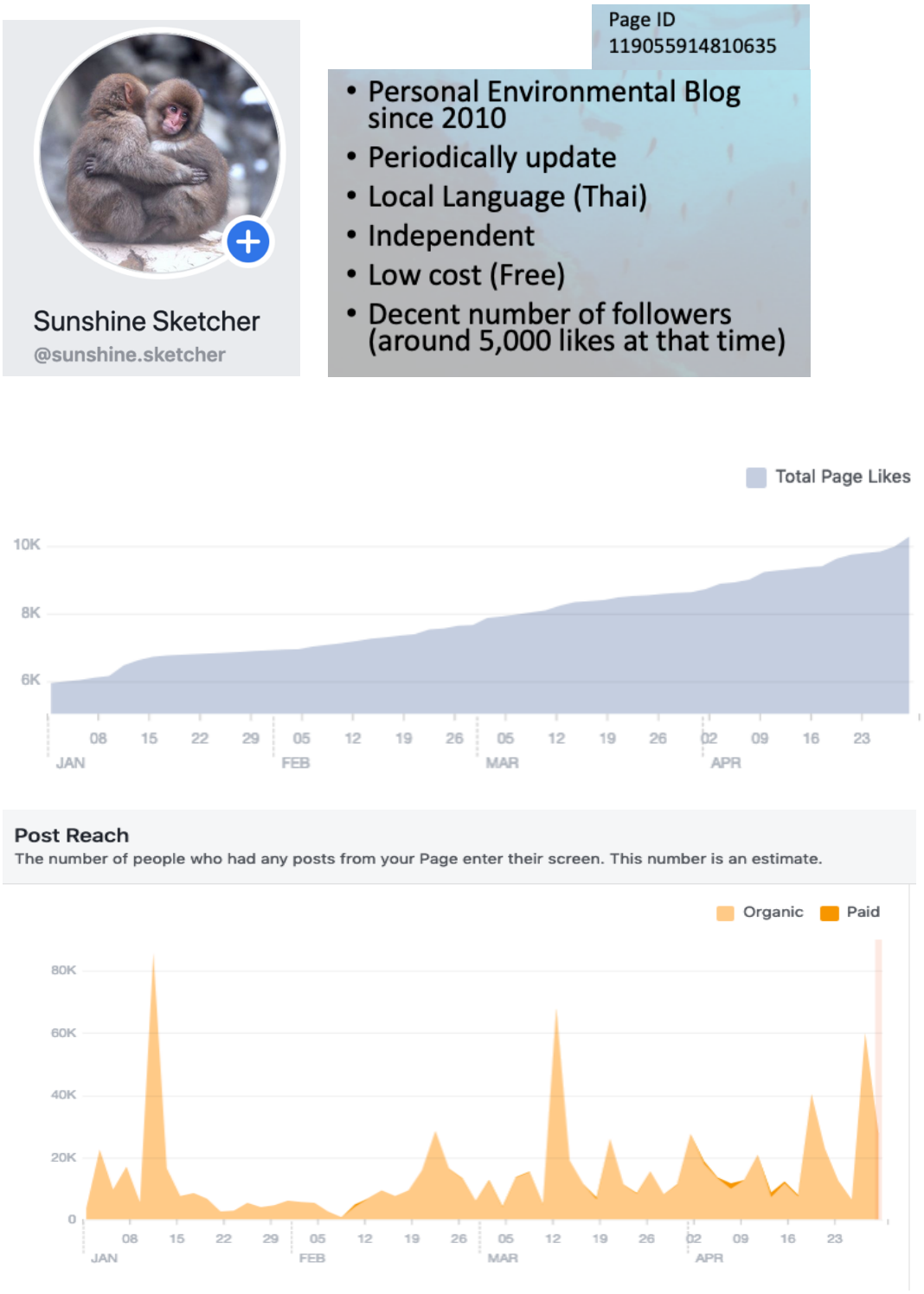


Figure 33. Facebook page 'Sunshine Sketcher' was used for campaign and page statistic during the campaign in 2014.

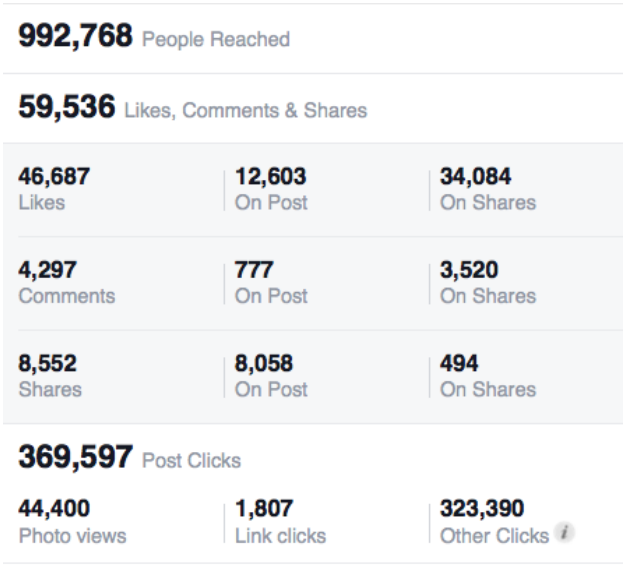


Figure 34. Online campaign on facebook page. Facebook algorithm shows number of people reach and engagement for every post.

Figure 35. Online petition was launched on change.org on July 18, 2014. In total 23,037 people signed the petition and the campaign proclaimed victory on August 5, 2014.

Table 16. The social media post timeline and how many people the post reached before and during the campaign.

Date	Topic	Social media engagement	Background/Reference:
22 March 2014	Why we need to save parrotfish?	1,214 likes; 1,732 shares; 100,184 people reached	Mumby et al. 2013. Operationalizing the resilience of coral reefs in an era of climate change. Conservation Letters. doi: 10.1111/conl.12047
19 June 2014	Please don't eat me	9,400 likes; 7,913 shares; 846,337 people reached	Photo of parrotfish on sale taken at Villa Supermarket in Phuket on that day.
21 June 2014	Please don't eat me (repost)	1,912 likes; 1,696 shares; 188,074 people reached	Repost with another picture of parrotfish on sale at Ranong Pier
24 June 2014	Critical role of herbivorous fish in coral reef ecosystem	113 likes; 59 shares; 3,288 people reached	Hughes et al. 2007. Phase shift, herbivory and the resilience of coral reefs to climate change. Current Biology. https://doi.org/10.1016/j.cub.2006.12.049
4 July 2014	To save coral reefs, start with parrotfish	277 likes; 424 shares; 47,172 people reached	Johnson, A. 2014. To save coral reefs, start with parrotfish. National Geographic. July 2, 2014.

5 July 2014	Why shouldn't parrotfish be on the menu?	328 likes; 209 shares; 12,523 people reached	Response to TV cooking show using parrotfish as properties of scene
9 July 2014	No parrotfish, no corals	130 likes; 68 shares; 3,565 people reached	P.J. Mumby et al. 2013. *Op cit*"
18 July 2014	First announcement about online petition to ban parrotfish sale targeting retailer CEOs	12,700 likes; 7,906 shares; 992,768 people reached	www.change.org/p/หยุดขายปลานกแก้ว-stop-selling-parrotfish
21 July 2014	Second announcement about online petition to ban parrotfish sale targeting retailer CEOs	138 likes; 84 shares; 4,980 people reached	www.change.org/p/หยุดขายปลานกแก้ว-stop-selling-parrotfish
21 July 2014	TESCO Lotus announced the ban of parrotfish sale	846 likes; 520shares; 35,838 people reached	Public announcement letter
22 July 2014	Central Food announced the ban of parrotfish sale	433 likes; 292 shares; 18,126 people reached	Public announcement letter
22 July 2014	Makro announced the ban of parrotfish sale	368 likes; 255 shares; 16,036 people reached	Public announcement letter
23 July 2014	Thammachart Seafood announced the ban of parrotfish sale and distribution	285 likes; 130 shares; 9,432 people reached	Public announcement letter
25 July 2014	The Mall Group announced the ban of parrotfish sale	322 likes; 40 shares; 4,947 people reached	Public announcement letter
29 July 2014	Villa Market announces the ban of parrotfish sale	86 likes; 25 shares; 3,298 people reached	Confirmed email by the Vice President
		Total 2,286,568 people reached	

Table 17. The number of Television Media reporting and estimated media coverage values

Date	Channel	Headline	PRValue (THB)	PRValue (USD)
26 June 2014	Nation TV	Please don't eat me - Parrotfish campaign	4500000	136364
21 July 2014	Voice TV	Saving Parrotfish Campaign before we destroy ecosystem	415000	12576

Date	Channel	Headline	PRValue (THB)	PRValue (USD)
22 July 2014	Nation TV	Pressures mounts for two remaining retailers to ban parrotfish sale	315000	25000
23 July 2014	Channel 3 Morning News	More retailers announced ban parrotfish sale after conservation group keep pressing	825000	9545
24 July 2014	Channel 3 Family News	Important role of parrotfish to marine ecosystem	710000	21515
25 July 2014	Channel 7	Don't catch parrotfish	862500	26136
28 July 2014	Spring News	Why we shouldn't eat parrotfish	425000	12879
28 July 2014	Thai PBS	Why we need to stop eating parrotfish	652500	19773
29 July 2014	Now 26	Retailers announced ban in parrotfish sale after conservation pressure mounts	530000	16061
2 August 2014	Voice TV	Parrotfish should be protected or eaten	323000	9788
			9,558,000	289636

Table 18. The number of Print Media reporting and estimated media coverage values

Date	Publication list	Headline	PRValue (THB)	PRValue (USD)
23 June 2014	Matichon	IUCN concerns at widespread commercial sale of parrotfish	70000	2121
17 July 2014	Daily News	Change your behaviour, stop eating parrotfish reduces threats to coral reefs	117000	3545
19 July 2014	Bangkok Biz News	You are? What you eat (stop eating parrotfish)	140000	4242
22 July 2014	Post Today	Central announced banning parrotfish sale	70000	2121
24 July 2014	Khao Sod	Makro announed banning parrotfish sale	78000	2364

Date	Publication list	Headline	PRValue (THB)	PRValue (USD)
24 July 2014	Bangkok Biz News	Conservationists pressure retailers to stop selling parrotfish	70000	2121
28 July 2014	Naewna	Stop eating, buying and selling parrotfish safeguarding coral reef ecosystem	140000	4242
2 August 2014	Post Today	Stop selling parrotfish, stop destroying coral reefs	1170000	35455
4 August 2014	Manager Online	Stop selling parrotfish, Say no to shark fins campaign power and effectiveness of social media	70000	2121
6 August 2014	Manager Online	Conservationists celebrate as five major retailers cancelled parrotfish sale	117000	3545
			2,042,000	61,879

Table 19. The number of Online Media reporting and estimated media coverage values

Date	Publication list	Headline	PRValue (THB)	PRValue (USD)
21 June 2014	Khon Anurak	Parrotfish request – let's campaign to stop eating and setting parrotfish	15,000	455
23 June 2014	Khon Anurak	Parrotfish can't be captive bred	15,000	455
28 June 2014	TCIJ	Parrotfish campaign – stop eating, buying and selling parrotfish	25,000	758
17 July 2014	Isara News	Saving parrotfish campaign arrotfis major retailers: Makro and TESCO Lotus announced ban	25,000	758
18 July 2014	Seub Nakhasathien Facebook	To save coral reefs, start with parrotfish	25,000	758

Date	Publication list	Headline	PRValue (THB)	PRValue (USD)
24 July 2014	CatDumb	Parrotfish campaign's Victory – Major retailers announced 'banning parrotfish sale'	25,000	758
24 July 2014	Change.org	More retailers quit selling parrotfish	40,000	1,212
3 August 2014	Greenpeace Thailand Facebook	Parrotfish – species to avoid eating	20,000	606
4 August 2014	kredkwamru.net	Parrotfish – colours of the sea and saving parrotfish campaign	15,000	455
6 August 2014	Sawinew online	Success! Retailers ban parrotfish sale	15,000	455
7 August 2014	DMCR News	Stop selling parrotfish, stop destroying coral reefs	20,000	606
11 August 2014	Smart SME	Why you need to stop eating parrotfish	15,000	455
11 August 2014	Smart SME	Why you need to stop eating parrotfish	**305,000**	9,242
29 September 2014	Thai Publica	Thailand Social Movement 2.0: arrotfish campaign and Big Trees	25,000	758
30 September 2014	Wix.com	Why we need to save parrotfish and Parrotfish campaign archive	25,000	758
			305,000	9,242

Following the success of the parrotfish campaign, there has been a surge in similar marine conservation campaigns in Thailand using social media as a trigger for change. Many of these relate to creating reform in the Marine Protected Area system with issues ranging from resource degradation from tourism, through to governance transparency (**Appendix XIII)**

Chapter 6

Discussion and Conclusion

6.1 Synthesis

Ongoing degradation in the structure and function of the world's coral reefs from a combination of local disturbance and global climate change requires novel approaches to sustain these ecosystems. Thailand's Andaman Marine Protected Areas (MPAs) experienced an unprecedented loss of coral reef in 2010 from bleaching but have since shown promising signs of recovery. This dissertation presents the results of a research project that focused on how coral reef resilience can be enhanced by developing an MPA network in the Andaman Sea taking climate change into account. The four-part results have focused on identification of resilient reef areas after the major coral bleaching event in twenty MPAs and beyond, determining gaps and opportunities to expand the current MPA system, guidance on management interventions based on a resilience assessment, and the potential for communication through social media to help enhance coral reef resilience in Thailand. Although the Andaman coast of Thailand has suffered serious degradation of marine resources over the years, this research reveals that functioning coral reefs exist across the Andaman and can be used as core areas for management to develop a resilient MPA network around those reef sources. This understanding offers insights into opportunities to improve the management of this large marine ecosystem. In conclusion, this Chapter summarizes methodological and theoretical insights, policy and management implications, the role of social media in conservation, and opportunities for future research and cooperation.

6.2 Result discussion

6.2.1 Implications of resilience rankings

It is notable that the majority of low-scoring resilience sites are located near major human settlements. Sediment loading, pollution and physical damage likely affect overall scores. Fishing pressures were evidently high in low resilience sites in area outside MPAs in Ranong (Mu Ko Chang T01, Ko Payam T02), Phuket (Laem Panwa T32) and Phang-nga (Ko Lipi T37).

High resilience sites should be highly protected to serve as a source of recovery for nearby reefs in time of high disturbance e.g. Ko Yung (T41), Ko Pai (T42) in Hat Noppharat Thara-Mu Ko Phi Phi NP, Ko Rok (T47) in Mu Ko Lanta NP, Ko Liang Nua (T48) in Mu Ko Phetra NP, Laem Hang Nak (T40) in Than Bok Khorani NP. Ko Phrathong offshore (T16) is an interesting one with a high score but it lies outside MPA boundaries. This site has high coral and fish diversity but has no formal management structure. This reef is one part of a relatively small barrier reef that extends southwards all the way to the north of Phuket.

Low-scoring reefs should be managed to enhance their resiliency. For example, the resilience of Ao Ton Sai (T43) on Phi Phi Don can be improved by addressing sediment loading from infrastructure development on the Island through law enforcement or better zoning to prevent land-based pollution. Similarly, anthropogenic physical impacts emerged as a major threat that lowers resilience in Ko Chuek (T45), Kradan (T46) and Ko Payam (T02). These are the types of impact that can be easily mitigated through management actions by installing markers to delineate reef areas where anchoring is prohibited.

The ecological connectivity between Thailand and Myanmar is a subject that requires further research but it is clear from the survey that recruitment of coral in Thailand's offshore reefs (Mu

Ko Surin and Similan) comes mainly from the southern Myeik Archipelago based on oceanography and the relatively undisturbed condition of some sites.

Although, the assessment could not cover all available reef areas in the Andaman bioregion, it is the first comprehensive assessment of coral reef resilience based on a unified framework. The resilient reef areas identified from this exercise can serve as cornerstones in developing a more resilient MPA network and provide a conservation-based platform for long-term marine spatial planning in the Andaman, this will be discussed further in following section. Further assessment should be carried out at a finer scale to help identify specific management actions. The following section provides an example of such an assessment.

6.2.2 Implication for management actions

Based on the resilience assessment result, the study sites at Mu Ko Surin National Park can be grouped into high, moderate and low resilience. Management interventions aiming to build coral reef resilience can be developed accordingly (**Figure 36**).

High resilience sites should be given strict protection to ensure that these sites can continue to supply recruitment within and beyond the Mu Ko Surin area. Some measures have been implemented as Ao Suthep, Ao Phakkad and Ao Chak have been designated as strict protection zone. Reef protection markers have been installed to delineate the coral areas where anchoring is prohibited and access by tourism activities are limited during low tide to avoid accidental damage by snorkelers.

The sites with least overall resilience scores urgently need direct interventions to improve their resilience. Ao Sapparos faces the highest impact from human activities because of its proximity to the Moken village and constant boat traffic from tourists. The abundance of fisheries target

species is also very low because park officials allow subsistence fishing by the Moken people. Community-based no-take areas that involve Moken people in their location and management should be set up within the bay area. This will encourage the Moken to take ownership of their own resources and fish more sustainably within the limit. Waste management and pollution have become an issue at the Moken village in recent years because of the materials and food brought in from outside usually with plastic packaging. This emerging problem affects corals directly both in the short and long term. Plastic pollution can increase the chances of corals contracting diseases and infection more than 20 fold (Lamb et al. 2018). New arrangements are now being discussed with all stakeholders to ensure pollution, sedimentation and fishing pressure are kept within standards set by park management guidelines including sanitary systems and waste management.

Ko Torinla and Hin Pae, are areas with very low coral recruitment and even seven years after the bleaching event still showed no sign of recovery. Researchers and park officials hypothesize that lack of suitable substrate and abundance of coral competitors could be the main reason obstructing natural recovery processes. Active restoration by clearing *Acropora* rubble and bringing in live corals from nearby areas has been undertaken at Ko Torinla and Hin Pae as an experiment starting in 2018. Broken branches of *Acropora* were attached to elevated metal bars drilled to the seabed to provide stability. The two sites have been assigned as recovery zone (**Figure 36**).

By adopting the resilience assessment framework with 22 resilience indicators, additional parameters have now been added to the regular monitoring protocol which provides much needed ecological information to understand overall resilience mechanism. Quantitative study of coral recruitment, systematic survey of coral diseases and observing signs of anthropogenic

impact are now part of regular surveys. This kind of observation provides key information for adaptive management in a timely manner. For example, a blast from dynamite fishing heard at Ko Stork during the survey in 2013 together with low resilience scores regarding fishing pressure and physical damage led the park to operate more regular patrols in the area. Similarly, results of the assessment helped to identify fishing prone areas (Ko Stork, Ko Pachumba, Ko Torinla) and prompted park authorities to increases their patrol efforts in target areas especially during off season.

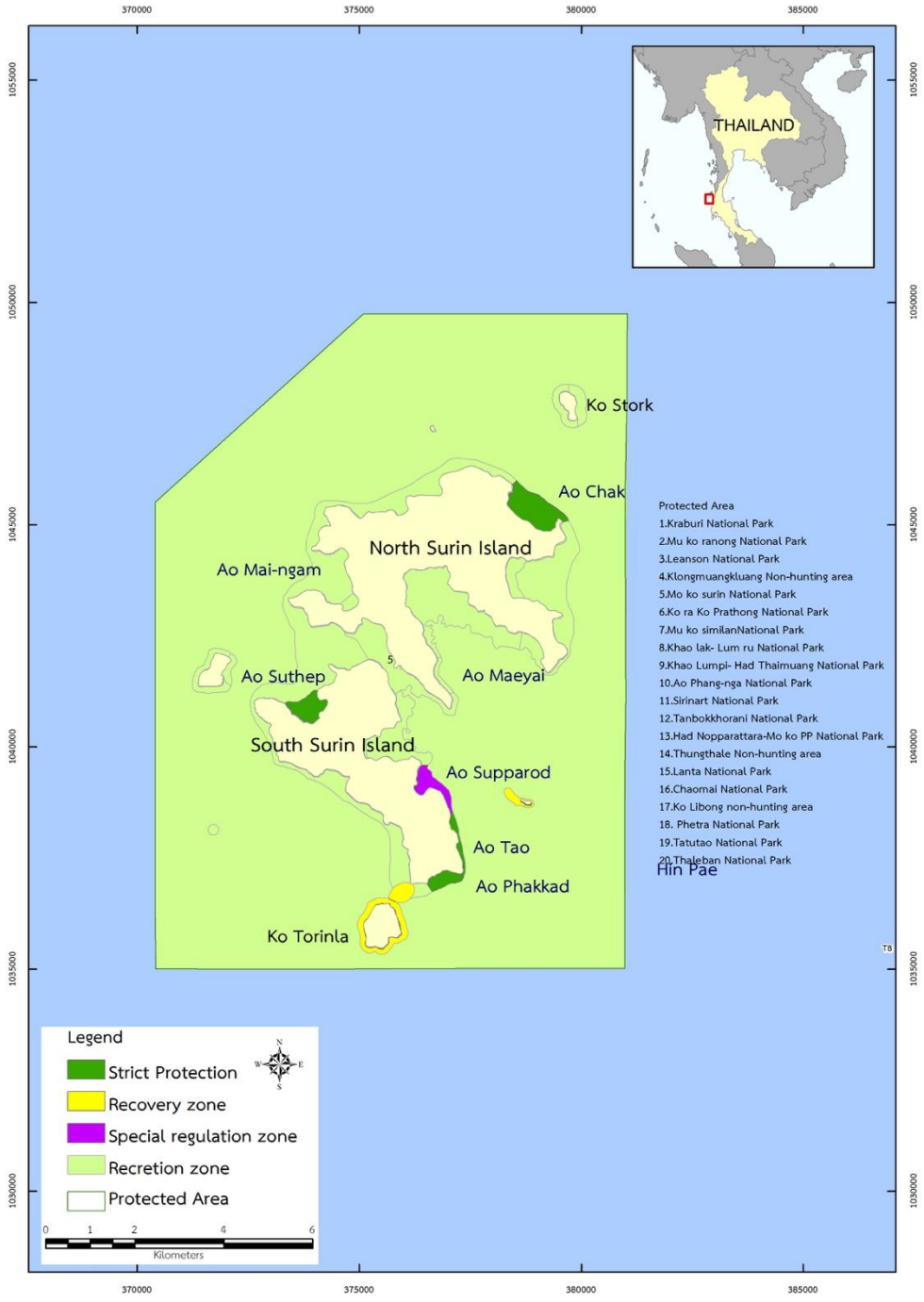


Figure 36. Recommended zoning in Mu Ko Surin National Park based on resilience assessment.

6.2.3 A resilient MPA network development on the Andaman coast

On the Andaman coast, resilient reef areas should serve as cornerstones for further developing the MPA network. However, the best chance to expand protected areas with existing MPAs is not boundary expansion but to incorporate other types of marine managed area into conservation planning and further develop biological corridors to link among them.

Previous gaps for MPAs in Thailand have been identified for large estuary and mudflat ecosystem such as Ao Ban Don (Surat Thani), Ao Pattani (Pattani), Inner Gulf of Thailand (Samut Songkram, Samut Sakorn, Samut Prakarn), Mu Ko Pra Thong (Phang-nga), Krabi River Estuary (Krabi) (ACB 2010). This particular ecosystem is very important for migratory bird species in the East Asia-Australasia flyway and at present largely unmanaged because they often occur near major cities and are highly accessible which make it more challenging to become formal MPAs such as national parks. On the Andaman coast, most of the significant estuary areas have already been designated as Ramsar sites namely Kaper Estuary - Laemson Marine National Park - Kraburi Estuary (1,084 km^2) in Ranong, Ko Ra-Ko Phra Thong (196 km^2) in Phang-nga, Phang-nga Bay (400 km^2) in Phang-nga, Krabi River Estuary (213 km^2) in Krabi and Trang River Estuary (825 km^2) in Trang (**Figure 23**). These Ramsar sites provide an ideal platform to incorporate various coastal habitats into the MPA system because of their relatively large size that already cover critical habitats (mudflat, seagrass, mangrove and coral reef) both inside and outside MPAs. For example, the Kapur Estuary -Laemson Marine National Park-Kraburi Estuary Ramsar site with an area of 1,084 km^2, covers a large proportion of Ranong's mangrove forest, seagrass habitat and nearshore coral reefs cutting across 3 National Parks and one Non-hunting Area. I assisted with the master plan development of this particular Ramsar site during 2017-18. However Ramsar sites have few protective covenants. Developing a master

plan and implementation plan for all coastal Ramsar sites is an important next step for achieving an ecologically well-represented MPA network.

For example, EPAs – Environmental Protection Areas which cover a large part of Phuket, Phang-Nga and Krabi provinces (See **Figure 24**) could effectively serve as buffer zones and ecological corridors for marine areas between MPAs in the three provinces. Similarly, the remaining mangroves south of Mu Ko Phetra Naional Parks could be established as biological corridors connecting to Thale Ban National Park (See **Figure 30**). This will ensure nearshore habitat protection for offshores reefs in Tarutao National Park. The endangered leatherback turtle that came to nest for the first time in five years in late 2018 used beaches outside current MPAs but that fall within EPA jurisdiction. The gap around Ko Prathong in northern Phang-nga and Phuket Channel where important seagrass bed are located would be addressed if EPAs were to be incorporated into the MPA network (See **Figure 31-32).** Although EPAs are classified as IUCN protected area category VI, not a no-take zone, EPAs for the three provinces provide legal protection for over 90 marine species including ecologically important groups e.g. parrotfish (*Scaridae*), sharks (*Carcharhinidae*), guitarfish (*Rhinobatidae*), surgeonfish (*Acanthrus*) (See Appendix XI for a full list of protected species).

EPAs are normally governed by provincial offices. Making EPAs part of the Andaman MPA network may thereby help to increase local participation in managing marine and coastal resources. In recent years, nearshore coral reefs around Phuket have been recovering surprisingly well and should be given special consideration for incorporating these areas into MPA system. The area outside formal protection ones such as Rawai and Pa Klok has seen thriving *Acropora* in very shallow water, signs of resilient reefs that withstand both anthropogenic stressors as well as thermal anomalies (**Figure 37**). These areas are not

recognized as MPAs but there are local arrangements for managing marine resources in the area such as Pa Klok community conservation area. Community-based marine managed areas like this could help enhance the resiliency of current Andaman MPAs. The idea of 'Community Corals' – similar to 'Community Forest' where the community plays a big part in the control and sustainable use of the area, has been discussed in Protected Area Advisory meetings of several MPAs in the Andaman with positive responses. It is recommended that DMCR conduct a comprehensive review of potential community-based marine managed areas throughout the Andaman.

DoF's species conservation areas are another area-based management tool that could enhance connectivity among existing MPAs in the Andaman. For example, the area around Cape Panwa is a species conservation area covering important nearshore reefs and nearby islands. If this area is recognized as part of the larger MPA network, it could help bring attention and resources needed to manage the area effectively.

Public-private partnerships in protecting and restoring ecosystems are also growing. The IUCN-Marriott Partnership in Phuket which led to the development of an on-site Reef Education Centre as well as site-based management demonstrated a lot of potential for coral reef conservation. By committing to the promotion of environmentally friendly guidelines and instructing guests on how to enjoy the reef in a sustainable way, coastal hotels can provide a lot of input for enhancing the MPA network.

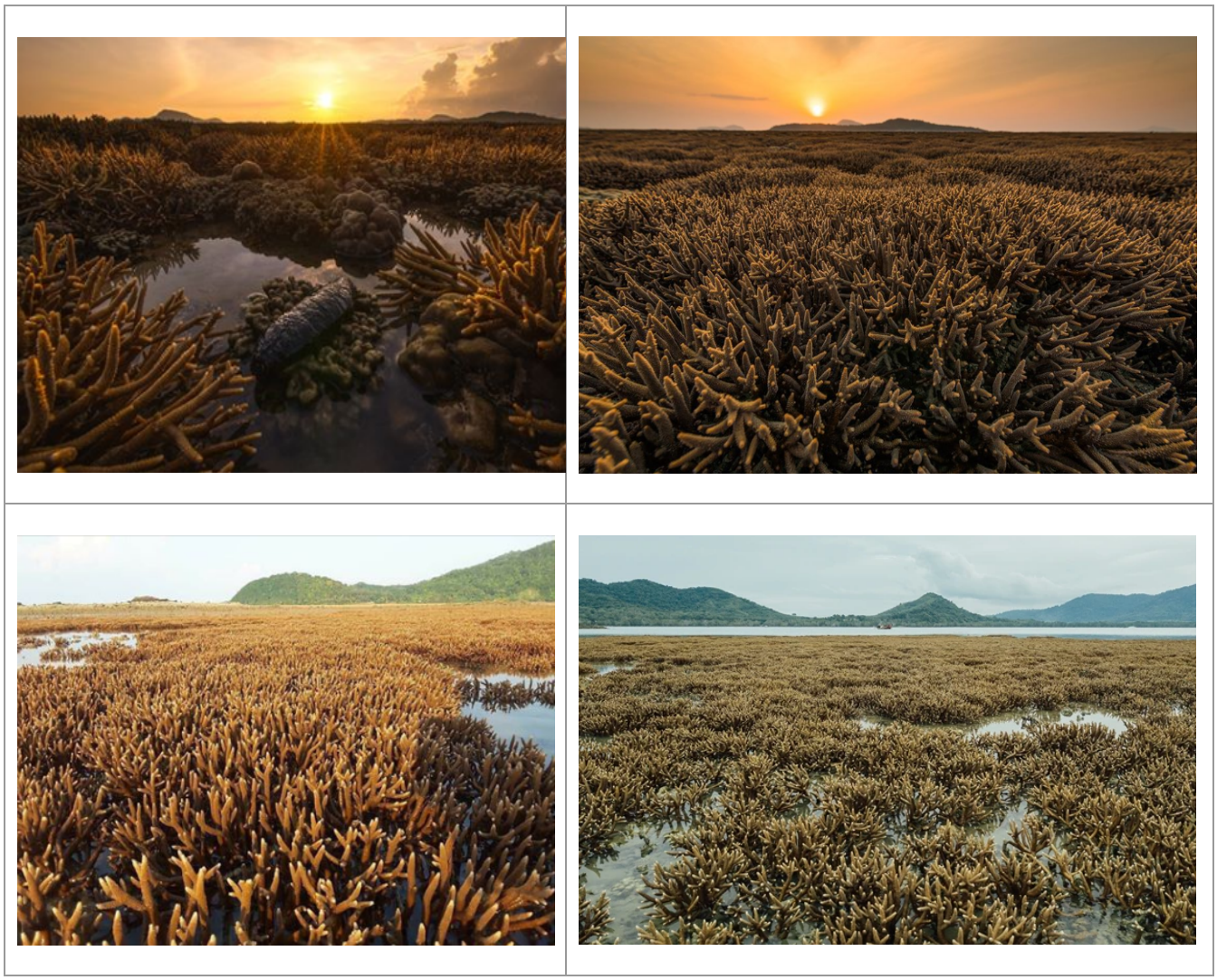


Figure 37. Recovering near-shore reefs outside MPAs around Phuket (2018) (Rawai and Pa Klok area) Photo by Pam Wushu

Thailand's most recent National Biodiversity Strategy and Action Plan (NBSAP, 2015), submitted to the Convention on Biological Diversity, highlights the importance of engaging private and civic sector actors in implementing the plan. The private sector is called on to "Promote and support conservation and sustainable utilization of biodiversity; and awareness raising and education;" and NGOs are called on to "Cooperate with public and private sectors, individuals and other organizations in promoting and supporting conservation and sustainable utilization of biodiversity."(NBSAP Page 42). Privately protected areas are a new concept in

Thailand and may be limited by land tenure issues. Nevertheless, co-management with the private sector could open up a lot of possibilities in marine and coastal areas where coastal tourism dominates.

More adaptive and flexible, smaller in size, but greater in community engagement and public participation should be the traits of additional marine conservation areas that would enhance ecological connectivity of the Andaman MPA network.

6.2.4 Key lesson learned and successful factors from parrotfish campaign

When local action or management interventions alone are insufficient to maintain resilience, in this case parrotfish harvesting control, it is critical to build awareness, change attitudes and create an enabling environment for transformation to drive the desired change that supports maintaining the integrity of the social-ecological system (Morecroft et al. 2012). In the case of parrotfish sales in Thailand, the emerging trade in parrotfish acted as an external, beyond local control factor that could pose a serious threat to local populations of herbivorous fish on coral reefs. Therefore, effective communication can be used to help create an enabling environment to influence public perceptions and attitudes, and allow policy improvements to take place.

While planning for transformations may seem very complicated, crises often represent opportunities and trigger transformations allowing cross-learning in the public sphere and new awareness to emerge and spread (Folke 2016). Improved interdisciplinary science communication capitalizing on crises can increase public engagement dramatically (Duffy 2015). Getting a species to be protected under the law could take more than 20 years and countless resources based on the history of additional marine species listed in WARPA (2019). This case

study suggests that communication through social media can be an important, cost-effective and timely strategy to facilitate intervention and transformation.

Social media allows scientists to communicate directly with their peers as well as the general public in almost real time and in a cost-effective manner. Some interested and active citizens do follow news of their interest on Facebook pages. Scientists like me, who write regularly can build a large number of followers. An interactive platform such as Facebook encourages members of the general public to participate and form public opinion on certain issues through processes such as signing petitions or the overwhelming number of 'like' and 'share' on the post.

Strengthening public awareness and empowering individual actions play an important role in building stewardship in biodiversity conservation and environmental protection (Jefferson et al 2015, Steel et al. 2005). Information that touches on individual emotions, attitudes, knowledge and beliefs can influence people to act and demand policy change from relevant authorities (Gadenne et al. 2009).

Companies invest heavily in Corporate Social Responsibility to create a trusted brand. A campaign that has enough public support, at least 10,000 signatures based on past campaign in change.org, tends to get noticed readily when it involves media and potentially viral content on social media. Targeting five major companies all at once also created peer-pressure among competing players. The first company to ban parrotfish sales will likely earn a better reputation for being a 'good' company because they are receptive to public opinion (on the news) and concerns (petition). Subsequently, follower companies need to follow suit to avoid being branded as 'bad' company by ignoring the fact that they are selling an ecologically important species.

One of the key success factors in this campaign was acting early. Commercial sale of parrotfish in retail stores was just introduced to consumers and the market was in an early stage of development. The market value of the new commodity was probably still relatively small. Giving up on the new commodity in order to address public concern was a much easier decision for the companies compared to eliminating more well-established commodities. For example, campaigning for banning shark fin consumption has been undertaken by various organizations for a long time without much success. Part of the reason is that it is a well-established market with an annual trade worth USD34.5 million (FAO, 2015). Another example is the #PassOnParrotfish campaign launched in2017 by The Nature Conservancy and partners in the Caribbean in to raise awareness about the need to protect parrotfish. It was a much harder market to stop since parrotfish were already popular for consumption and a common feature on many dishes (CaribbeanDevTrend 2016). The attempt to ban commercial sale of parrotfish was not successful and faced strong opposition as the species is an important part of the livelihood for local people (Jamaican Observer 2019). Similarly in the Philippines, parrotfish (known locally as Loro fish) is a favorite in Filipino cuisine. There has been a number of public outcries reported on the news in the Philippines through social media that people should stop eating parrotfish because of its important role in maintaining resilient reefs, but so far without success (Madarang 2018, 2019).

Guidance for achieving transformation, in this case seeing parrotfish as friend not food, includes threshold and barrier identification, alternative states, system tipping point, adaptive strategies and multi-stakeholder facilitator (Folke 2016). Acting as a catalyst, social media allows scientists to shape public opinion and develop new awareness that emerges out of the crisis. The nature of the interactive platform offers opportunities for scientists to address the barrier (lack of

awareness) and threshold (overfishing), potential alternative states (conservation), reach a tipping point (critical mass public opinion) and develop an adaptive strategy (ban parrotfish sale and protect fish population in protected areas) through multi-stakeholder consultation on social media.

In the parrotfish campaign, the banning of commercial sale by major retailers not only prevented substantial demand from emerging but also greatly helped raise public awareness both among the general population and media on the issue of coral reef resilience and overfishing. Although, parrotfish are still not protected by law, the campaign success established a new social norm that it is not appropriate to buy or consume parrotfish because of its critical role in coral reef resilience. In the years after the campaign, there have been several complaints on social media when people see parrotfish on sale in a market and local government had to take preventive action by officially requesting sellers to abandon the practice (Jaiharn 2016). In some tourist areas like Koh Phi Phi in Krabi, the local municipality has voluntarily banned parrotfish selling and consumption altogether (Tabthong 2017).

6.3 Methodological insights

The coral reefs of the Andaman Sea in Thailand have been mapped and studied since the1980s giving Thailand an advantage compared to most other countries in the region. However, the ecological parameters that have been collected using a line intercept approach are quite limited and focus mainly on live coral cover and other living organisms (such as sponge, macroalgae, sea anemone) which intersect or underlay the measuring tape. Collecting information on the twenty-two resilience indicators provides much more detail into the health of ecosystems including fish assemblages (herbivorous, predatory and commercially targeted), bleaching history and management effectiveness (e.g. fishing pressure, sedimentation, physical damages).

Counting coral recruitment also gives much needed understanding about the likelihood of coral recovery that varies significantly from site to site. The information on physical characteristics such as shading, cooling and proximity to other habitats is also useful as an influential factor when everything else is even. Maynard et al. (2010) suggested that the extent to which any resilience indicator confers resilience to a reef site will vary spatially, especially in relation to human impacts, indicator weightings may need to be re-evaluated for other studies.

Collecting twenty-two parameters is time-consuming and resource-demanding. Normally, at least a four to five person team is required to complete one transect. The human resource constraint is a major issue in field work and taking on volunteers or collaborating with university research teams has been one of the common solutions to address this challenge. However, inherent subjectivity and the variable experience of the observers may also influence data quality and consistency. For example, rating management-oriented resilience indicators can be quite subjective depending on prior observer experiences of different sites. Thorough training about resilience indicators needs to be given prior to any data collection. Careful review of data sets after each dive among observers is highly recommended to help verify information and have a second opinion on semi-quantitative ratings. Skilled observers who can confidently identify and count fish and coral disease are also very limited. From this study, a number of sites were omitted because of the lack of a complete data set especially relating to the fish community and coral disease data. Given these constraints future monitoring will need to move towards employing advanced technology for data collection. Autonomous Underwater Vehicles (AUVs), Remotely Operated Vehicles (ROVs), Baited Remote Underwater Video (BRUVs), including stereo applications for benthic fish and habitat structure, and for pelagic fish, Automated Image Collection and Processing, and Remote Sensing technique are just some examples that have seen

rapid development over the last few years (Obura et al. 2019). Piloting these techniques using the resilience framework would allow more consistent data collection. This standardized technique coupled with use of more advanced environmental data loggers would allow more sophisticated analysis to detect climate change impacts such as ocean acidification.

It is also important to have a central database regarding resilience assessment. My dataset will be available at both the Marine National Park Operation Center (MNPOC) under the Department of National Parks, Wildlife and Plant Conservation (DNP) and Phuket Marine Biological Center (PMBC) under Department of Marine and Coastal Resources (DMCR). Given the mandate of the agencies that have developed databases for all marine and coastal resources both inside and outside marine national parks, DMCR should be responsible to store and manage this resilience assessment database.

The prevalence of social media users and popularity of scuba diving in Thailand offers great potential to develop a citizen science programme to help detect climatic and environmental changes such as the early onset of coral bleaching, coral disease, Crown-of-Thorns and invasive species outbreaks. Programmes such as the Eyes of the Reef Network (EOR) in Hawaii (https://eorhawaii.org/about-3/) and Eye on the Reef Sightings Network in the Great Barrier Reef (http://www.gbrmpa.gov.au/sightings-network/), are community reporting networks for coral disease and bleaching; wildlife, marine pollution and any other incident requiring attention. The effective statewide reporting system enables all community members and ocean users to contribute to the long-term data collection and protection of the reefs (GBRMPA 2016). Such a programme could be readily set up and linked with existing Thai Coral Reef Network Facebook Groups (https://www.facebook.com/groups/175422549249325/) that already have more than 3,200 members, many of whom are active marine scientists and experts . The parrotfish

communication case demonstrated an effectiveness of timely communication through social media that can widely influence public opinion and management interventions. This citizen science approach not only provides an early warning about changes for government to take action but also helps facilitate participation in management by local communities and diver volunteers. The exchange of information and communication flow can help ease tension when conflict occurs between MPA stakeholders and leads to problem-solving and improvement of MPA management as evident in the case of over-capacity tourism and irregularities in marine national park entrance fee collection.

From this research, the reef resilience assessment framework represents a step forward in incorporating the concept of resilience and climate change impact into MPA planning and management in Thailand. This assessment can be applied and implemented wherever sites have been monitored. It can also be used in explaining to park users about resilience of the reef and building support among local communities and stakeholders for management responses to climate change.

6.4 Theoretical insights

To counter the global decline of coral reefs, scientists have recommended to move beyond conventional management and support resilience enhancement of social-ecological systems of coral reefs (Hoegh-Guldberg et al. 2007; Mcleod et al. 2019). Resilience-based management (RBM) has been proposed for coral reef management as climate impacts have intensified around the world (Graham et al. 2013; Anthony et al. 2015). In Thailand, the 2010 mass coral bleaching was a wake-up call for marine scientists and park managers because even the most pristine and relatively well-managed MPAs faced unprecedented loss of coral cover in a relatively short time.

Catastrophic coral bleaching served as a shock that could shift the system into less preferable alternative states i.e. degraded corals.

In theory, RBM aims to identify and prioritize management actions that can improve system capacity (e.g. protecting critical species and processes) to resist shock or recover after major disturbances. RBM includes strategies that help build adaptive capacity and adaptation in society and communities that depend on reefs and guide proactive decision-making under risk and uncertainty.

This crisis of coral bleaching made it much easier for marine scientists in Thailand to convince policy-makers to move towards a more integrated approach in managing MPA as a network and the importance of adaptive management to deal with an abrupt change or uncertainty. It has led to a quest to better understand coral reef vulnerability to climate change impact and how existing MPAs can safeguard their future. Resilience assessment of MPAs to identify resilient reefs is an important first step to protect the key resources. Adopting resilience indicators as a regular protocol can be interpreted as capacity-building in society to try to understand how to avoid the tipping point when corals become permanently degraded. Although local management efforts can not mitigate large-scale impacts such as mass coral bleaching, our resilience assessment suggests that best practices inside MPAs can support recovery following disturbances (e.g. a measure like area closure and increased law enforcement). In the Andaman bioregion, protecting functional groups such as parrotfish and sharks has also been a key conservation strategy to protect reef ecosystems and communicate to the public about reef resilience. This has been very successful in highlighting the resilience of some MPAs when key species are found to be recovered. For example, the large school of blacktip reef sharks (50-100 individuals) has

returned to Maya Bay area in Mu Ko Phi Phi national park within 4 months after the area closure for ecosystem restoration in June 2018.

Sometimes, the complexity of ecological processes behind coral reef resilience forces MPA management to adopt a precautionary principle such as protecting a diversity of species, keeping a herbivorous fish abundance, minimising sedimentation loading etc. to ensure best environmental conditions for the reef to recover. Adopting a 'safe operating space' for coral reefs (Norstrom et al. 2016) that outlines a safe level of fishing (the heathy range is to leave more than 500-250 kg fish biomass per hectare), water quality (phytoplankton biomass should stay below 0.45–0.55 μg chlorophyll per litre), CO_2 concentration (CO_2 should remain below 340-480 parts per million (ppm) might be suitable for coral reef areas outside MPAs.

In term of communication about resilience, social media acts as a catalyst and allows scientist to shape public opinion and develop new awareness that emerges out of the crisis (in this case the commercial sale of parrotfish). This seems to fit guidance for achieving transformation in resilience thinking, in this case changing parrotfish status from food to critical species for maintaining ecosystem resilience, that includes threshold and barrier identification, alternative states, system tipping point, adaptive strategies and multi-stakeholder facilitator (Folke 2016). The nature of the interactive platform offers opportunities for scientists to 1) address the barrier: major retailers with more than 1,000 outlets; lack of awareness about importance of parrotfish; 2) understand threshold: amount of fish caught and s old; the number of people signed on for petitions ; 3) predict potential alternative states: parrotfish become household species for consumption, commercial sale led to overexploitation of parrotfish; 4) reach a tipping point: corals do not recover; public outcry and petition, and 5) develop an adaptive strategy:

commercial sale of parrotfish sale banned; parrotfish population is protected, through multi-stakeholder consultation on social media platform.

6.5 Policy and Management Implications

One important policy implication from this research is that Thailand needs to scale up its MPA coverage as well as increase strict protection areas throughout the country. There is also a need to create a central database on MPAs and designate focal government agencies to correspond with global database management authority e.g. International Union for Conservation of Nature (IUCN) -World Conservation Monitoring Center (WCMC) (i.e. World Database on Protected Area) and Marine Conservation Institute (i.e. MPAtlas) about current fact and figure of MPAs in Thailand to avoid confusion and misrepresentation internationally. The current coverage for MPA based on IUCN's guideline stands at 5.6% and the no-take area accounts for only 1.76% of the total marine area. Expanding MPA coverage and developing MPA networks is an urgent priority for Thailand if the country aims to reach the CBD target of at least 10% of marine and coastal habitat protected by 2020. How best to design, implement and manage coral reef protected areas needs to be adapted to address the needs of the local situation . This study suggests three important areas: 1) Expanding MPAs; 2). A bottom-up' approach that incorporates adaptive and flexible governance; and 3) Adaptive management.

1. Expanding MPAs in the Andaman should prioritize 'identified resilient reefs areas' and 'biological corridors' that are currently outside of any form of protected area because they are likely to withstand and adaptive to a changing climate. Those resilient reefs should be further studied and incorporated into the MPA network to foster connectivity between nearshore habitats and offshore reefs. The development of the MPA network should align with upcoming opportunities (i.e. proposed MPAs under the DMCR Act).

This would also include detailed mapping of potential biological corridors between Ramsar sites (Phang-Nga Bay and Krabi Estuary Ramsar Site; Laemson and Ko Ra-Ko Phrathong National Park) and between MPAs (e.g. Mu Ko Phetra and Thale Ban National Park). More marine biological corridors between island groups should be explored further (e.g. Mu Ko Surin and Mu Ko Similan, Mu Ko Racha and Mu Ko Phi Phil, Mu Ko Rok and Mu Ko Ngai/Muk/Kradan) to ensure connectivity and recommend suitable management schemes.

2. Recognizing that social and ecological systems are tightly linked and that Thailand MPAs generally do not have necessary community support, the addition of new MPAs needs to move towards a 'bottom-up' approach and explore more adaptive and flexible governance approaches. Community-based mangrove management along the Andaman coast has been successful because of collective action with support by Non-Governmental Organization (NGOs), a shift to cooperation with government and enhancement of sustainable management (Kongkeaw et al. 2019). Community-based resource management initiatives such as community coral areas (e.g. nearshore resilient reefs areas around Phuket and Phang-Nga) would enhance social-ecological connectivity of the MPA network. These community-based opportunities should be integrated with systematic conservation planning to ensure they are part of the MPA system and achieve ecological and social objectives (e.g. fisheries enhancement, biodiversity conservation, integration of local and scientific knowledge, equity concern) (Ban et al. 2011; Kockel et al. 2019).
3. Adaptive management of MPAs is being used in other areas to address key shortcomings of MPAs such as mismatch of MPA scale and ecological expectation, inappropriate planning, and failure due to degradation of the unprotected surrounding ecosystem

(Agardy et al. 2011; Ban et al. 2012; Nickols et al. 2019). Adaptive management, identifying whether and when adjustments to management might be necessary to achieve MPA goals is a critical process in managing MPA networks. On the Andaman coast, a 'Ridge to Reef' approach together with adaptive management was used in some areas (e.g. Ranong and Phang-Nga) to reduce impacts from outside areas (Wetlands International, 2008). From this research, the use of the resilience assessment provides much needed information and opportunities for adaptive management of MPAs. By determining priority resilient sites within the whole area both inside and outside MPAs, resource managers can focus their effort on mitigating impacts during and after severe bleaching events. For example, identification of high resilient areas in Mu Ko Surin (e.g. Ao Chak, Ao Suthep) can be used to set up strict protection and low resilient areas (e.g. Hin Pae, Ko Tolinla) for post-bleaching restoration initiative. Experimental intervention to increase the persistence and resilience of coral reefs such as shading of coral reefs, mixing of cool water, managed relocation and genetic manipulation of coral species (NASEM 2019) can be performed at key resilient sites during extreme temperature years. This information needs to be monitored regularly to adjust zoning for park recreation, public access and other activities based on real time situation.

Moving forward, the key management actions to promote reef resilience include protecting a diversity of coral species, habitat and functional groups especially herbivores, reducing reef stressors (e.g. pollution, sedimentation, physical impacts), implement MPA to support resilience including protecting of refuges (e.g. naturally resilient area), maintain pathways of coral connectivity and invest in experimental approaches to support resilience (Mcleod et al. 2019).

All of these management interventions are directly relevant to the situation with the Andaman coral reefs as a whole.

The Development of an MPA system master plan for Thailand is an important next step to set the vision and articulate the values, benefits and potential outcomes of a properly managed MPA network. The MPA Master Plan which will combine all different management categories of MPAs under different agencies will strategically position how MPAs will contribute to Thailand's conservation and development agenda. Resilience assessments and management effectiveness evaluations should be adopted as one of the key approaches for MPA system development in Thailand.

From a resilience building perspective, Thailand's initiative to nominate the Andaman bioregion as a world heritage site should be encouraged. The process can help rally support for an ecosystem-based approach and foster transboundary cooperation between Thailand and Myanmar because Myanmar's Myeik Archipelago is already on the world heritage's tentative list.

6.6 Social media and conservation

Scientists around the world are harnessing the power of social media to speed up the pace in which they are sharing information and affecting public policy (Bik & Goldstien 2013; Darling et al. 2013). A few key patterns have emerged from marine conservation cases on social media in Thailand that yielded substantial conservation outcomes. First, these marine conservation movements, including the parrotfish campaign, are led by marine scientists who have strong public support. Second, these campaigns effectively made use of scientific research and case studies on an attractive reef species elsewhere e.g. impact of herbivory in Caribbean and the

Great Barrier Reef. (Hughes et al. 2007; Mumby et al. 2013; Johnson 2014). Third, the movement has been communicated widely on social media and consequently attracted national media outlet. Fourth, scientists are involved directly with a structured campaign with specific ask (i.e. public petition via change.org). The campaign led to public discourse and helped identify solutions (e.g. retailers banning the sale of parrotfish, DNP investigated over-tourism problem that led to area closure for restoration). Parrotfish were used effectively as a flagship species to maintain the resilience of coral reef ecosystems as well as represent an overfishing problem.

Social media empowers individuals to participate and recognizes the importance of local actions. The process for change has been significantly shortened compared with traditional public consultation processes such as holding workshops and meetings. Media attention and direct participation from the public serve as an external force for actions that need to be implemented. Conservation scientists have long known that public engagement is key to conservation success (Jefferson et al. 2015) and a well-informed public can increase support in conservation initiatives (Cigliano et al. 2015). However, the efforts of scientists often fall short of achieving the desired policy change largely due to a lack of public awareness and support.

The parrotfish case study highlights the importance of science communication and the usefulness of social networks for conservation. Key success factors included employing role-play techniques in communication, acting early before the market value becomes significant and creating peer-pressure among competing players. It demonstrates that social media, in this case Facebook Page, when used effectively, allows scientists and the general public to collaborate directly and create change in a participatory manner. Science-based, real-time information (including photos and video documenting the status of the species and its threat) is a powerful

tool for public engagement and enabling conservation success. Social media can catalyze attitudes, awareness and engagement to safeguard species and the natural environment.

A recent study confirmed that social media (in this case Twitter) can be used as a first step to disseminate scientific messages beyond the scientific community and create public pressure necessary to drive change at the policy level (Cote & Darling 2018). However, their study suggests that social media is not likely an effective replacement for more direct science-to-policy outreach e.g. testifying in front of special government committees because the majority of scientists have relatively small number of followers. Their review showed that for scientists who have fewer than 1000 followers, their followers are predominantly (~55%) other scientists. Social media partly becomes an echo chamber for academic scientists. However, beyond this threshold, the tweets of academic scientists can reach a more varied audience, that has the potential to function as an outreach tool (Cote & Darling 2018).

The situation in Thailand, may be explained as a case beyond threshold. The Facebook page that I used to run science communication now has over 110,000 followers and, based on the parrotfish campaign, some posts can easily reach more than a million people in one day. More diverse members and varied audience were, in turn followed by more people, resulting in an exponential increase in the social media reach of conservation related posts. Historical studies in nonviolent resistance suggested that no public campaign failed once they had achieved the active and sustained participation of 3.5% of the population and a lot of campaigns succeeded with far less than that threshold (Chenoweth & Stephan 2012). In Thailand, 3.5% of the total population (~70 million) would be almost 2.5 million people or 350,000 people of the Bangkok population (~10 million). The parrotfish campaign reached more than 2 million people from the original

facebook channel alone. I would argue that the impact of conservation campaign on social media that can reach close to, or above, these thresholds are likely to succeed.

To conserve the world's oceans and address climate crisis scientists are recommended to go beyond science, and use scientific findings to inform policy and management, and ultimately to catalyze change (Hines, Parsons & Cigliano 2011; Cigliano et al. 2015; Ripple et al. 2019). Social media is now recognized as a powerful tool that can galvanize public opinion, catalyze public support for conservation action ranging from the wildlife trade in Vietnam to dolphin conservation in China (Ngiem et al. 2012; Wijedasa t al. 2013; Wu et al. 2018). Scientists should equip themselves with communication skills or work with a communications specialist to contextualize scientific findings for mainstream audiences and seize upon communication opportunities. The parrotfish case study in Thailand reinforced that using scientific data in combination with smart advocacy can make a difference and result in significant conservation outcomes.

6.7 Limitations, future research and cooperation

The Resilience assessment, while providing a valuable first approach, has a number of limitations. The current resilience indicators are employed a semi-quantitative approach but the categories 1-5 are yet to be tested whether they reveal major difference in the system resilience. Some assessments can be very subjective and to ensure data consistencies, the observers require prior training. However, due to human resource and time constraints, training was not always possible. The resilience ranking, based on crude three categories, high, moderate, low, is also arbitrary. The ranking may be indicative of their resiliency but required closer investigation among those sites that have very similar resilience scores.

Nevertheless, resilience assessment provides useful initial understanding in terms of coral recovery patterns at finer scales. For example after severe disturbance within Mu Ko Surin the resilience assessment highlighted the importance of identifying source and sink reefs and protecting the upstream gene pool in Myanmar in order to preserve ecological connectivity.

The resilient reef areas of Ao Chak, Ao Suthep, Ao Tao and Ao Phakkad in Mu Ko Surin National Park near the Myanmar border had the fastest recovery of live coral cover and feature some of the highest coral recruit density among other reefs in Thailand after the 2010 coral bleaching (Yucharoen et al. 2015). These particular locations should be further investigated to understand the underpinning ecological processes such as herbivory (primary production), predation (secondary production), bioerosion (Calcium carbonate production) and nutrient uptake (Brandl et al. 2019). It is equally interesting to understand why some low resilient areas did not recover and what enabling environments can be created to overcome these barriers.

To ensure ecological connectivity in the Andaman bioregion, creating Transboundary MPAs is a recommended next step. In fact, there have been several joint workshops between Thailand and Myanmar with representatives from universities, government and NGOs hosted by DMCR. These workshops laid some groundwork for data sharing as well as building the capacity of Myanmar researchers. A joint survey and monitoring of coral reef resilience at MacLeod Island groups, Myanmar (Nga Khin Nyo Gyee, Nyaung Oo Phee and Cockburn), a clearly resilient and source reef near the border, is feasible since the area has already been open to tourism from Thailand. Further investigation on larval dispersal will increase our understanding about connectivity within the Andaman bioregion. Transboundary cooperation through responsible tourism development, shared governance, exchange learning and joint natural world heritage nomination are highly recommended.

6.8 Conclusion

Climate change has already affected much of the world's ocean and the phenomenon of coral bleaching is clearly here to stay over the coming centuries because of the greenhouse gas concentration that is already in the atmosphere. The Andaman coast of Thailand has experienced an unprecedented mass coral bleaching in 2010 and is likely going to face more similar events in the future. Large-scale and indiscriminating disturbance such as the mass bleaching events provide a unique opportunity to review MPA systems and assess whether or not they are well planned and managed to withstand conditions that are going to become more prevalent under future climate change regimes. Resilient reef areas that have been identified from this study, the first comprehensive assessment of coral reef resilience in Thailand, will serve as cornerstones in developing a more resilient MPA network and provide a conservation-based platform for long-term marine spatial planning in the Andaman bioregion. Assessing coral reef resilience at a local scale can be used to determine recovery potential and necessary management actions. Resilience assessments improve understanding of recovery processes and connectivity in transboundary areas and emphasize the importance of transboundary conservation initiatives. Communicating about resilience using social media as demonstrated in this research about the role of parrotfish can be very effective in raising public awareness about resilience management and improved coral reef conservation. The future of coral reefs in the Andaman bioregion will depend on how society recognises their vulnerability and is willing to adapt and reduce our impact locally as well as cumulative global impacts of greenhouse gas emission. This research shows that it is possible to expand and develop a more resilient MPA network on the Andaman coast.

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Appendices

Appendix I - Location, geographical coordinates and prominent habitat of MPA's along the Andaman coast of Thailand (DNP 2018). Note Habitat: C = Coral Reef, S = Seagrass Bed, M.= Mangrove, B = Beach, E = Estuary, K = Karst Topography, F = Evergreen. Remark: * In a process of being designated

No.	Protected Areas	Location	Geographical coordinates	Year	Area (Sq.km.)	Habitat
1	Lam Nam Kraburi NP	Amphoe Kraburi, La-un, Muang Ranong; Ranong Province	N 9° 57' 37" - 10° 22' 38" E 98° 34' 49" - 98° 46' 15"	1999	166.1	M E
2	Mu Ko Ranong NP	Amphoe Muang Ranong; Ranong Province	N 9° 23' 46" - 9° 57' 03" E 98° 22' 12" - 98° 35' 45"	2009	356.7	M E
3	Laem Son NP	Amphoe Muang, Kapoe, Suk Samran; Ranong Province and Amphoe Khura Buri; Phangnga Province	N 9° 16' 24" - 9° 41' 11" E 98° 18' 47" - 98° 30' 37"	1982	315	C M B
4	Klong Muang Kluang Non-Hunting Area	Amphoe Suk Samran, Ranong Province	N 9° 23' 36" - 9° 38' 6" E 98° 24' 51" - 98° 35' 00"	In process	131.04	M S
5	Mu Ko Ra-Ko Phra Thong NP*	Amphoe Khura Buri, Takha Pa; Phangnga Province	N 9° 02' 04" - 9° 16' 38" E 98° 15' 04" - 98° 23' 05"	In process	166.1	M B E
6	Khao Lak-Lam Ru NP	Amphoe Takha Pa, Kapong, Thai Mueang, Mueang Phangnga; Phangnga Province	N 8° 34' 17" - 8° 40' 45" E 98° 13' 45" - 98° 32' 11"	1991	125	F
7	Khao Lampi-Hat Thai Mueang NP	Amphoe Thai Mueang; Phangnga Province	N 8° 23' 33" - 8° 32' 22" E 98° 12' 36" - 98° 20' 22"	1981	72	S M B F
8	Sirinat NP	Amphoe Thalang; Phuket Province	N 8° 01' 42" - 8° 11' 59" E 98° 15' 12" - 98° 18' 32"	1981	90	C S M B
9	Mu Ko Surin NP	Amphoe Khura Buri; Phangnga Province	N 9° 20' 36" - 9° 29' 14" E 97° 49' 21" - 98° 00' 29"	1981	141.2	C B
10	Mu Ko Similan NP	Amphoe Khura Buri; Phangnga Province	N 8° 28' 08" - 9° 05' 21" E 97° 36' 45" - 97° 49' 36"	1982	140	C B
11	Ao Phang-nga NP	Amphoe Takha Thung, Mueang Phangnga, Ko Yao; Phangnga Province	N 8° 4' 20" - 8° 24' 13" E 98° 25' 33" - 98° 38' 31"	1981	400	M K

No.	Protected Areas	Location	Geographical coordinates	Year	Area (Sq.km.)	Habitat
12	Than Bok Khorani NP	Amphoe Ao Luek, Mueang Krabi; Krabi Province	N 8° 03' 47" - 8° 25' 37" E 98° 36' 54" - 98° 44' 50"	1998	104	M E K
13	Hat Noppharat Thara-Mu Ko Phi Phi NP	Amphoe Mueang Krabi; Krabi Province	N 7° 38' 59" - 8° 08' 01" E 98° 43' 57" - 98° 55' 11"	1983	387.9	C S M
14	Mu Ko Lanta NP	Amphoe Ko Lanta; Krabi Province	N 7° 08' 31" - 7° 45' 03" E 98° 48' 57" - 99° 14' 02"	1990	134	C M S B
15	Thung Thale Non-Hunting Area	Amphoe Ko Lanta; Krabi Province	N 7° 40' 37" - 7° 46' 22" E 99° 0' 54" - 99° 6' 21"	1999	53.18	M B
16	Hat Chao Mai NP	Amphoe Kantang; Trang Province	N 7° 17' 38" - 7° 31' 45" E 99° 13' 13" - 99° 29' 10"	1981	230.8	C M S B
17	Mu Ko Li Bong Non-Hunting Area	Amphoe Kantang, Palian, Hat Samran; Trang Province	N 7° 11' 20" - 7° 25' 01" E 99° 20' 13" - 99° 35' 06"	1979	447.5	S M
18	Mu Ko Phetra NP	Trang and Satun Province	N 6° 45' 31" - 7° 08' 30" E 99° 22' 41" - 99° 48' 40"	1984	494.4	C M B
19	Tarutao NP	Amphoe Mueang Satun; Satun Province	N 6° 29' 07" - 6° 45' 11" E 99° 27' 08" - 99° 45' 19"	1974	1490	C M B
20	Thale Ban NP	Amphoe Khuan Don, Mueang Satun; Satun Province	N 6° 25' 43" - 6° 48' 27" E 100° 06' 12" - 100° 12' 49"	1980	196	F L

Appendix II - Brief Description of Andaman MPAs in each ecoregion

Ecoregion	Andaman MPA
The Northern Mangrove and Inshore Islands	**Lam Nam Kraburi National Park** features Kraburi river and estuary ecosystem prominently with an area of 64 km^2 or about 40% of the total park area. Mangrove are mostly found near Khlong La-un estuary, Khao Hin Chang and islands above Khlong La-un estuary. The Park is the estuary with turbid water and high-level of sediment so, it is not the suitable habitat for corals or seagrasses.
	Mu Ko Ranong National Park can be divided into 3 groups; coastal area, near shore area and offshore area bordering with Myanmar. Corals can be found on the western rocky shore of several islands including Ko Chang, Ko Phayam, Ko Thalu with relatively low live coral cover (5-20%). Small patches of seagrass are found on the northeast coast of Ko Chang. The coastal area includes part of Ranong mangrove Biosphere Reserve and features a very high diversity of old growth mangrove.
	Laemson National Park features healthy beach forest as well as small well-established coral reefs around near-shore islands. Coral reefs can be found on the east side of Ko Kang Kao, the west side of Ko Kam Yai, Ko Kam Nui, Ko Lan and Ko Kai Yai. Live coral cover ranges from 15-40%. High level of sediment usually occurs and Porites spp. or boulder corals are dominant species in this area.
	Klong Muang Kluang Non-Hunting Area offers protection of coastal evergreen forest and mangrove area around the estuary. The predominant ecosystem is mangrove with small seagrass bed. The area is feeding ground for turtle and dugong population in the northern part of Andaman Bioregion.
The Northern Offshore Islands	**Mu Ko Surin National Park** consists of five islands: Ko Surin Nua which is the location of the National Park office; Ko Surin Tai which includes steep terrain, tropical rainforest and Moken settlement; Ko Torinla to the south; Ko Stork to the north near the Myanmar border and Ko

	Pachumba to the west, plus a small rocky outcrop known as Hin Pae. The topography of Mu Ko Surin is suitable for the development of coral reefs with large bay areas providing good wave protection, clear water and optimum temperatures. At sheltered sites, the reefs show distinct zonation, i.e., reef flat, reef edge and reef slope, while on wave exposed sites the zonation is not obvious. Most reefs around Mu Ko Surin are fringing reefs on sandy bottoms and were originally dominated by branching coral species (Acropora spp.).
	Mu Ko Similan National Park composed of nine islands on a the north-south axis; Huyong Island, Payang Island, Payan Island, Miang Island, Ha&Hok Island, Payu Island, Similan Island , Bangu Island , plus the outlying islands of Tachai Island and Bon Island. Topography of Mu Ko Similan is also suitable for the development of coral reefs especially at deeper level from 10-30 m. The largest area of coral reef is found on the east and northwest coast of Similan Island. The density is higher in the deep zone than the shallow zone. Other islands with significant reef coverage include Ko Miang, Ko Ba Ngu and Ko Huyong. The total area of coral reef observed is around 3.55 km^2 (Phongsuwan et al. 2013). Several species of soft coral and many types of sea fan can be found in abundant at Mu Ko Similan.
The Central Beaches and Coastal Gallery Forests ecoregion	**Mu Ko Ra-Ko Phra Thong Non-Hunting Area** consists of more than 30 inshore islands and is roughly 1-4 km offshore. The three main islands, Ko Ra, Ko Phra Thong and Ko Khor Khao, are biologically diverse with savannah grassland, evergreen forest, beach forest and mangrove forest. Seagrass beds are formed in the north and the east of the island. Most of them are found near an estuary or mangrove forest. With suitable substrate for seagrass development, Ko Phrathong is the largest seagrass area in Phang-nga covering area 7.216 km^2 and

	home to small remnant of dugongs (DMCR 2013). Corals can be found in nearshore shallow area with depth 1-5 m and offshore at 20-25 m depth. The area was designated as Ramsar site, a wetland of international importance in 2013.
	Khao Lak-Lam Ru National Park covers mostly terrestrial area with 90% tropical rain forest and the highest mountain peak of 1,077 m. Some mangrove species are found in nearby area. The park serves as an important coastal forest area and important watershed area for major rivers in Phangnga Province. Several whale and dolphins are often observed in the open sea area in proximity to the park. Khao Lak is also a major coastal tourism destination.
	Khao Lampi-Hat Thai Mueang National Park covers mostly terrestrial area, so, no marine resource is found in the boundary. However, nearby areas are biologically diverse with large coral patch of 3.48 km^2 found about 600 m from shore as well as seagrass in Ban Ta Dindaeng and mangrove in the estuary area. This small barrier reef extends southwards to the island of Phuket and potentially plays a very important role in enhancing connectivity between inshore and offshore habitat. The beach in the park is the last remaining nesting site of endangered leatherback turtle in the region with nesting found in early 2019.
	Sirinat National Park is the only formal MPA in Phuket and house significant area of coastal wetland and high diversity of coral reefs as well as last remnant of turtle nesting site and beach forest on the island. Coral reef in the park covers an area approximately 1.01 sq.km with live coral cover around 15-60%. The park is very accessible and located next to several development, airport and hotels and sufferes high-level encroachment. The reefs here seem to connect to the barrier reef in Phang-Nga and could play important role as stepping-stones to offshore reefs as well.
The Greater Ao Phang-nga	**Ao Phang-nga National Park** covers a unique seascape and landscape from vast mangrove in estuary area to limestone karst inselbergs providing natural habitat for limestone endemic species. Some coral reefs can be found along the west coast of Ko Yao Yai and Ko Yao Noi with total area more than 3 km^2. Although reef condition ranges from poor to fair but these areas were rather undisturbed during mass coral bleaching event. This could be naturally turbid water condition that help produce tough condition for reefs to survive and could serve

	as important genetic reservoir. Seagrass bed are found in abundance around Makham Bay and Chongkhad Bay and Ko Lawa with total area of 2.5 km^2.
	Than Bok Khorani National Park features similar topography as Ao Phang-nga with vast mangrove in estuary and limestone karst islands nearshore. Corals can be found in small patches scattered around the islands with total area of around 0.3 km^2 in relatively turbid condition. Seagrass can be found in Muang Bay around 700-1,000 m from shore.
	Hat Noppharat Thara-Mu Ko Phi Phi National Park comprises of coastal beach forest, historical shell fossil site and a small archipelago of Phi Phi. The largest coral area is found around Ko Phi Phi Don with an area approximately 3.11 km^2 and smaller patch of reefs found in Ko Pai, coastal area of Ao Nang – Ao Nam Mao and Ko Phi Phi Le. The large seagrass area at Ko Jam and Ko Sri-Boya is an important dugong habitat with total area of 0.585 km^2 covering 85% of the bay area. Maya Bay in Phi Phi Le is the subject of international attention as Thai government decided to close the area to tourism for restoration due to tourism damages since June 2018. The area will remain close at least until 2021 and since the closure is taken place large school of blacktip reef shark of 50-100 individuals have used the area frequently.
	Mu Ko Lanta National Park comprised of four main island groups namely Ko Lanta, Ko Rok and Ko Ngai (nearshore) and Ko Ha (offshore). The park covers coastal evergreen forest, mangrove forest, beach forest. Corals are found mainly around Ko Rok, Ko Ngai and Ko Lanta Yai with total areas around 3 km^2. The offshore islands of Ko Ha is part of the Southern Offshore Islands ecoregion and frequently used by whale sharks and manta rays. Mangrove forests are found in small islands inside the park but large tract of mangroves are mostly found outside the park boundaries.
	Thung Thale Non-Hunting Area covers mainly remaining mangrove forests along the estuary in the northern part of Ko Lanta Noi with total area of around 53 km^2. This non-hunting area was not part of Andaman Sea Nature Reserve nomination but should be considered

	part of the MPA network linking between Hat Noppharat Thara-Mu Ko Phi Phil and Mu Ko Lanta National Park.
The Southern Coastal Forests	**Hat Chao Mai National Park** comprises areas of shoreline mountainous forests, sandy beaches, mud flats and nearshore islands. There are also grasslands, evergreen forests, mangrove forests, nypa forests, beach forests and sandy beaches on the shoreline. The shoreline comprises mostly steep limestone mountains with Chong Chun, Kuan Merd Joon and Kuan Kway mountain ranges lying east of the northern part of the shoreline. Coral reefs are found on island's shelf with high slope such as those around Wan, Chuck and Kradan islands.
	Mu Ko Li Bong Non-Hunting Area is well known for its abundant and diversity of seagrass meadow covering total area of 19 km^2, about 7 km^2 extending outside the boundaries. These seagrass areas provide a core feeding ground area of an estimated 200 dugongs – the largest population in the country (DMCR 2019). The extensive mudflat also supports more than 44 species migratory shorebirds including globally threatened species such as Chinese Egret (Vulnerable), Chinese Crested Tern (Critically Endangered) and Nordmann's Greenshank (Endangered).
	Mu Ko Phetra National Park consists of coastal areas and 22 nearshore islands. The largest islands are Ko Phetra and Ko Kao Yai that are covered with evergreen forest, limestone cliff and pristine beaches. Coral reefs can be found around all the islands with largest areas on the west coast of Ko Phetra and Ko Bulon Lay. Staghorn corals (Acropora spp.) in shallow water of Ko Bulon Lay survived mass coral bleaching event of 2010 and are still in good condition. These shallow reefs could potentially be an important refugia for reseeding in far southern region.
	Tarutao National Park consists of small and large 51 islands. Large 7 islands are Tarutao, Adang, Ra Wi, Li Pe, Klang, Bu Tong and Bitsi Islands. It can be divided into 2 groups of island; Tarutao Islands

	(nearshore) and Adang-Ra Wi Islands (offshore). Coral reefs can be found around all islands but widely developed on the west coast of Tarutao, Bu Tong, Adang and Rawi Island. Coral reefs here represent the southern Andaman assemblages and suffered low mortality during 2010 bleaching event. This could potentially be naturally resilient reef areas for the southern region. Adang-Rawi islands are part of the Southern Offshore Islands ecoregion and because of its distant locations, subject to a lot of commercial fisheries activities.
The Southern Offshore Islands	The southern offshore islands are geologically similar to the northern offshore islands, but differ significantly in certain aspects, mainly their geology and their proximity to the Indonesian Through-flow from the Straits of Malacca. Sheltered from the full force of the Indian Ocean by the bulk of Sumatra to the west, these islands support extensive fringing coral reefs. Consequently, coral assemblages are much different in character and composition to the northern reefs, and provide a rich community supporting a vital and diverse reef ecosystem. These islands are influenced by the Indonesian Through-flow that connects the South China Sea to the Indian Ocean via the Straits of Malacca. This ecoregion provides robust contrast to the Northern Offshore Islands in terms of biotic affiliations. Marine species diversity is extremely high; more than 400 fish species have been recorded here. Almost all of the hard coral species in the Andaman biogeographic province (more than 160 species) are documented here. The Indian Ocean species found to the north are supplemented by immigrants from the Indonesian Centre of Diversity to form the richest coral assemblages in Thailand. The damage to the corals in this area is caused from outbreak of Crown-of-Thorn Sea Star in 1986 but during the 2010 mass bleaching event the area did not suffer the same level of mortality as the northern region. The offshore islands in this ecoregion are frequently used by endangered whale sharks, manta rays, several types of whales and dolphins as well as sea turtles.

Appendix III - Brief summary of key legislation concerning MPAs in Thailand

Key legislation	Brief Summary and update
National Park Act, 1961 (last amended 2019)	The National Park Act is the main law in the management of MPAs in the Andaman Sea. The purpose of the Act is to establish appropriate area with outstanding environment state to be in the original state of environment to preserve for the benefit of study and recreation of people by issuing the ordinance on the designated national park area. The Act consists of major measures on the prohibition of harmful activities to natural resources or any activities that are not complied with the principles of national park. Approaches to the national park management in Thailand are complied with Category II of protected area classified by IUCN, which has the main objective in protection of natural resources and environment, recreation and research. DNP has responsibility for the preservation, promotion and restoration of biodiversity and natural resources in the area. By law, all types of extraction activities are not allowed, for example, collect any plants and animals, or harm anything, collect or harm any orchids, honey, charcoal, bat guano, flowers, leaves, fruits etc. In practice, although illegal, certain fishing activities have been compromised to reduce conflict with local communities. The latest amendment, article 65 of the Act allows DNP to put in place a management measure for sustainable use of the resources. Superintendents are required to conduct feasible study to determine the level of sustainable use for renewable resources collection that could be regulated and monitored. It is not yet clear how this may affect the fishing activities inside the marine national parks.

Wildlife Animal Reservation and Protection Act, 1992 (last amended 2019).	The wildlife law that can be used to designate an appropriate area to be wildlife sanctuary area (an area providing safe habitat to wildlife to maintain wildlife species), resulting in prohibiting any hunting, whether it is a preserved wildlife or protected wildlife. In addition to announcing the wildlife sanctuary, announcement of non-hunting area under the Wildlife Preservation and Protection Act, 1992 is another measure used to maintain coastal resources. The primary purpose of the non-hunting wildlife area is to prohibit hunting of specified species such as dugong or other aquatic animals living in the coastal area and prohibit destruction of flora in the non-hunting wildlife area. In 2018, 11 threatened marine fishes (manta ray, mobula ray, guitarfish, sawfish) were added to the protected species under the wildlife law. In the latest amendment, four endangered marine species were up-listed from protected species to reserve species – the highest categories which receives maximum protection i.e. leatherback turtle, whale shark, Bryde's whale and Omura whale. The maximum penalty has been adjusted substantially from maximum 4 years jail time to 10 years and from maximum 40,000 THB fine to 1,000,000-1,500,000 THB fine to serve as a sufficient disincentive.
Fisheries Act 1947 (last amended 2015)	The law is applicable to the fishery management and aims to promote sustainable harvest of aquatic animals by conserving fishing grounds. Fishing grounds[3] can be

[3] Fisheries Act, Section 4(5) "fishing grounds" means land with still or running water such as sea, river, canal, swamp, marsh and beach, which are domaine public of State, including forest and ground which are inundated during flood season, not withstanding that it be domaine public of State of the land owned by any person, and being within territorial waters, or any

	designated as species conservation area to preserve flora and aquatic animals or prohibition of dumping, discarding, dropping, releasing of toxic substance into the fishing grounds. The control of fishing technique, fishing method, fishing gears[4], fishing season or prohibition of fishing for specific aquatic animals as announced in the notification of DoF to prohibit destructive fishing gears such as trawl net and push net with engine in the distance of 3,000-5,000 meter from the shoreline across the country. In addition, there are Notification of Ministry of Agriculture and Cooperatives issued under the Fisheries Act, 1947 (24 October 2008) on the prohibition of all type and size of trawl net equipped to engine boat, surrounding nets, and gill nets with mesh size less than 4.7 centimeter, to conduct the fishing activities in the sea of Phuket, Phang-nga, Krabi and Trang Provinces (from Cape Panwa, Phuket Province to Young Star Cape, Pa Lian District, Trang Province) during spawning and nursery season from 1 April to 30 June of each year. One of the loophole is that it provides exception for anchovy surrounding nets in day time, beam trawls **(**otter board trawls with beam or otter trawl with booms**)** equipped to engine boat with artificial rope in night time and bamboo strake trap. Apart from addressing IUU (Illegal, Unregulated, Unreported) Fisheries, an important aspect of 2015 amendment was the establishment of provincial fisheries committee to promote more public participation and

other waters in which Thailand exercises or may be entitled to exercise its fishery rights, as such water publicly appear to be delimited by local or international law or usage, by treaty or in any other way.

[4] Fisheries Act, Section 4(3) "fishing gears" means machinery, instrument, accessories, component parts, arms, stakes, or vessels which are used in fishing operation.

	encourage local actions in fisheries management and conservation.
The Promotion of Marine and Coastal Resources Management Act 2015	This is the main legislation for DMCR to promote the sustainable management of marine and coastal resources. The National Policy and Plan Committee on Marine and Coastal Resources Management chaired by the Deputy Prime Minister have been appointed as well as the Provincial Committee chaired by the Governor. This newly established mechanism is instrumental in coordinating among stakeholders and various agencies. One of the priorities is to promote participation of the community and local administration organization in management and conservation of marine and coastal resources. In case of severe damage and emergency, DMCR has the power to take action to rectify the damage that occurs to the marine and coastal resources in such area. In order to preserve natural condition of the ecosystem, DMCR can designate an area to become a marine and coastal resources protected area. In the case of mangrove forest, an area can be designated to be a conserved mangrove forest area. To avoid overlapping jurisdiction, it is specified that the designated area shall not be an area in any conservation area or an area permitted to practice aquaculture under the Fisheries law. MPAs that will be established by DMCR could potentially be complimentary to existing MPAs that form a more connected network of MPAs for Thailand.

Appendix IV - Agenda and Participant List for Resilience Workshop

Agenda
Thailand Coral Bleaching and Coral Reef Resilience Workshop
11-13 July 2011
Phuket Marine Biological Center, DMCR

11 July 2011

08.30-09.00 Registration
09.00-09.20 Opening ceremony and workshop objectives
09.20-10.40 Thailand Coral bleaching history and 2010 mass coral bleaching situation
10.40-11.00 Break
11.00-12.00 Resilience and coral reefs
12.00-13.00 Lunch
13.00-14.00 Resilience indicators from previous studies
1400-15.00 Break-out group discussion to review resilience indicators: ecological
15.00-15.20 Break
15.20-16.20 Break out group discussion on resilience indicators: physical
16.20-17.00 Presentation and debriefing
18.00 Dinner

12 July 2011

09.00-10.20 Group discussion on resilience indicators: management
10.20-10.40 Break
10.40-12.00 Group discussion on resilience indicator for Thailand
12.00-13.00 Lunch
13.00-15.30 Review previous database
15.30-15.50 Break
15.50-17.30 Application of resilience indicators
18.00 Dinner

13 July 2011

09.00-10.30 Thailand coral bleaching response plan
10.30-10.50 Break
10.50-12.30 Networking and data sharing
12.30 Meeting adjurns

Participant list

No.	Name	Organization
1	Ukrit Sattaphumin	DMCR
2	Niphon Phongsuwan	DMCR
3	Dr Suree Sattaphumin	PMBC/DMCR
4	Dr Nalinee Thongtam	PMBC/DMCR
5	Sombat Poovachiranon	DMCR
6	Chanakan Boonsriphum	PMBC/DMCR
7	Chaimongkol Yamarunpattana	DMCR
8	Anchalee Chankong	DMCR
9	Ornanong Bandit	DMCR
10	Srisakul Piromvaragorn	Prince Songkla University
11	Dr James True	Prince Songkla University
12	Phongteera Buaphet	Prince Songkla University
13	Aorn Sillapasathitwong	Prince Songkla University
14	Dr Thanongsak Chanmethakul	Phuket Rajabhat University
15	Dr Suchana Chavanit	Chulalongkorn University
16	Dr Suchai Worachananant	Kasetsart University
17	Dr Pasinee Worachananant	Kasetsart University
18	Chainarong Ruengthong	MNPOC no.1 Chumporn/DNP
19	Prarop Plang-ngan	MNPOC no. 2 Phuket/DNP
20	Suppaprn Prempree	MNPOC no. 3 Trang/DNP
21	Aladin Pakbara	MNPOC no. 3 Trang/DNP
22	Jirapong Jeewarongkakul	Consultant
23	Petch Manopawitr	University of Victoria/IUCN

Appendix V - Agenda and Participant List for 2nd Resilience Workshop

Agenda
Thailand Coral Reef Resilience Indicator Workshop
21-24 November 2015
Phuket Marine Biological Center, DMCR

21 November 2015
15.30-16.30 Arrival
16.30-17.00 Registration
17.00-18.30 Workshop introduction and data collection by participating agencies
18.30-19.30 Dinner

22 November 2015
08.30-09.00 Registration
09.00-09.20 Opening ceremony and workshop objectives
09.20-10.40 Introduction to resilience concept and coral bleaching
10.40-11.0 Break
11.00-12.00 Resilience data collection
12.00-13.00 Lunch
13.00-14.00 Andaman resilience assessment
1400-14.30 Break-out group discussion on resilience indicators in Andaman
14.30-14.45 Break
14.45-17.45 Break out group discussion on resilience indicators in Gulf of Thailand
18.00 Dinner

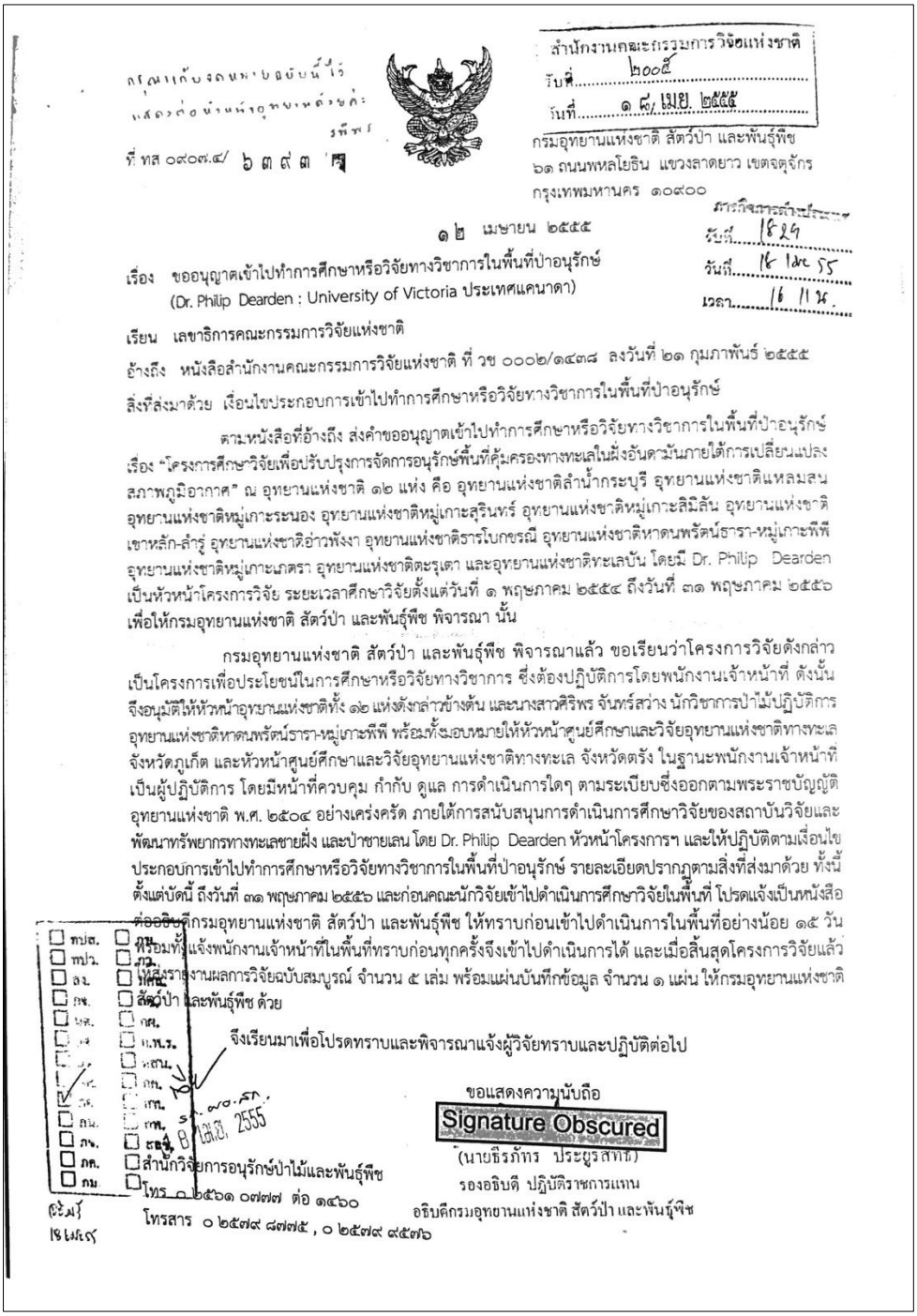
23 November 2015
09.00-10.20 Group discussion to determine coral reef resilience for Thailand
10.20-10.40 Introduction on standard data collection
10.40-11.00 Break
11.00-12.00 Break-out group discussion on data collection methodology
12.00-13.00 Lunch
13.00-14.30 Break-out group discussion on ecological, physical and management factors
14.30-15.30 Presentation and recommendation on data collection method
15.30-15.50 Break
15.50-16.00 Resilience ranking and analysis of resilience scores
16.00-17.30 Data analysis Exercise
17.30 Dinner

24 November 2015
09.00-10.45 Group discussion on resilience assessment case study
10.45-11.00 Break
11.00-12.00 Cooperation and data sharing among agencies and future research
12.00-13.00 Break
13.00-15.00 Resilience and coral recovery studies in Thailand
15.00-15.15 Break
15.15-16.00 Meeting adjourns

Participant list

No.	Name	Organization
1	Ukrit Sattaphumin	DMCR
2	Niphon Phongsuwan	DMCR
3	Dr Suree Sattaphumin	PMBC/DMCR
4	Ronnawan Boonprakob	PMBC/DMCR
5	Nararat Chantarawas	PMBC/DMCR
6	Chanakan Boonsriphum	PMBC/DMCR
7	Dr Nalinee Thongtam	PMBC/DMCR
8	Weerachat Pengchamras	DMCR
9	Chaimongkol Yamarunpattana	DMCR
10	Anchalee Chankong	DMCR
11	Ornanong Bandit	DMCR
12	Padorn Kaewkamnerd	DMCR
13	Anant Suthipol	DMCR
14	Narong Sorrep	DMCR
15	Srisakul Piromwaragorn	Prince Songkla University
16	Dr James True	Prince Songkla University
17	Phongteera Buaphet	Prince Songkla Univeristy
18	Wipusit Mantajit	Burapha University
19	Dr Thanongsak Chanmethakul	Phuket Rajabhat University
20	Dr Suchana Chavanit	Chulalongkorn University
21	Dr Suchai Worachananant	Kasetsart University
22	Dr Pasinee Worachananant	Kasetsart University
23	Prarop Plang-ngan	MNPOC no. 2 Phuket/DNP
24	Chainarong Ruengthong	MNPOC no.1 Chumporn/DNP
25	Jirapong Jeewarongkakul	Consultant
26	Petch Manopawitr	University of Victoria/IUCN

Appendix VI - Research Permit



สำนักงานคณะกรรมการวิจัยแห่งชาติ
รับที่ ๒๐๐๕
วันที่ ๑๘ เมย. ๒๕๕๕

กรมอุทยานแห่งชาติ สัตว์ป่า และพันธุ์พืช
๖๑ ถนนพหลโยธิน แขวงลาดยาว เขตจตุจักร
กรุงเทพมหานคร ๑๐๙๐๐

ที่ ทส ๐๙๐๓.๔/ ๖๓๙๓

๑๒ เมษายน ๒๕๕๕

เรื่อง ขออนุญาตเข้าไปทำการศึกษาหรือวิจัยทางวิชาการในพื้นที่ป่าอนุรักษ์
(Dr. Philip Dearden : University of Victoria ประเทศแคนาดา)

เรียน เลขาธิการคณะกรรมการวิจัยแห่งชาติ

อ้างถึง หนังสือสำนักงานคณะกรรมการวิจัยแห่งชาติ ที่ วช ๐๐๐๒/๑๔๓๘ ลงวันที่ ๒๑ กุมภาพันธ์ ๒๕๕๕

สิ่งที่ส่งมาด้วย เงื่อนไขประกอบการเข้าไปทำการศึกษาหรือวิจัยทางวิชาการในพื้นที่ป่าอนุรักษ์

ตามหนังสือที่อ้างถึง ส่งคำขออนุญาตเข้าไปทำการศึกษาหรือวิจัยทางวิชาการในพื้นที่ป่าอนุรักษ์ เรื่อง "โครงการศึกษาวิจัยเพื่อปรับปรุงการจัดการอนุรักษ์พื้นที่คุ้มครองทางทะเลในฝั่งอันดามันภายใต้การเปลี่ยนแปลงสภาพภูมิอากาศ" ณ อุทยานแห่งชาติ ๑๒ แห่ง คือ อุทยานแห่งชาติลำน้ำกระบุรี อุทยานแห่งชาติแหลมสน อุทยานแห่งชาติหมู่เกาะระนอง อุทยานแห่งชาติหมู่เกาะสุรินทร์ อุทยานแห่งชาติหมู่เกาะสิมิลัน อุทยานแห่งชาติเขาหลัก-ลำรู้ อุทยานแห่งชาติอ่าวพังงา อุทยานแห่งชาติธารโบกขรณี อุทยานแห่งชาติหาดนพรัตน์ธารา-หมู่เกาะพีพี อุทยานแห่งชาติหมู่เกาะเภตรา อุทยานแห่งชาติตะรุเตา และอุทยานแห่งชาติทะเลบัน โดยมี Dr. Philip Dearden เป็นหัวหน้าโครงการวิจัย ระยะเวลาศึกษาวิจัยตั้งแต่วันที่ ๑ พฤษภาคม ๒๕๕๔ ถึงวันที่ ๓๑ พฤษภาคม ๒๕๕๖ เพื่อให้กรมอุทยานแห่งชาติ สัตว์ป่า และพันธุ์พืช พิจารณา นั้น

กรมอุทยานแห่งชาติ สัตว์ป่า และพันธุ์พืช พิจารณาแล้ว ขอเรียนว่าโครงการวิจัยดังกล่าวเป็นโครงการเพื่อประโยชน์ในการศึกษาหรือวิจัยทางวิชาการ ซึ่งต้องปฏิบัติการโดยพนักงานเจ้าหน้าที่ ดังนั้น จึงอนุมัติให้หัวหน้าอุทยานแห่งชาติทั้ง ๑๒ แห่งดังกล่าวข้างต้น และนางสาวศิริพร จันทร์สว่าง นักวิชาการป่าไม้ปฏิบัติการอุทยานแห่งชาติหาดนพรัตน์ธารา-หมู่เกาะพีพี พร้อมทั้งมอบหมายให้หัวหน้าศูนย์ศึกษาและวิจัยอุทยานแห่งชาติทางทะเล จังหวัดภูเก็ต และหัวหน้าศูนย์ศึกษาและวิจัยอุทยานแห่งชาติทางทะเล จังหวัดตรัง ในฐานะพนักงานเจ้าหน้าที่เป็นผู้ปฏิบัติการ โดยมีหน้าที่ควบคุม กำกับ ดูแล การดำเนินการใดๆ ตามระเบียบซึ่งออกตามพระราชบัญญัติอุทยานแห่งชาติ พ.ศ. ๒๕๐๔ อย่างเคร่งครัด ภายใต้การสนับสนุนการดำเนินการศึกษาวิจัยของสถาบันวิจัยและพัฒนาทรัพยากรทางทะเลชายฝั่ง และป่าชายเลน โดย Dr. Philip Dearden หัวหน้าโครงการฯ และให้ปฏิบัติตามเงื่อนไขประกอบการเข้าไปทำการศึกษาหรือวิจัยทางวิชาการในพื้นที่ป่าอนุรักษ์ รายละเอียดปรากฏตามสิ่งที่ส่งมาด้วย ทั้งนี้ ตั้งแต่บัดนี้ ถึงวันที่ ๓๑ พฤษภาคม ๒๕๕๖ และก่อนคณะนักวิจัยเข้าไปดำเนินการศึกษาวิจัยในพื้นที่ โปรดแจ้งเป็นหนังสือต่ออธิบดีกรมอุทยานแห่งชาติ สัตว์ป่า และพันธุ์พืช ให้ทราบก่อนเข้าไปดำเนินการในพื้นที่อย่างน้อย ๑๕ วัน พร้อมทั้งแจ้งพนักงานเจ้าหน้าที่ในพื้นที่ทราบก่อนทุกครั้งจึงเข้าไปดำเนินการได้ และเมื่อสิ้นสุดโครงการวิจัยแล้ว ให้ส่งรายงานผลการวิจัยฉบับสมบูรณ์ จำนวน ๕ เล่ม พร้อมแผ่นบันทึกข้อมูล จำนวน ๑ แผ่น ให้กรมอุทยานแห่งชาติ สัตว์ป่า และพันธุ์พืช ด้วย

จึงเรียนมาเพื่อโปรดทราบและพิจารณาแจ้งผู้วิจัยทราบและปฏิบัติต่อไป

ขอแสดงความนับถือ

Signature Obscured

(นายธีรภัทร ประยูรสิทธิ์)
รองอธิบดี ปฏิบัติราชการแทน
อธิบดีกรมอุทยานแห่งชาติ สัตว์ป่า และพันธุ์พืช

สำนักวิจัยการอนุรักษ์ป่าไม้และพันธุ์พืช
โทร ๐ ๒๕๖๑ ๐๗๗๗ ต่อ ๑๔๖๐
โทรสาร ๐ ๒๕๗๙ ๘๗๗๕ , ๐ ๒๕๗๙ ๔๕๗๖

Appendix VII - Rapid ecological assessment of the Myeik Archipelago

4-10 February 2014 and 22-31 January 2015 (BOBLME 2015)

List of scientists participated in the survey

	Name	Specialist	Address
1	Dr James True	Reef resilience (Dive Instructor)	CBIPT, PSU - Leader
2	Ms Srisakul Piromvaragorn	Hard corals/reef resilience	CBIPT, PSU
3	Mr Petch Manopawitr	Conservation/MPA management	IUCN – Project Manager
4	Dr Thanongsak Chanmethakul	Soft coral & sea fan (dive instructor)	Phuket Rajabhat University
5	Mr Jirapong Jeewarongkakul	Reef fish	Independent researcher
6	Dr Narinrathana Khongchangtree	Hard corals/coral disease	Aquatic Science, Burapha University
7	Dr Kitithorn Sanpanich	Mollusc	Institute of Marine Science, Burapha University
8	Ass. Prof. Teerapong Daungdee	Mollusc	Marine Science Department, Faculty of Fisheries, Kasetsart University
9	Mr Bunnavit Pangsuk	Sponge	Institute of Marine Science, Burapha University
10	Ms Waranya Sonkam	Echinoderm	Institute of Marine Science, Burapha University
11	Mr Phiraphat Boonpetch	Dive instructor	Rayong Dive Center, Rayong
12	Ms Anchalee Chankong	Hard corals	Thailand's DMCR
13	Dr Narumon Arunotai	Anthropologist/moken	Chulalongkorn University
14	Prof. Philip Dearden	MPA management	University of Victoria, Canada
15	Ms Julia Fogerite	Social Science	IUCN
16	Ms Panwad Wongthong	SocMon/tourism	IUCN
17	Ms Maeve Nightingale	SocMon/Marine Scientist	MFF

18	Ms Waraporn Khanthasiri	SocMon/Artist	IUCN
19	Ms Cecilia Blomstrand	Environmental DNA	Geogenetic Center, University of Copenhagen
20	Dr Steen Knudsen	Fish Taxonomist	Danish Natural History Museum
21	Mr Sirachai Arunrugstichai	Sharks/dive instructor/photographer	Prince of Songkla University
22	Mr Waran Suwanno	Photographer/cinematographer	PixPro house/Nikon Thailand
23	Mr Kittipan Sabkhoon	Conservation	Mai Khao Turtle Foundation
24	Mr Zau Lunn	Marine Scientist	FFI Myanmar

Summaray of findings:

The survey cruise departed from the port of Ranong, the northernmost port in Andaman Thailand and progressed north to the northernmost island of the Myeik Archipelago: the island of Kabuzya Kyun (12° 48' 45"N, 97°50' 36"E) before returning to Ranong ten days later. A total of thirty sites were examined for ecological data, and another five sites were used in the socio-ecological survey that complemented the ecological research program. Hlaing Gu Island was the only site from the first IUCN survey to be resurveyed on this cruise. However, many of the northern offshore sites were visited during the first FFI cruise in March 2014; this allowed a very basic comparison of reef condition between years for those sites, although the differences in survey methodology between the researchers on each cruise meant that observations about changes must be taken in a very general sense. A few sites were also visited during the second FFI cruise in December 2014, which allowed good comparison between the techniques used by each survey team, and a rapid snapshot of the rate at which human activities are changing the face of Myanmar's coral reefs.

The survey found that – for the most part - the abundance of key reef infrastructure species is generally low, and the overall condition of most coral reefs is either poor or very poor. Many outer and mid-shelf reefs have less than <20% live hard coral cover, and are dominated by corallimorphs and algae growing on dead coral and rubble.

The effects of the 2010 bleaching event appear to have been far-reaching, with evidence of a mass mortality event on many of the outer reefs (especially amongst the Acroporids). In general, however, the outer island reefs of the northern Myeik region were in better condition than those of the southern region, although levels of recruitment appeared to be marginally lower than indicated by results of the 2014 expedition.

There was strong evidence of recent blast fishing activity on the more southerly reefs, and in one case, the survey happened upon a blast fishing operation in progress. The blast fishers appear to be moving north, as the southern reefs are increasingly depauperised and the dense populations of fish that attract this type of fishing activity can no longer be found. One site (Bailey Island) was found to be in excellent condition in December 2014 by the FFI expedition; by the end of January, 2015, when the IUCN survey team reached Bailey Island, the blast fishers had reduced a thriving reef to mostly rubble, and the abundant fish populations were largely absent. Another site (North Pinnacle) showed a similar decline since March 2014, and the dead and dying fish resulting from the bombing covered ¼ hectare of the seafloor. The abundant Tubastrea and Gorgonian corals observed in the March survey were gone – replaced by algae, corallimorphs and broken stumps of corals.

Reefs closer inshore varied widely in condition; where they were accessible or easy to fish, the reefs were often badly degraded. Where conditions made fishing difficult, or where the fishermen were generally unaware of the reef habitat (usually, it would seem, because of high turbidity), reefs were often outstandingly diverse and were generally quite healthy, although every site exhibited a complement of broken and discarded fishing gear.

There were no consistent or distinct latitudinal patterns apparent in the composition of biota of the Myeik Archipelago, although the northern and southern regions exhibited different community types and levels of biodiversity. The geological correlation to reef composition and topology observed in the first IUCN cruise

persisted in the northern part of the Archipelago. Reef formation (carbonate platform deposition) was noted to be poor throughout the Archipelago, although this does not appear to be unusual in Andaman reef systems. Porites corals that were cored appeared to have skeletal densities appropriate to their location and did not appear to suffer from reduced calcification.

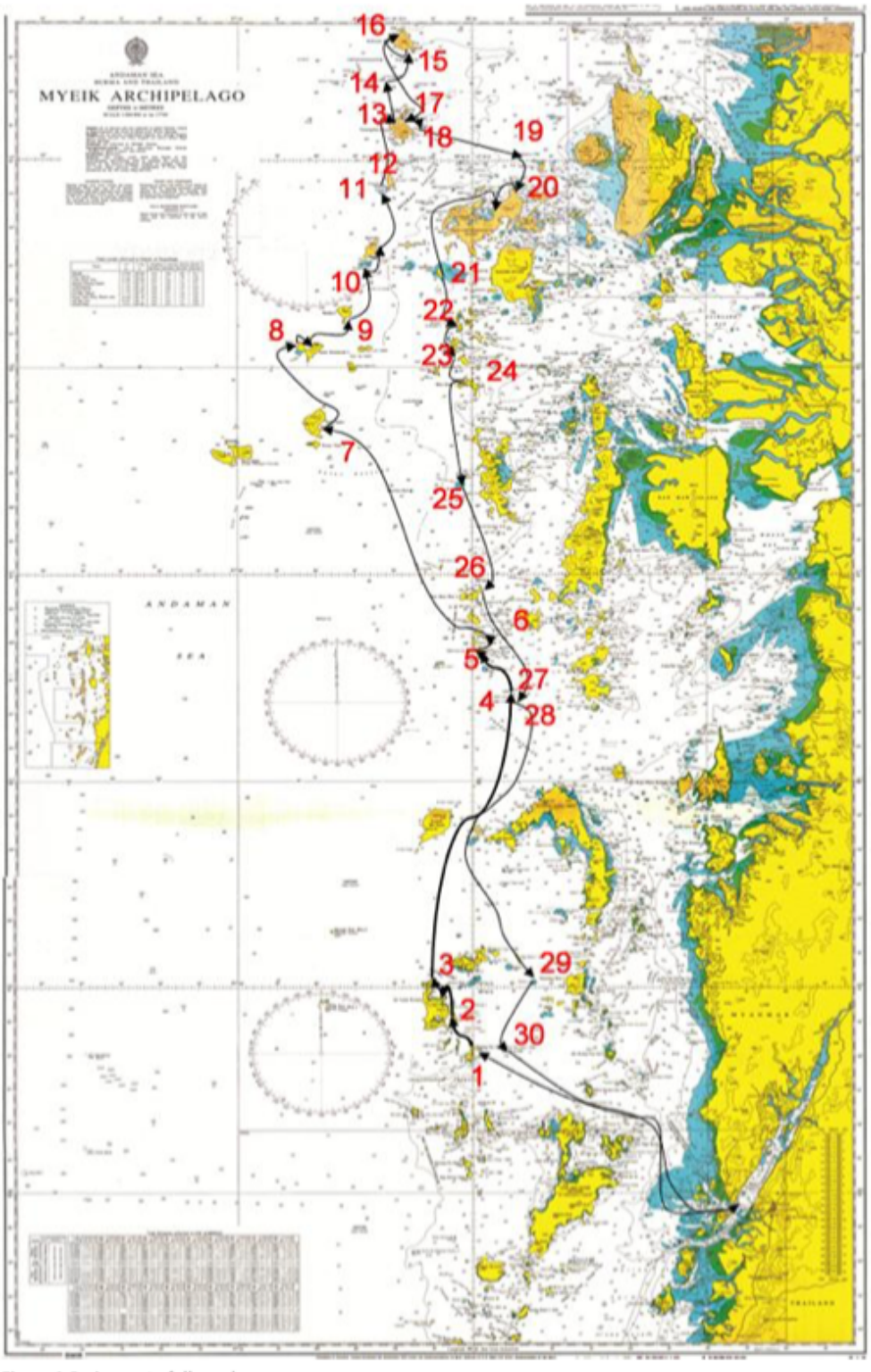
Offshore sites tended to have better water quality in terms of clarity and level of organic material in sediments and the water column, but the waters were not as clear as seen in the offshore sites of 2014. The inshore sites were often extremely dark and turbid; this is probably a consequence of strong tidal currents resuspending the fine terrigenous and organic material that coated the substrate. Many of the corals both inshore and offshore tended to be species that are known to be quite heterotrophic, and appeared to benefit from the abundant plankton in the water at almost all sites. Offshore sites were often dominated by encrusting or robust forms in exposed areas, and bay sites usually supported large numbers of Porites of different morphologies (albeit usually massive).

Fishing activity was ubiquitous throughout the Archipelago. At night, researchers could count up to a dozen vessels operating powerful floodlights to attract squid and small fishes. Trawlers were observed every day, often operating quite close to shore. Even at offshore sites, “local” vessels (those of <15 m length, operated by small-gear fishermen) were everywhere, and larger vessels often anchored in offshore bays at night. Hookah-equipped boats, with crews of up to 8 or 9 were surprisingly common at many locations – some of the more inshore reefs hosted up to 9 of these. The practice of the hookah-equipped boats is to spear fish at night, targeting especially the sleeping parrot fish. The consequences of their extraordinary skill and efficiency were quite obvious at all sites visited, with abundances of many key reef species very low (much lower than recorded in the previous surveys), and occasional heavy growth of marine algae on reefs. Abundance of grazing invertebrates – especially sea urchins – was quite high, but

for the most part, they had not entirely replaced parrot fish in the role of primary grazers.

Despite the horrendous levels of environmental destruction visited on Myeik coral reefs, it appears that the system as a whole is relatively robust and resilient. The results of these four wide-scale surveys of Myeik Archipelago demonstrate clearly that the importance of areas protected from destructive fishing cannot be overstated. There appear to be enough small pockets reef community that are relatively untouched that replenishment for most reefs is regular and sufficient to allow recovery, given the opportunity.

As noted, however, levels of recruitment – both in fish and hard corals – appeared to be marginally lower than reported in the 2014 survey. Although this result is somewhat alarming, it should be interpreted conservatively, because the 2015 survey examined different sites. It is possible, however, that the intense fishing pressure is having some effect on recruitment levels, and this may have far-reaching consequences for the overall resilience of the Myeik Archipelago. Should the levels of destructive fishing that cause the observed degradation of reef resources be allowed to continue unchecked, it is likely that large areas of the Archipelago will suffer permanent declines in both biodiversity, and in their ability to supply ecosystem goods and services to the people of Myanmar including significant tourism opportunities. At present, although the natural values of the Myeik Archipelago would suggest that it is a candidate for World Heritage nomination, the lack of governance and the continued decline in the integrity of the Archipelago's reefs would indicate that such a nomination would fail. Only by halting or reversing the current destruction, and by curbing the over-exploitation of the minority, can the future of this singular seascape be preserved and sustain the delivery of ecosystem services that the coastal population depends on.



Survey route from 22-31 January 2015

Appendix VIII – Agenda and list of participants in a workshop on Understanding & Strengthening Resilience to Coral Bleaching Events

Agenda
Workshop on Understanding & Strengthening Resilience to Coral Bleaching Events (Andaman Region)
16 October 2013
JW Marriott Mai Khao

Workshop Goals:

1. Learn from the 2010 coral bleaching event
2. Identify and prioritize options for building social & ecological resilience to future bleaching events
3. Identify and prioritize questions for future research about the impacts of bleaching and potential responsive actions

8:30 Registration of participants
8:45 Introductions

- **Workshop facilitators and participants**
- **Workshop Goals**

9:15 Impacts of the 2010 bleaching event

- Heat stress & climate impacts on coral reef ecosystsms
- Ecological impacts: locally & regionally

9:40 Introductions to the small group discussions
9:45 Coffee Break

10:00 Small Group Work

- *Discussion Questions*: How did you experience the 2010 bleaching event? What impacts were most important? Why? What questions did you have about the event or its impacts? Which questions are most important?
- *Expected Outputs for each group*: 1) prioritized list of impacts; 2) prioritized list of questions

10:00 Small Group Work

• Discussion Questions: How did you experience the 2010 bleaching event? What impacts were most important? Why? What questions did you have about the event or its impacts? Which questions are most important?
• Expected Outputs for each group: 1) prioritized list of impacts; 2) prioritized list of questions

11:00 Group report – small group representatives will summarize discussions

11:25 Impacts of the 2010 bleaching event

- Impacts to tourist diver experiences
- Economic impacts

11:40 Morning Synthesis

- Whole group discussion to identify cross-cutting experiences, developing a shared list of the major issues and impacts.
- Expected Outputs for each group: 1) prioritized list of impacts; 2) prioritized list of questions

12:00 Photo opportunity and lunch

12:45 Strategies for Supporting Social & Ecological Resilience

- Supporting reef resilience to bleaching & climate change
- Supporting social resilience to bleaching & climate change
- Example: Malaysia's Bleaching Response Plan

1:25 Introductions to the small group discussions

1:30 Small Group Work

- Discussion Questions: What actions are most important to implement during a bleaching event to support social & ecological resilience? Why? What barriers exist to implementing these actions? How should these actions be implemented and by whom? What questions do you have about actions that could be taken during bleaching events to support resilience?
- Expected Outputs for each group: 1) prioritized list of actions; 2) prioritized list of questions; 3) for top 3-5 actions, identification of key barriers and who should take action

2:30 Coffee break

2:50 Group report – small group representatives will summarize discussions

3:20 Whole group discussion – The group discussion with confirm cross-cutting ideas and prioritizing a list of actions that could be implemented during future bleaching events.

3:45 Closing

Coordinator and Resource Persons

	Name	Affiliation
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Workshop Participants

	Name	Affiliation
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3	Jirapong Jeewarongkakul	Reef management co.ltd.Owner
4	Prarop Plangngan	Phuket marine national park protected areas innovation center
4	John Roberts	Anantara
6	Wichin Suebpala	Ramkhamhaeng University
7	Brendon Sing	Shark Guardian
8	Kristan Hart	International Coastal Network
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10	Kanokwan Homcha-aim	SEEK Phuket
11	Nok Malaidang	Phuket marine national park protected areas innovation center
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13	Phongtheera Buapet	PSU Phuket
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18	Krongkaew Soo-ampon	SAMPAN Project
19	Hansa Chansang	PMBC
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21	Matt O'Connor	Scuba Ninjas
22	Nick Anthony	SEEK Phuket
23	Niphon Phongsuwan	PMBC
24	Wolfgang Sauerhammer	Paradise Diving Asia
25	Mike crwashaw	green fin
26	Andrew Hewett	The Adventure Club
27	Suwat Murngdee	Similan National Park
28	Tipamat Upanoi	PMBC
29	Kittipan Sabkhoon	Maikhao Marine turtle Foundation
30	Onanong Cheablam	Walailak University
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32	Supaporn buaniam	Phuket Marine nationalpark proteced areas innovation center
33	Kanyapoj Chaiprapan	Class Act Media Co., Ltd.

Appendix IX - List of Participants and Agenda for Management Effectiveness Evaluation of Thailand's marine and coastal protected area workshop 1—2 April 2011

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Appendix X

Ten key recommendations from management effectiveness evaluation of Thailand's marine and coastal protected areas (IUCN 2012)

Thematic area	Recommendations
Strengthen the foundations of the protected area system	Review and reform the National Parks Act (1961) to align it with contemporary protected area (PA) legislation, including its relationship to other statutes (especially the Fisheries Act) and incorporate marine protected area management, management planning, zoning, community consultation and management of tourism and commercial activities. The reform process would benefit from several IUCN guidelines in particular the IUCN Guidelines for Protected Area Legislation and the IUCN Guidelines on Protected Management Area Categories.
	Adopt the Thai Protected Area Master Plan and complete the Thai protected area system which sets the vision for the protected area system and articulates the values, benefits and potential outcomes of a properly resourced protected area system as a contributor to Thailand's conservation and development aspirations. The Master Plan should guide the completion by 2020 of the Thai MCPA network (of which MNPs are only a part) implementing the findings of the gap analyses conducted over the past decade to build a balanced and resilient system having regard to comprehensiveness, adequacy, representativeness and connectivity. By 2020 DNP should ensure that each unit has an effective and implemented management plan.
Address the threat of uncontrolled fishing	Initiate an integrated programme to improve fisheries management within MNPs addressing legal and institutional reform and harmonization; improved training of protected area staff, livelihood security; and strengthened monitoring of marine

	resources. Develop and implement zoning systems for MNPs which can accommodate no-take zones as well as multiple use zones thereby balancing sustainable marine use with conservation.
Coordinate protected area system management	Reform DNP and interagency relationships within the Thai Ministry of Natural Resources and Environment and other relevant Ministries to streamline management accountabilities and coordinate activities between agencies. Review delegations of authority to regional protected area offices and protected area managers to improve decision-making processes and enhance liaison with provincial, local and community governments and the business sector.
Increase management capacity	Establish a sustainable financing base for marine protected area management by segregating MNP budgets from terrestrial protected areas, diversifying revenue sources, establishing site-based incentives for revenue generation in each MNP and developing periodic (3 to 5 years) departmental corporate plans and annual business plans to inform government and provide leadership to managers about corporate direction, programs and strategies.
	Reform staff placement and training policies to provide continuity in delivery of services and programs by qualified and experienced staff, particularly focusing on the rotation of MNP Superintendents and their staff and the provision of needs-based training in marine and coastal management, law enforcement, community engagement and tourism management. Consider establishing a core group of staff who are qualified and experienced in marine and coastal management who remain in the MNP system to provide ongoing expertise, guidance and on-the-job training to other staff. Aim to have at least 75% of MNP superintendents with a marine background by 2015 and for all

	MNPs to have at least one permanent professional staff member with relevant marine management experience and training.
	Develop an integrated programming, planning, research, monitoring and reporting system to embed the principles of management effectiveness evaluation and adaptive management in the MNP system and which will complement other initiatives such as CATSPA and the PA Master Plan. Consider the preparation of a periodic (every 3 to 5 years) State of the Parks report based on a regular program of site-based management effectiveness assessment to track changes in MNP site condition and management improvement.
Engage stakeholders and communities	Include local communities in MNP decision-making by assessing and adopting different governance mechanisms which have been used or proposed for the Thai PA system. For example, through expanding the Andaman Seas Committee structure proposed as part of the planned World Heritage nomination or through replicating and formalizing the Provincial Conservation Forums currently operating in the Western Forest Complex. Use these forums and the existing Protected Area Committees to engage communities in management planning processes and resolve disputes about encroachments whilst providing land and livelihood security through valuesbased boundary rationalisation.
	Develop partnerships with the tourism industry and Ministry of Tourism to protect and restore MNP natural values which provide the setting for tourist activities and services. Engage on an equal footing with the tourism sector in developing public-private partnerships and niche marketing strategies for the sustainable use of MNPs that yield an appropriate financial return to the system.
Enhance MNP resilience	Address the key threats to the condition of biodiversity within MNPs by undertaking a risk-based vulnerability assessment of

	climate change, extreme weather events, tsunamis and earthquakes. Use the assessment to guide planning and management to reduce the impact of damaging human-induced pressures that exacerbate the effects of natural disasters. Develop a disaster response plan to inform visitors about hazards and provide managers with the training and means to respond promptly and effectively to major incidents.

Appendix XI - Key resource person on Coral Reef Resilience and MPA management

	Name	Specialist	Affiliation
1	Niphon Phongsuwan	Reef resilience	Phuket Marine Biological Center
2	Dr James True	Reef resilience	Prince Songkla University
3	Dr Thanongsak Chanmethakul	Hard corals/reef resilience	Phuket Rajabhat University
4	Dr Thon Thamrongnawasawat	Marine Conservation	Kasetsart Universtiy
5	Mr Jirapong Jeewarongkakul	Reef fish	Independent researcher
6	Jeffrey McNeely	Protected Area Management	DNP Advisor
7	Dr Marc Hockings	Management Effectiveness Evaluation	IUCN/University of Queensland
8	Peter Shadie	Protected Area Management	IUCN
9	Dr Suvaluck Satumanatpan	Resource Governance	Mahidol University
10	Dr Dachanee Emphandhu	Protected Area Management	Kasetsart University
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12	Dr Robert Mather	Biodiversity Conservation	IUCN – SE Asia
13	Dr Nalinee Thongtam	Reef biology	Phuket Marine Biological Center
14	Prarop Plang-ngan	Protected Area Management	DNP
15	Suppaporn Prempree	Protected Area Management	DNP

Appendix XII - List of species regulated and protected under Environmental Protection Areas Phuket, Krabi and Phang-Nga

ลำดับที่	รายชื่อ	กำหนดขนาด
	Acanthuridae	
๑	ปลาขี้ตังเบ็ดทุกชนิดในสกุล (Genus) *Acanthurus*	ความยาวไม่เกิน ๒๐ ซม.
๒	ปลาขี้ตังเบ็ดทุกชนิดในสกุล (Genus) *Ctenochaetus*	
๓	ปลาขี้ตังเบ็ดทุกชนิดในสกุล (Genus) *Naso*	ความยาวไม่เกิน ๒๐ ซม.
๔	ปลาขี้ตังเบ็ดทุกชนิดในสกุล (Genus) *Paracanthurus*	
๕	ปลาขี้ตังเบ็ดทุกชนิดในสกุล (Genus) *Zebrasoma*	
	Antennariidae	
๖	ปลากบทุกชนิดในวงศ์ (Family) Antennariidae	
	Apogonidae	
๗	ปลาอมไข่ทุกชนิดในวงศ์ (Family) Apogonidae	
	Balistidae	
๘	ปลาวัวทุกชนิดในสกุล (Genus) *Balistapus*	
๙	ปลาวัวทุกชนิดในสกุล (Genus) *Balistoides*	
๑๐	ปลาวัวทุกชนิดในสกุล (Genus) *Melichthys*	
๑๑	ปลาวัวทุกชนิดในสกุล (Genus) *Odonus*	
๑๒	ปลาวัวทุกชนิดในสกุล (Genus) *Pseudobalistes*	
๑๓	ปลาวัวทุกชนิดในสกุล (Genus) *Rhinecanthus*	
	Blenniidae	
๑๔	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Alticus*	
๑๕	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Andamia*	
๑๖	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Aspidontus*	
๑๗	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Atrosalarias*	
๑๘	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Blenniella*	
๑๙	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Cirripectes*	
๒๐	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Ecsenius*	
๒๑	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Entomacrodus*	
๒๒	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Exallias*	
๒๓	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Istiblennius*	
๒๔	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Laiphognathus*	
๒๕	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Meiacanthus*	
๒๖	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Plagiotremus*	
๒๗	ปลาตั๊กแตนหินทุกชนิดในสกุล (Genus) *Salarias*	

ลำดับที่	รายชื่อ	กำหนดขนาด
	Carcharhinidae	
๒๘	ปลาฉลามทุกชนิดในวงศ์ (Family) Carcharhinidae	ความยาวไม่เกิน ๕๐ ซม.
	Centriscidae	
๒๙	ปลาข้างใสทุกชนิดในวงศ์ (Family) Centriscidae	
	Chaetodontidae	
๓๐	ปลาผีเสื้อและปลาโนรีทุกชนิดในวงศ์ (Family) Chaetodontidae	
	Cirrhitidae	
๓๑	ปลาเหยี่ยวทุกชนิดในวงศ์ (Family) Cirrhitidae	
	Gobiidae	
๓๒	ปลาบู่กุ้งทุกชนิดในสกุล (Genus) *Amblyeleotris*	
๓๓	ปลาบู่ทุกชนิดในสกุล (Genus) *Amblygobius*	
๓๔	ปลาบู่ทุกชนิดในสกุล (Genus) *Asteropteryx*	
๓๕	ปลาบู่ทุกชนิดในสกุล (Genus) *Bathygobius*	
๓๖	ปลาบู่ทุกชนิดในสกุล (Genus) *Callogobius*	
๓๗	ปลาบู่กุ้งทุกชนิดในสกุล (Genus) *Cryptocentrus*	
๓๘	ปลาบู่กุ้งทุกชนิดในสกุล (Genus) *Ctenogobiops*	
๓๙	ปลาบู่จิ๋วทุกชนิดในสกุล (Genus) *Eviota*	
๔๐	ปลาบู่ทุกชนิดในสกุล (Genus) *Exyrias*	
๔๑	ปลาบู่ทุกชนิดในสกุล (Genus) *Gnatholepis*	
๔๒	ปลาบู่ปะการังทุกชนิดในสกุล (Genus) *Gobiodon*	
๔๓	ปลาบู่ทุกชนิดในสกุล (Genus) *Istigobius*	
๔๔	ปลาบู่มหิดลทุกชนิดในสกุล (Genus) *Mahidolia*	
๔๕	ปลาบู่กุ้งทุกชนิดในสกุล (Genus) *Myersina*	
๔๖	ปลาบู่จิ๋วทุกชนิดในสกุล (Genus) *Priolepis*	
๔๗	ปลาบู่กุ้งทุกชนิดในสกุล (Genus) *Stonogobiops*	
๔๘	ปลาบู่จิ๋วทุกชนิดในสกุล (Genus) *Trimma*	
๔๙	ปลาบู่ทรายทุกชนิดในสกุล (Genus) *Valenciennea*	
๕๐	ปลาบู่กุ้งทุกชนิดในสกุล (Genus) *Vanderhorstia*	
	Grammistidae	
๕๑	ปลากะรังเมือกทุกชนิดในวงศ์ (Family) Grammistidae	
	Holocentridae	
๕๒	ปลาข้าวเม่าน้ำลึกทุกชนิดในวงศ์ (Family) Holocentridae	
	Labridae	
๕๓	ปลานกขุนทองทุกชนิดในวงศ์ (Family) Labridae	

ลำดับที่	รายชื่อ	กำหนดขนาด
	Malacanthidae	
๕๔	ปลาจรวดทรายทุกชนิดในสกุล (Genus) *Hoplolatilus*	
๕๕	ปลาจรวดทรายทุกชนิดในสกุล (Genus) *Malacanthus*	
	Microdesmidae	
๕๖	ปลาบู่ลูกดอกทุกชนิดในสกุล (Genus) *Nemateleotris*	
๕๗	ปลาบู่ลูกดอกทุกชนิดในสกุล (Genus) *Parioglossus*	
๕๘	ปลาบู่ลูกดอกทุกชนิดในสกุล (Genus) *Ptereleotris*	
	Monacanthidae	
๕๙	ปลาวัวทุกชนิดในสกุล (Genus) *Amanses*	
๖๐	ปลาวัวทุกชนิดในสกุล (Genus) *Cantherhines*	
๖๑	ปลาวัวทุกชนิดในสกุล (Genus) *Oxymonacanthus*	
๖๒	ปลาวัวทุกชนิดในสกุล (Genus) *Paraluteres*	
๖๓	ปลาวัวทุกชนิดในสกุล (Genus) *Pervagore*	
	Muraenidae	
๖๔	ปลาไหลทุกชนิดในวงศ์ (Family) Muraenidae	
	Ostraciidae	
๖๕	ปลาปักเป้ากล่องทุกชนิดในสกุล (Genus) *Ostracion*	
	Pempheridae	
๖๖	ปลากระตี่ทะเลทุกชนิดในวงศ์ (Family) Pempheridae	
	Pinguipedidae (Mugiloididae)	
๖๗	ปลาตาแหงนทุกชนิดในสกุล (Genus) *Parapercis*	
	Plesiopidae	
๖๘	ปลาครีบยาวทุกชนิดในวงศ์ (Family) Plesiopidae	
	Pomacanthidae	
๖๙	ปลาสินสมุทรทุกชนิดในวงศ์ (Family) Pomacanthidae	
	Pomacentridae	
๗๐	ปลาสลิดหินและปลาการ์ตูนทุกชนิดในวงศ์ (Family) Pomacentridae	
	Pseudochromidae	
๗๑	ปลาไหลทรายทุกชนิดในสกุล (Genus) *Blennodesmus*	
๗๒	ปลาไหลทรายทุกชนิดในสกุล (Genus) *Congrogadus*	
๗๓	ปลาหลังจุดทุกชนิดในสกุล (Genus) *Pseudochromis*	
๗๔	ปลาหลังจุดทุกชนิดในสกุล (Genus) *Pseudoplesiops*	
	Rhinobatidae	
๗๕	ปลาโรนินและปลาโรนันทุกชนิดในวงศ์ (Family) Rhinobatidae	ความยาวไม่เกิน ๕๐ ซม.

ลำดับที่	รายชื่อ	กำหนดขนาด
	Scaridae	
๗๖	ปลานกแก้วทุกชนิดในวงศ์ (Family) Scaridae	ความยาวไม่เกิน ๕๐ ซม.
	Scorpaenidae	
๗๗	ปลาสิงโตและปลาหินทุกชนิดในวงศ์ (Family) Scorpaenidae	
	Ostraciidae	
๗๘	ปลากะรังจิ๋วทุกชนิดในสกุล (Genus) *Liopropoma*	
๗๙	ปลากะรังจิ๋วทุกชนิดในสกุล (Genus) *Pseudanthias*	
	Siganidae	
๘๐	ปลาสลิดทะเลโฉมงามชนิด *Siganus magnificus*	
๘๑	ปลาสลิดทะเลเหลืองชนิด *Siganus puelloides*	
	Solenostomidae	
๘๒	ปลาจิ้มฟันจระเข้ปีศาจทุกชนิดในวงศ์ (Family) Solenostomidae	
	Stegostomidae	
๘๓	ปลาฉลามลายเสือดาวชนิด *Stegostoma fasciatum*	
	Syngnathidae	
๘๔	ปลาจิ้มฟันจระเข้ทุกชนิดในสกุล (Genus) *Bhanotia*	
๘๕	ปลาจิ้มฟันจระเข้ทุกชนิดในสกุล (Genus) *Choeroichthys*	
๘๖	ปลาจิ้มฟันจระเข้ทุกชนิดในสกุล (Genus) *Corythoichthys*	
๘๗	ปลาจิ้มฟันจระเข้ทุกชนิดในสกุล (Genus) *Doryrhamphus*	
๘๘	ปลาจิ้มฟันจระเข้ทุกชนิดในสกุล (Genus) *Dunckerocampus*	
๘๙	ปลาจิ้มฟันจระเข้ทุกชนิดในสกุล (Genus) *Halicampus*	
๙๐	ปลาจิ้มฟันจระเข้ทุกชนิดในสกุล (Genus) *Phoxocampus*	
๙๑	ปลาจิ้มฟันจระเข้ทุกชนิดในสกุล (Genus) *Trachyrhamphus*	
	Tetraodontidae	
๙๒	ปลาปักเป้าทุกชนิดในสกุล (Genus) *Arothron*	
๙๓	ปลาปักเป้าทุกชนิดในสกุล (Genus) *Canthigaster*	
	Tripterygiidae	
๙๔	ปลาสามครีบทุกชนิดในวงศ์ (Family) Tripterygiidae	
	Zanclidae	
๙๕	ปลาผีเสื้อเทวรูปชนิด *Zanclus cornutus*	

Appendix XIII - Major marine conservation developments triggered by social media movement. All financial figures are in THB

Timeline	Major development	Social Media trigger	Outcome
March – May 2015	Crisis in tourism management in Mu Ko Similan National Park	"Death from above" picture posted on 8 March 2015 by Waran Rbj Suwanno, a photographer and marine scientist showing aerial picture and underwater picture of Koh Tachai showing dead corals in shallow area because of mass tourism.	Hearing was organized by National Reform Council under Marine Reform committee to gather information and propose management measures. DNP announced the closure of Koh Tachai in Muko Similan National Park indefinitely for restoration since 15 May 2015 (Daily News 2015) Carrying capacity for tourism activities was revisited and was finally enforced in 2018.
July 2015 onwards	Marine National Park Entrance fee collection leakage which effected overall management effectiveness (20% of fee goes back directly to site management, 5% goes to local administration and 75% goes to central office)	Dr Thon Thamrongnawasawat, a prominent marine scientist at Kasetsart University had been using his facebook to probe the question about mismatch in tourist number and available financial resources at the National Park level giving example of Phang Nga Bay	Where tourist numbers had only increased slightly , on-site monitoring and public attention led to the increase of fee collection more than 10 fold within two years before and after the public outcry from 35.1 m (2014) to 62.7 m (2015) to 382.2 m (2016) in Phang Nga Bay NP and more than 20 fold from 24 m (2014) to 84.9 m (2015) to 559.8

		National Park and Hat Noppharat Thara–Mu Ko Phi Phi National Park	m THB (2016) in Hat Noppharat Thara–Mu Ko Phi Phi NP. Therefore more than 188 m THB or USD 5.7 m made available for conservation and management in these two parks alone. (DNP 2017) This development reflected in overall DNP annual revenue increase by four times from 696.3 m in 2014 to 2,664.3 m THB in 2017 (Greennews 2018)
Mar-June 2018	Crisis in tourism management in Hat Noppharat Thara–Mu Ko Phi Phi National Park	Dr Thon Thamrongnawasawat rallied public support to overhaul management of Maya Bay and Mu Ko Phi Phi under campaigncalled 'Phi Phi Model' emphasizing degradation of coral reefs from overcrowded tourists at key sites and overall lack of effective management.	DNP announced the closure of Maya Bay in Hat Noppharat Thara–Mu Ko Phi Phi National Park from June-September 2018 and later extended the closure indefinitely for rezoning and coral restoration. Other areas have also been closed for restoration such as Ko Yung. Parrotfish and shark sale ban imposed with agreement from all shops and restaurants in Koh Phi Phi.