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Coral reef and water quality status and community understanding of threats in the Eastern Gulf of Thailand

Prepared by:
RW (Bill) Carter and Katherine Kelly,
University of the Sunshine Coast, Australia
with
Harriot Beazley and Neil Tindale,
University of the Sunshine Coast, Australia
S (Yo) Worachananant and P (Ja) Worachananant,
Kasetsart University, Thailand
Sokhom Thok,
Ministry of Tourism, Cambodia

University of the Sunshine Coast
Sustainability Research Centre

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Part One: Introduction

1.1 Background

Coral reefs are biologically diverse ecosystems that provide goods and services to millions of people around the world (Moberg & Folke 1999). Human induced habitat degradation of coastal ecosystems presents a direct threat to the food and economic security of coastal communities (Macusi et al. 2011; UNEP 2004). The loss of biodiversity and food security is considered the two most significant threats to human well-being in the 21st century (Foale et al. 2013). Overharvesting of marine resources, marine habitat modification and ecological phase-shifts threaten the integrity and resilience of the marine environment (UNEP 2004). For the people of the Gulf of Thailand, for whom marine resources are integral to their livelihood and culture (Carter 2012; Carter et al. 2013b; UNEP 2004), continuing degradation of their resources could be catastrophic.

1.1.1 Biophysical state of the marine environment

The east Gulf of Thailand coastal waters comprise extensive coral reefs, beaches, seagrass meadows and mangrove communities that support coastal fisheries, tourism and aquaculture activities. The livelihoods of Thailand, Cambodian and Vietnamese coastal communities in the east Gulf of Thailand depend primarily on ecosystem benefits and services derived from the marine resources. The southern and eastern coastlines of the South China Sea, including the Gulf of Thailand, are considered to fall within the Indo-Pacific 'coral triangle' region, a recognized region of high biodiversity corals and coral reef fish species (Bellwood & Hughes 2001; Veron 1993). The state of the marine environment is investigated in this research to provide a baseline assessment of the status and health of coral reefs within the study area, which includes the Koh Chang island group in Thailand, the coastal and offshore islands of Cambodia, and Vietnam's Phu Quoc Island.

Environmental factors influencing the biodiversity, status and health of coral reefs in the east Gulf of Thailand include oceanography, climate and freshwater flows. These factors influence the estuarine and marine water circulation patterns, water quality and ambient environmental parameters including salinity profiles, sea temperature, pH, turbidity and dissolved oxygen. Seventy per cent of annual rainfall in the Gulf of Thailand occurs between June and November with the remaining 30 per cent between December and May (Aschariyaphotha & Wongwises 2012; UNEP 2004). High seasonal rainfall and large volumes of water enter the Gulf causing low salinities and high sediment loads, particularly in coastal areas. These seasonal freshwater flows directly influence the local estuarine dynamics, regional coastal circulation and water quality (Aschariyaphotha & Wongwises 2012).

In the east Gulf of Thailand, fringing coral reefs occur in the shallow, seasonally turbid waters of coastal and offshore islands. The reefs are dominated by *Porities* spp. and Favid spp., with *Acropora* spp. generally rare (Kongjandtre et al. 2010; Latypov 2003; Latypov & Selin 2011; Plathong et al. 2006; van Bochove et al. 2006; van Bochove et al. 2011; Yeemin et al. 2013). The fringing reefs display weak structural and morphological zonation, are typically narrow in width (50-100m) and consist of reef slope and patch reefs with minimal to no reef flat present (Latypov & Selin 2011). Water depth, water quality, substrate type, wave regimes, sediment loads and light attenuation are some of the critical environmental factors that influence coral reef species zonation, reef structure, reef complexity and species diversity in this area (Latypov 2003). Evidence of white band disease for some live coral species and high levels of sediment occur on some parts of reefs within the study site (Latypov & Selin 2011).

Coastal seagrass meadows and mangrove communities provide important nursery grounds and refugia for fish and crustacean species. These marine habitats contribute to the reef fish assemblages and commercially fished species found on coral reefs within the study area. Widespread loss of seagrass meadows and mangroves are a result of fishing activities, land-based activities, including agricultural and aquaculture farming expansion and unregulated coastal development. Mangroves continue to be cut for firewood and charcoal production. Illegal fishing using push nets and shallow water bottom trawling is also occurring over sensitive seagrass meadows.

Increased levels of pesticides, fertilizer and sediment in marine waters derived from agricultural run-off and unregulated coastal development contribute to the degradation of water quality and coral reef resilience (Fabricius & De'Ath 2004). Short and long-term changes to water quality parameters including turbidity levels, ambient sea temperatures, dissolved oxygen and pH of the marine water influences the growth and survival of corals (Fabricius 2005). Water quality is being seriously degraded in the Gulf of Thailand, primarily from untreated sewage, poor land-use practices and aquaculture farming (see Reopanichkul et al. 2010; Reopanichkul et al. 2009b).

The risk of extinction for coral reef fish is considered to be high from human-induced fisheries over-exploitation (Graham et al. 2011). Through a lack of effective management, coastal fisheries resources are overfished and severely depleted with biological and economic over-fishing occurring throughout South-east Asia (Noranarttragoon et al. 2013; Stobutzki et al. 2006a). High population numbers and poverty have created intensive fishing pressure in the Gulf of Thailand over time. The Gulf of Thailand is overfished as a direct result of extreme fishing effort from both large commercial fishing vessels and smaller artisanal fishing operations. Removal of fish guilds from the coral reef ecosystem leads to trophic imbalances in the food chain and can result in phase-shifts, where coral-dominated reefs may shift to algae-dominated reefs over time. Intense fishing efforts have removed top predatory fish species from the marine ecosystem (Pauly & Chuenpagdee 2003).

The historical development of fishing activities in the Gulf of Thailand has resulted in the present dynamics of fishing fleets and the status of the fisheries within the study area. Fishing activities, such as purse seining, gill-netting over reef areas, motorized push netting on seagrass meadows, fish trapping and illegal poaching, have contributed to the over-exploitation of targeted and non-targeted fish species (Ibrahim 1999; MAFF 2012; Pomeroy 2012). By 1995, fishing effort in the Gulf of Thailand had exceeded twice the maximum sustainable yield (Kongprom et al. 2003 in Ahmed et al. 2007; Stobutzki et al. (2006a). Malthusian overfishing in the Gulf has taken place where marine fisheries, once dominated by carnivorous reef fish such as snapper, have been replaced by a squid dominated fishery (Blaber 2011; Pauly 1994; Pauly & Chuenpagdee 2003). Increased fishing effort and decreased fish catch and fish size is reported for Vietnam (Dao & Pham 2011; Son & Thuoc 2003). The number of Vietnamese vessels licensed since 2000 has increased particularly in the small-scale fishing sector, regardless of the depleted nature of the fishery (Masudur et al. 2003 in Stobutzki et al. 2006a).

Climate change is rapidly emerging as one of the greatest threats to coral reef health and status and coral reef fish assemblages, through the direct effects of rising sea temperatures, increasing acidification of marine waters, rising sea level and more frequent and intense storm activities and storm surge (Pratchett et al. 2008; Wilson et al. 2006a). Sustained and ongoing climate change and associated declines in coral reef health and status diminishes the value of goods and services that the reef provides, resulting in negative consequences for the communities dependent on coral reefs (Hughes et al. 2003). Climate change impacts on coral reefs have the potential to affect fisheries, the livelihoods and health of fisheries-dependent communities, reef-related and coastal tourism and important ecosystem services that benefit human well-being (Brown et al. 2006; Cinner et al. 2009; Macusi et al. 2011; Wilkinson 1996).

Coral bleaching events have occurred in the Gulf of Thailand as a result of rising sea temperatures and lowered salinity (Doshi et al. 2012; Hoeksema et al. 2013; Sutthacheep et al. 2013; Yeemin et al. 2013). Coral reef bleaching is projected to become more prevalent as sea temperatures continue to rise, bringing baseline ocean temperatures closer to the maximum thermal tolerances for corals. Changes to biota from climate change include phenological changes in an altered timing of breeding events and shifts in the distribution of corals and coral reef fish species (Pratchett et al. 2008).

1.1.2 Social and cultural influences

Social and cultural aspects of Thailand, Cambodia and Vietnam variously influence coastal community use, understanding and levels of protection of their marine resources. Social and cultural beliefs and practices are highly varied in the east Gulf of Thailand, depending on nationality, religion, ethnic group, culture, economic status, position in the community and level of ownership. Thailand, Cambodia and Vietnam vary in population size, ethnic groups, religions, social structures and cultural practices. In 2013, population estimates were approximately 67 million people in Thailand, 15 million people in Cambodia, and 92 million people in Vietnam[1]. The coastal populations are rapidly expanding with immigration to coastal areas placing further pressure on sensitive coastal areas and marine resources.

Local perception of the status of marine resources and management varies widely, emphasizing the need to understand local community beliefs and the level of satisfaction in management decisions and process. Within country co-management is most effective when local fishing communities are involved in the development of co-management measures and the on-going management of fisheries. Previous experience indicates that a lack of involvement in these processes results in reduced access, depleted resources and reduced economic benefit.

1.1.3 Coral reefs, sustainable tourism and economic benefit

The financial benefits that coral reefs provide globally are estimated at around US $30 billion per year (Pratchett et al. 2008). The coastal resources of South-east Asia have a gross approximate value of US $37 billion (Macusi et al. 2011). The ongoing degradation of coastal habitat and resources from rapid urbanization, population growth, coastal developments, overfishing and destructive fishing activities is negatively affecting the revenue generated by coastal resource use (Macusi et al. 2011). The bleaching event in Thailand in 2010 was estimated to result in an economic loss between $50 and $80 million (Doshi et al. 2012).

Thailand, Cambodia and Vietnam all gain economic benefit from the coastal tourism sector. It is a rapidly expanding sector, which is resulting in increasing pressures on coastal areas through unregulated development of coastal infrastructure (hotels, roads, and airports), increasing human interaction and use of the coastal areas and the production of waste (Carter et al. 2013a; Carter & Nguyen 2012; Reopanichkul et al. 2010; Reopanichkul et al. 2009a; Worachananant et al. 2008). Coastal land use practices and tourism associated developments can influence the health and status of coral reefs and water quality within the study area. Rapidly expanding coastal tourism is attracting foreign investment to develop large resorts with minimal pre-development government approval conditions based on mitigation of impacts. Sustainable tourism in sensitive coastal areas requires the implementation of effective environmental protection measures for the ongoing protection and sustainability of sensitive coastal areas, the marine environment and marine

[1] http://worldpopulationreview.com/countries/: accessed 16/12/2013

resources. The economic benefits the tourism industry brings to Thailand, Cambodia and Vietnam depends on the sustainable management and protection of the very environment that attracts local, national and international tourists initially and for repeated visits over time.

1.2 Research need

a. Coral reef status and levels of protection

Little is known about the status and health of coral reefs in the contiguous coastal zone of the east Gulf of Thailand. The implications of the potential loss or shift in fish species assemblages and abundance to the well-being of coastal communities in developing countries that rely on a reliable supply of coral reef fish as a cheap source of protein is poorly understood. Fisheries, marine and coastal zone managers require detailed information on the status and health of coral reefs and marine habitats to prioritize the protection and management of areas of high biodiversity value.

Future protection of coral reefs for ongoing food security and sustainable tourism may include the development of a network of marine protected areas to facilitate fish and coral larval supply to natal and neighboring reefs and effective protection from destructive extractive activities such as fishing, mining, dredging and poaching. Due to the lack of information on the status and health of coral reefs found within the study area, a comprehensive baseline assessment is required to describe the dominant coral species and morphologies, percentage of live coral cover, coral reef structural complexity and the presence of key reef fish and fish species assemblages.

Although the development of a network of marine protected areas may be effective for protection of coral reefs from over-fishing and extractive activities, they do not mitigate the impacts to coral reef health from degraded water quality. Destruction of mangroves and the associated release of sediments, coastal aquaculture expansion and land reclamation on tidal land may result in eutrophication of the receiving marine waters from nutrient inputs, changes to pH levels, lowered dissolved oxygen and in-flows of large volumes of herbicides and pesticides. The percentage loss of mangrove habitat has been estimated at 28 per cent for Cambodia, 84 per cent for Thailand and 61 per cent for Vietnam (Macusi et al. 2011)[2].

b. Water quality status and sources of pollution

Water quality and impacts from coastal land-use practices to water quality has not been described for the study area. Describing water quality properties and the level of variability between locations and sites assists in the identification of primary sources of pollution and increased sedimentation. This information is critical for identifying protection measures. Further, there is currently a serious lack of appropriate water quality infrastructure from either primary or secondary sewage treatment plants in existing coastal developments. The assessment of water quality parameters and identification of reef health within the study area can contribute to future tourism planning, development of pre-approval conditions that protect the marine environment and the sustainable management of environmentally sensitive coastal areas.

c. Fishing pressure

Fishing vessel type, activities and intensity vary greatly between the Thailand, Cambodian and Vietnamese fishing fleets operating in the Gulf of Thailand. Fishing practices such as purse-seining and drift netting have contributed to the depletion of fish stocks in the Gulf of Thailand. Over harvesting of marine resources through increasing fishing effort has been compounded by a lack of effective fisheries management measures and enforcement in all three countries (Pauly & Chuenpagdee 2003; Son & Thuoc 2003; Stobutzki et al. 2006a; Stobutzki et al. 2006b). The practice of blast or dynamite fishing in the Gulf of Thailand is on-going, resulting in partially or fully dead

[2] Note: these figures are indicative and do not strictly apply for the east Gulf of Thailand apart from Cambodia

coral areas (Dayton et al. 1995; Marschke & Sinclair 2009). Although illegal, these practices are generally not monitored, with minimal to no enforcement of legislation. Fishing vessel licensing arrangements are haphazard and there is a serious lack of effective enforcement of licensed fishing vessels in the three countries in terms of monitoring fish catch and fishing effort (MAFF 2006). Effective fisheries management inputs such as limiting the number of fishing licenses for a fishery, fishing gear restrictions and management, such as the enforcement of size limits, catch limits, area closures and mesh sizes, are not legislated or enforced (MAFF 2012).

Reduction in illegal fishing activities is possible through the development of enforceable transnational laws and community-based management measures (ISRS 2004). There are currently minimal co-management arrangements or formal agreements in place between Thailand, Cambodia and Vietnam (Pomeroy 2012), although Thai and Vietnamese fishing vessels access Cambodian waters. Although reliable marine fish catch and effort data (CPUE) is limited, some CPUE data exists for Koh Chang, Thailand (Lunn & Dearden 2006), Vietnam fisheries (Dao & Pham 2011) and Cambodia (MAFF 2012). Desktop analysis of this information provides catch and effort trend data that may be applied to the status of fisheries in the east Gulf of Thailand.

The removal of top predators in the marine ecosystem alters the trophic food webs and biological interactions, resulting in trophic cascades for coral reef, mangrove and seagrass ecosystems within the study area. Further knowledge on the status of key fish species in the study area is required to inform the development of effective management measures that promote sustainability of fisheries within-country and across the political borders.

d. Governance arrangements and approaches

Marine environments do not recognize political boundaries or social and cultural practices. Understanding the social and cultural structure of Thailand, Cambodia and Vietnam is critical for effective management. Effective management of marine resources across political boundaries with economic, social and cultural differences is complex, dynamic and difficult to implement. Co-management measures made through mutual agreement can reduce transaction and management costs, particularly where there are limited economic resources.

Co-management frameworks developed and enforced by large scale institutions, such as governments, usually require predictable outcomes that generally are not sensitive to the actual situation. In view of this, the focus can tend to be on convincing participants of the management recommendations rather than providing participants with specific choices (Wilson et al. 2006). Co-management experience is not always positive for all participants. Understanding kinship, religious, linguistic, social, economic, political and cultural factors that affect natural resource management practices is often more critical than understanding ecological processes (Baird 1999). Research in Thailand identified that organizing communities around particular issues, such as the use of differing fishing gear types and activities (e.g. trawling and push netting) is critical for developing a co-management approach (Vo et al. 2013).

Given the common pressures and threats of degraded water quality and over-fishing to the health and status of the coral reef ecosystem in the study area, a transnational co-management approach by Thailand, Cambodia and Vietnam is worth exploring. This approach is supported by UNEP as part of the recommendations from the "Reversing environmental degradation trends in the South China Sea and Gulf of Thailand" project (Vo & Pernetta 2010) and current research on managing over-capacity in small-scale fisheries in South-east Asia (Pomeroy 2012; Russ et al. 2004).

1.3 Research objectives

This research aims to establish baseline information on the status and health of the coral reefs within the study area and to establish the level of variability between locations and sites. Identifying the biophysical health and status coral reefs assists in the decision making process for future management measures. Identification of the factors influencing the status and health of coral reefs is based on underwater surveys of benthic reef communities and reef fish, water quality assessment and desktop assessment of fish catch and effort where possible. Community surveys conducted in fishing villages within the study site provide an indication of local community perceptions of the status of their fisheries and coral reef health. This information is important to inform future co-management arrangements, both within country at the local, regional and national level and transnationally.

The following data and information needs are addressed in this study.

- Baseline data on the status and health of coral reefs, including benthic community biodiversity and structure, key reef fish species and reef fish assemblages.
- Marine water quality parameters at coral reefs sites, population centers and freshwater flows.
- Fishing gear and trends in fisheries catch and effort for targeted species within the study area.
- Local fishing community perceptions of the status and health of local fisheries and coral reef between 2003 and 2013.

It is not possible to examine all components that influence the status and health of coral reefs in the east Gulf of Thailand. Regardless, it will be possible to quantify the percentage of live coral cover between sites and locations and correlate this information with water quality parameters and fishing activities. Pressures and threats to the status and health of coral reef, focusses on water quality parameters and fishing activities; however, recommendations for transnational co-management may be made, particularly in areas identified as critical marine resource habitat, such as the contiguous coral reefs along the coastal inshore and offshore islands.

Part two: **Coral reef and socio-economic status**

2.1 Background to coral reefs

Reef-building corals exist at low latitudes around the globe and are naturally constrained by sea temperature, sea level, tidal range and depth; as well as water quality parameters including salinity, turbidity, pH and light attenuation (Figure 2.1).

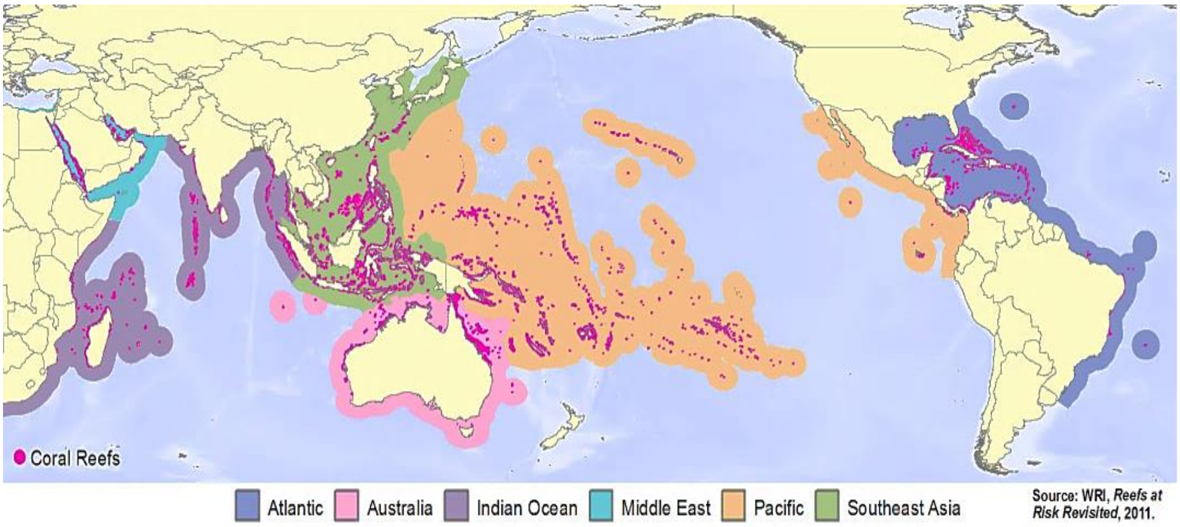


Figure 2.1 Major coral reef regions of the world

In the 21st century, tropical coral reefs are subject to a broad range of environmental, social and economic influences. The latitudinal range of tropical reefs has varied over time due to the dynamic nature of the earth's climate and large-scale geological events affecting the quality of the environment. Modern coral reefs appeared in the late Cretaceous / early Tertiary period (60 x 106 y BP), following an evolutionary progression from Precambrian carbonate and limestone reefs to modern calcium carbonate scleractinian reefs (Longhurst & Pauly 1987b).

The geomorphology of coral reefs varies between systems and may include open ocean atolls, fringing reefs, barrier reefs and patch reefs. Specifically, shallow water fringing reefs adjacent to mainland and islands differ globally in width, terracing and level of heterogeneity (Longhurst & Pauly 1987b). Heterogeneous coral reefs are considered to arise from several distinct generations succeeding each other. Coral reefs found within the east Gulf of Thailand are primarily shallow water fringing reefs adjacent to coastal islands and within the coastal zone.

The interdependence between reef fishes and coral reefs has been widely studied, where reef fish rely on healthy coral reefs for food, habitat and shelter; and coral reefs rely on reef fish for nutrients, colony defense and reduction of algae (Graham & Nash 2013; Hughes et al. 2007a; Jones et al. 2004; Pratchett et al. 2012). Coral reef fish species richness and assemblages exhibit vulnerability to changes in dominant coral species, health and structure; and coral health, growth and settlement on reefs show vulnerabilities to changes in the structure and species richness of reef fish assemblages (Bellwood et al. 2004; Feary et al. 2007b; Hughes et al. 2007b). Changes to coral reefs can be brought about by human induced degradation from destructive and extractive activities and poor land use practices causing increased sedimentation and degraded water quality.

The particular biophysical characteristics of coral reefs may also influence resilience, including reef depth, structural complexity, phenotypic and genetic diversity, proximity to the shore and population centers, connectivity to other coral reefs for larval supply, oceanographic influences for larval dispersal and connectivity to important coastal habitats such as mangroves and seagrass for fish nursery grounds.

2.2 Ecosystem services of coral reefs

Coral reefs are highly biodiverse ecosystems that provide food, recreation areas, coastal protection, aesthetic qualities, as well as social, cultural and economic benefits for human well-being (Moberg & Folke 1999). Critical ecosystem services of coral reefs that benefit human well-being are defined under the Millennium Ecosystem Assessment as provisioning, regulating, supporting and cultural services (MEA 2005) (Figure 2.2). Regulating services include flood and storm protection, erosion control and waste processing. Provisioning services include the provision of food, medicine and ornaments. Supporting services include nutrient cycling, primary production and trophic cascades. Cultural services include ecotourism, social relations and recreation. The underlying components and processes that support these ecosystem services are critical to the maintenance of coral reef ecosystem services. Ecosystem goods of coral reefs are renewable resources, which include fisheries products, seaweeds and reef mining, including the collection of mother of pearl (*Trochus* sp.) and giant clams (*Tridacna* sp.) for the ornamental trade.

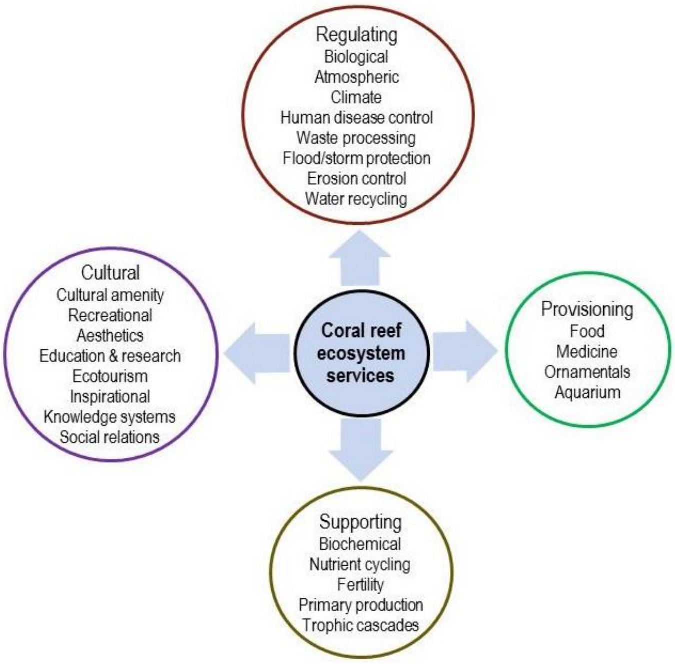


Figure 2.2 Coral reef ecosystem services

Causal links between human health and the coral reef environment are often indirect, and are spatially and temporally subjective and dependent on a variety of socio-cultural factors. However, the implications for human health and well-being from declining coral reef health include greater exposure to storm surge, higher rates of coastal erosion, reduced food supply, poorer general community health, and economic declines from tourism and resources, and even political conflict (Nelson 2007).

The ecosystem services that coral reefs provide to coastal communities of Thailand, Cambodia and Vietnam are important for food security, particularly for the poorer coastal communities that have little economic buffer to withstand declines in marine resources. Coral reef habitat loss and degradation is associated with shifts in reef fish assemblages and species abundance, loss of biodiversity and disturbance to the ecosystem services for human well-being. Declines in the sustainability, integrity and availability of coastal marine resources are thought to contribute to increased poverty among coastal fishers (Macusi et al. 2011). Several Millennium Development

Goals were developed to address global poverty through ensuring environmental sustainability and the need for a global partnership for development (Nelson 2007). These goals support the urgency for Thailand, Cambodia and Vietnam to develop effective sustainable management measures that ensure the protection of coral reefs for food security and economic stability and growth, both locally and regionally within each country and across political borders.

2.3 The study area: the east Gulf of Thailand

The South China Sea and the Gulf of Thailand are situated at the center of the Indo-Pacific biogeographic region. The Indo-Pacific contains 75 per cent of the world's coral reefs, which are now reported to be in decline (Bruno & Selig 2007). The average coral cover, 100-1000 years before present, was estimated at approximately 50 per cent for the Indo-Pacific region (Bruno & Selig 2007). A broad scale analysis, using Line Intercept Transect surveys, suggests there was an average coral cover of 22.1 per cent throughout the region in 2003; however, no significant differences in live coral cover were detected between sub-regions (Bruno & Selig 2007).

The Gulf of Thailand is a large shallow marine system measuring approximately 320,000 km^2 (Aschariyaphotha & Wongwises 2012; Pauly & Chuenpagdee 2003). It is a semi-enclosed, coastal embayment situated between 6°N to 14°N latitude and 99°E to 105°E longitude that opens to the South China Sea (Figure 2.3). The north-west, northern and north-east coast is under the jurisdiction of Thailand. The remaining east Gulf of Thailand is under the jurisdiction of Cambodia and Vietnam. The coastline exhibits gentle gradients that lack a marked reef shelf, with a maximum depth of 60 meters in the offshore waters of Cambodia (Beasley & Davidson 2007) to around 80 meters depth in the center of the gulf.

Figure 2.3 Bathymetry and country borders of the east Gulf of Thailand [3]

This study focuses on coastal islands in the Koh Chang archipelago in Trat Province, Thailand, Koh Kong and Preah Sihanouk Provinces in Cambodia () and Phu Quoc Island in Kien Giang Province, Vietnam (Figure 2.4).

[3] Source: Aschsriyaphotha et al. 2008

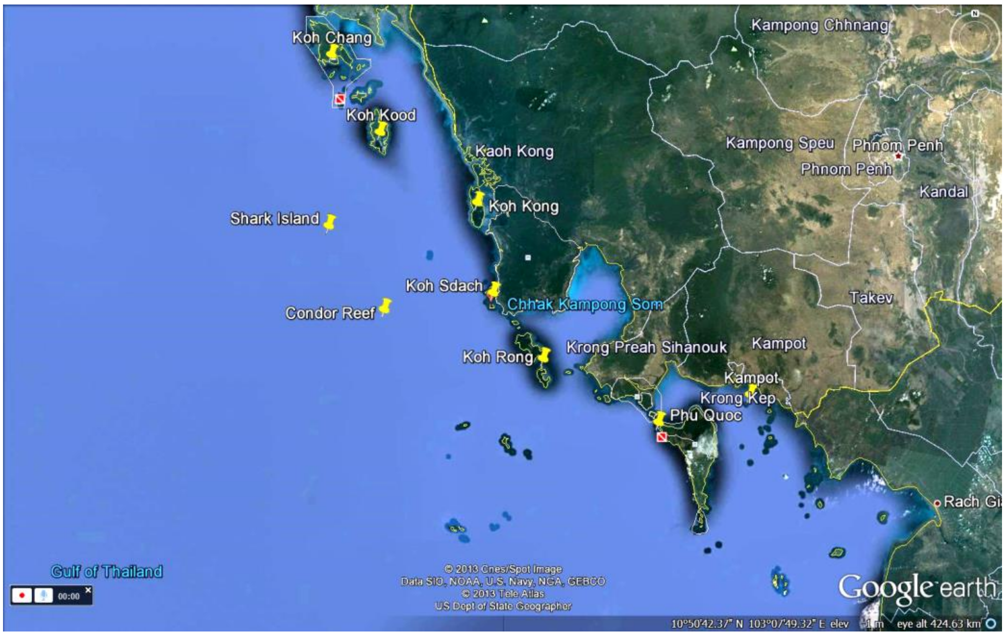


Figure 2.4 Study area in the east Gulf of Thailand

2.3.1 Current research on marine resources

The status and health of coral reef, seagrass meadows and mangrove communities within the study area are poorly understood. The on-going degradation of the coastal environment is apparent from the increasing occurrence of plankton blooms in estuaries and mangroves where nutrient loads are greatest (Suvapepun 1991). Changes to the species composition of demersal fishes and benthic communities, loss of fish species and reduced fish population sizes have been reported for the Gulf of Thailand (Cheevaporn & Menasveta 2003a; Pauly 1994; Pauly et al. 1998; Pauly & Chuenpagdee 2003). Although the principal cause for decline of fishery production is over-fishing, marine pollution from discharges of organic pollutants in some estuarine and coastal areas from aquaculture activities have impacted fisheries, including the bivalve fishery (Boonyapiwat 1999; Boonyatumanond et al. 2002; Cheevaporn & Menasveta 2003a; Suvapepun 1991). Estimated rates of decline in marine habitat, from a number of persistent and emerging threats, are 30 per cent loss of seagrass, 16 per cent loss of coral reefs and 16 per cent loss of mangroves per decade (Vo et al. 2013).

Research on the health and status of coral reefs in the east Gulf of Thailand is largely sectorial. Although not exhaustive, this research is summarized in Table 2.1. This table indicates the breadth and depth of research conducted in the Thai marine environment in comparison to research conducted in Cambodia and Vietnam. Other studies encompass countries and areas bordering the Gulf of Thailand including Malaysia, Thailand, and Vietnam (Nasuchon & Charles 2010) and South-east Asia and the South China Sea (Stobutzki et al. 2006a; Stobutzki et al. 2006b; Vo et al. 2013).

Table 2.1 Summary of literature on the status of marine resources for Thailand, Cambodia and Vietnam

#	Author	Focus		
	Thailand			
1.	Flaherty & Karnjanakesorn (1993)	Commercial and subsistence fisheries	Squid trap fishery	Conflict
2.	[1]Sinsakul (1997)	Coastal zone		
3.	Satapoomin (2000)	Coral reef fishes		
4.	Sathirathai & Barbier (2001)	Mangrove conservation	Values	
5.	Boonyatumanond et al. (2002)	Organochlorine pesticides residues	Green mussels (*Perna viridis*)	Monitoring

#	Author	Focus		
6.	[1] Vidthayanon & Premcharoen (2002)	Status	Fish diversity	Estuarine
7.	Barbier (2003)	Habitat-fishery linkages	Mangrove loss	
8.	[1] Pauly & Chuenpagdee (2003)	Fisheries development		Analysis
9.	Plathong et al. (2006)	Daytime gamete release	Reef building coral	*Pavona* sp.
10.	Ahmed et al. (2007)	Impacts over-fishing		
11.	Shinnaka et al. (2007)	Impacts mangrove loss	Fish assemblage	Pak Phanang Bay
12.	[1] Vibol (2007)	Coral reefs	Coastal waters	National reports
13.	Worachananant et al. (2008)	Impact scuba diver	Coral reefs	Management
14.	Jones et al. (2009)	Impact artisanal fishing	Coral reef fish health	Hat Thai Mueang
15.	Reopanichkul et al. (2009)	Impacts sewage	Coral reefs	Ecological structure
16.	Trisak et al. (2009)	Catch and effort	Small-scale swimming crab trap fishery	Seasonal variation
17.	Reopanichkul et al. (2010)	Impact wastewater	Coral reef	
18.	Kongjandtre et al. (2010)	Spawning patterns	Coral reefs inshore	*Favia* spp.
19.	Sanpanich (2011)	Marine bivalves		
20.	Weterings (2011)	Threats environmental	GIS-based assessment	Koh Tao
21.	Noranarttragoon et al. (2013)	FAD fishery		Management
22.	[1] Phongsuwan et al. (2013)	Status	Coral reef	Changing patterns
23.	[1] Sutthacheep et al. (2013)	Impacts coral bleaching		1998 and 2010 events
24.	Yeemin et al. (2013)	Impacts coral bleaching	*Acropora* spp.	Kut Island
	Cambodia			
1.	Mam (2002)	Coral reef & seagrass		
2.	[1] van Bochove et al. (2006)	Fringing reefs	Scientific surveys	
3.	[1] Viner et al. (2006)	Fisheries	Co-management	
4.	Beasley and Davidson (2007)	Status	Marine mammals	Cetacean records
5.	[1] Vibol (2007)	Coral reefs	Coastal waters	National reports
6.	[1] Vibol et al. (undated)	Seagrass diversity	Distribution	Kampot Province
7.	[1] Dara et al. (2009)	Zoning	Integrated assessment	Peam Krasop
8.	Nuon & Gallardob (2011)	Perceptions local	Fishery management	Krala Peah village
9.	van Bochove et al. (2011a)	Status	Coral reefs	Baseline surveys
10.	Latypov and Selin (2011)	Status	Coral reefs	Islands
11.	[1] van Bochove et al. (2012)	Scientific findings	MPA designation	Koh Rong island
12.	[1] Monyneath (undated)	Status	Coastal and marine	Policy & management
13.	[1] Nong (undated)	Mangroves		Peam Krasaop
	Vietnam			
1.	[1] Adger et al. (2001)	Environmental change	Social vulnerability	Adaptation, resilience
2.	Latypov (2003)	Reef-building corals	Coral reefs	
3.	[1] Son & Thuoc (2003)	Coastal fisheries		Management
4.	[1] Dung (2006)	Status	Leatherback turtles	
5.	Pho Hoang Han (2007)	Fisheries development	Economic zone	
6.	Raakjær et al. (2007)	Adaptive fisheries	Indicators	Management
7.	[1] Stiles (2009)	Product trade	Marine turtle	
8.	Latypov and Selin (2011)	Status	Coral reefs	Islands
9.	[1] Carter (2012b)	Conservation & development	Integrated planning	Dong Ho lagoon

[1] Not peer reviewed

2.3.2 Climate and oceanography

The two monsoonal periods that influence rainfall, freshwater flow, wind speed and direction are the north-east monsoon between October/November to January/March (anti-clockwise gyre) and the south-west monsoon (clockwise gyre) between May and September/October (Aschariyaphotha et al. 2007; Satapoomin 2000). Effects of the north-east monsoon in the Gulf of Thailand are mostly blocked by the mountains of Thailand (Aschariyaphotha & Wongwises 2012). During the north-east monsoonal period, waters flow into the gulf from the east bringing the South China Sea surface waters, which are derived from the North Equatorial Current, and primarily the Luzon Strait (Satapoomin 2000). These waters include the highly turbid waters emptying from the Mekong River along the southern Vietnam coast. During the southwest monsoonal period, oceanographic currents flow into the gulf from the south along the east coast of the Malay Peninsula (Satapoomin 2000). The monsoonal influence and associated rainfall creates seasonal variation in freshwater discharges and the levels of contaminants that circulate within the gulf. However, it is generally believed that average transport of ocean currents into the gulf is greater during the south-west monsoon. Distribution of planktonic organisms, nutrients and pollution loads are influenced by oceanographic currents (Wolanski and Hammer, 1988 in Wen et al. (2013). The genetic diversity and species of coral and coral reef fish that enter the Gulf during the planktonic phase, disperse and settle or recruit on coral reefs will vary depending on whether they originate from the northern or southern half of the South China Sea (Satapoomin 2000).

While information on circulation patterns within the Gulf of Thailand is conflicting, there is agreement that moderate to weak clockwise and anti-clockwise gyres exist in the inner gulf and outer gulf waters seasonally (Aschariyaphotha et al. 2007; Aschariyaphotha et al. 2008; Aschariyaphotha & Wongwises 2012; Nasir et al. 1999; Satapoomin 2000; Singhruck 2001; Snidvongs & Sojisuporn 1999; Tana 2005). Oceanographic currents within the Gulf of Thailand are influenced by tidal movement, sea level elevation, wind-forcing, salinity gradients and freshwater flows (Aschariyaphotha et al. 2008; Aschariyaphotha & Wongwises 2012; Oliver 2012; Wen et al. 2013; Zhuang et al. 2010). Wind forcing is important as average coastal wind speeds can be as high as two to four meters per second during monsoonal storms (WEPA 2013), not only driving currents, but also placing stress on coastal coral reefs and shorelines through increased wave action and storm surge.

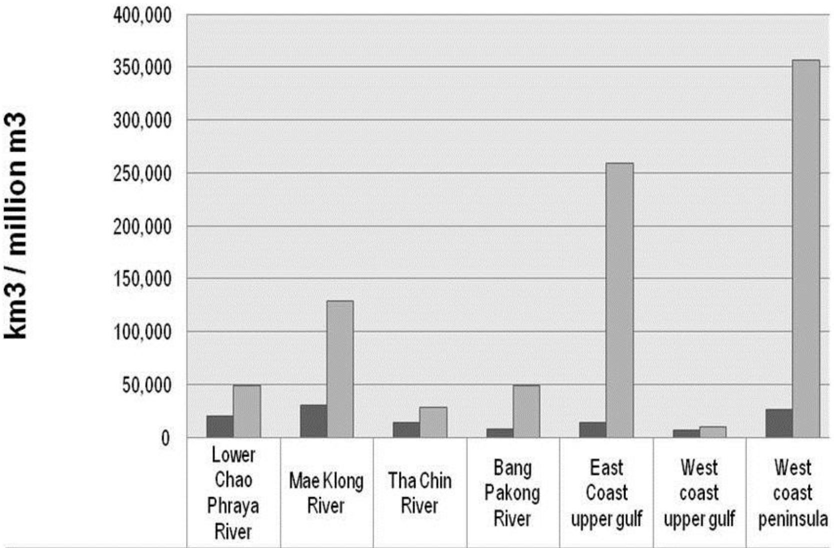
Sea surface elevation varies annually in the Gulf of Thailand by up to 50 per cent of the total tidal range during the monsoon periods and the dry season. This variation occurs particularly at the beginning of the dry season in October/November when freshwater in-flows cease and the sea level in the inner gulf drops (Aschariyaphotha & Wongwises 2012; Zhuang et al. 2010). This variation in sea level places additional stress on coral reefs and coastal areas during the rainy season when sea levels are highest in the inner gulf; an important factor when addressing the cumulative impacts of sea level rise from climate change.

2.3.3 Freshwater flows

The watershed areas and run-off from the major rivers that flow into the gulf from Thailand during the rainy seasons is substantial (Figure 2.5). These in-flows bring large volumes of freshwater that lower estuarine and ocean salinity levels, add high levels of nutrients from untreated sewage and fertilizer run-off, increase turbidity and sediment from land-use practices, and add pesticides and chemicals into the receiving waters.

The estimated total annual water derived from rainfall entering all river basins in Thailand was approximated at 800,000 million cubic meters in 2000 (Aschariyaphotha & Wongwises 2012). Evaporation and evapo-transpiration remove around 75 per cent of water with the remaining 25 per cent contained in streams, rivers and reservoirs. The Chao Phraya River, which runs through Bangkok, has the largest discharge into the inner Gulf with a 55-year average of an astounding 482 cubic meters of water per second per year (Aschariyaphotha & Wongwises 2012). The total contribution of freshwater into the Gulf of Thailand by smaller Thai rivers and the Chao Phraya River was estimated as 129.5 cubic kilometers per year (Aschariyaphotha & Wongwises 2012). These figures emphasize the extraordinary amount of freshwater entering the Gulf each year from

Thailand alone. The impact on salinity profiles and water quality from these freshwater flows has to be immense.



	Lower Chao Phraya River	Mae Klong River	Tha Chin River	Bang Pakong River	East Coast upper gulf	West coast upper gulf	West coast peninsula
Watershed Area (km3)	20,125.25	30,863.76	13,681.24	7,978.15	13,829.72	6,745.33	26,352.78
Run-off (million m3)	49,251	129,431	28,151	49,001	259,601	10,131	356,241

Figure 2.5 Total watershed area and annual run-off for major rivers in Thailand and Gulf of Thailand drainage basins[4]

Annual rainfall in Cambodia is estimated between 2,000 and 4,000 mm (WEPA 2013). The seven major rivers that flow into the east Gulf of Thailand are in Koh Kong province (four rivers), Preah Sihanouk province (two rivers) and one river in Kampot province (UNEP 2004). Freshwater flow data for these rivers are not available; however, flow rates during the rainy seasons are likely to be similar to that of Thailand and Vietnam, but volumes lower because of smaller catchments.

Phu Quoc Island is located in Kien Giang Province, Vietnam, within the monsoonal belt. Average temperature is 27.4°C with the hottest month in April (29°C) and the coolest in January (25.6°C) (Carter 2012b). Annual rainfall in Phu Quoc, Vietnam is seasonally during monsoonal periods similar to Cambodia; however, Phu Quoc Island experiences a higher annual rainfall between 2400 – 2900mm annually (Carter 2012b). Freshwater in-flows from river floodwater, local rainfall and tidal influence floods up to 3,400,000 ha in the Vietnamese part of the delta, including Kien Giang Province (Carter 2012b).

2.3.4 Coral reef benthic habitat

Tropical coral reefs thrive in waters with low nutrient and sediment levels in the equatorial zone and generally are not found in areas that are subject to high levels of organic detritus adjacent to turbid river discharges (Longhurst & Pauly 1987a). The percentage of live coral cover and the variability between locations and sites is an indicator of the status and health of coral reefs. There is broad variation in the pressures on coral reefs across Thailand, Cambodia and Vietnam from social and cultural variances, proximity of coral reefs to population centers of varying sizes and proximity to sources of freshwater flows.

Fringing reefs in the east Gulf of Thailand persist; however, they are typically narrow rarely ranging beyond 100 meters in width. These reefs typically lack a reef crest and have a maximum depth of around 12 meters, with patch reefs or coral bommies located at the deepest part of the reef. There

[4] Source: WEPA Website http://wepa-db.net/ State of Water Environmental Issues Thailand (Office of the National Water Resources Committee (2000))

is some distinct vertical zonation between reef slope and patch reefs (Latypov 2003). Offshore coral reefs occur either at submerged reef areas or adjacent to offshore islands between 10 and 20 meters depth and often with water clarity of up to 40 meters. The percentage of live coral cover provides a quantifiable measure that can be correlated with parameters such as water quality and analyzed to detect significant differences in coral reef health.

Dominant coral species at Koh Chang and Koh Kut islands in Thailand and Koh Sdach and Koh Kong islands in Cambodia are massive *Porities* spp., the foliose *Pavona decussata* and *Turbinaria* spp.; sub massive and massive *Galaxea* spp.; *Favia* spp., *Favites* spp. and *Diploastrea heliopora* (Phongsuwan et al. 2013; van Bochove et al. 2011a). Benthic communities also include soft corals (*Sarcophyton* sp. and *Sinularia* sp.), filamentous and coralline algae, anemones, gorgonians, bryozoans, whip corals and hydroids (Phongsuwan et al. 2013; van Bochove et al. 2006; van Bochove et al. 2012; Yeemin et al. 2013).

a. Thailand

The study site in Trat province, Thailand includes fringing coral reefs adjacent to Koh Chang and Koh Kut Islands in the upper east Gulf of Thailand (Figure 2.6).

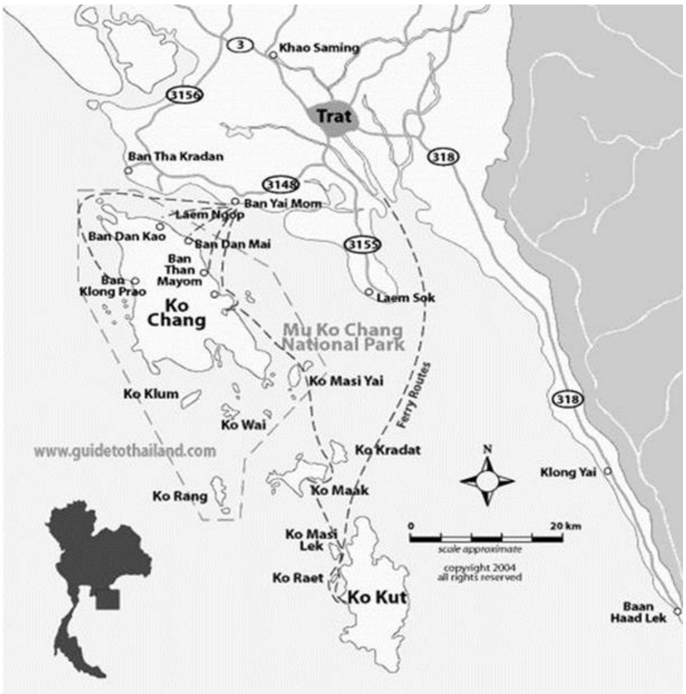


Figure 2.6 Trat Province islands, Thailand

The coral reef area around Koh Chang, Koh Kut and surrounding islands is estimated at approximately 18,500 hectares (Phongsuwan et al. 2013). Koh Chang is a designated Marine Protected Area closed to fishing. Tourism pressure is high at both of these sites, with diver impacts such as fin damage likely to be occurring (Worachananant et al. 2008). Dominant coral species for this location were recorded as *Porities lutea*, *Pavona* spp., *Symphyllia* spp., *Lobophyllia* spp., *Favia* spp. and *Favites* spp. (Phongsuwan et al. 2013).

Loss of live coral cover is reported for Thailand's corals reefs in the east Gulf of Thailand between 1995 and 2011. Percentage coral cover decreased from 37.4 per cent (1995) to 33.3 per cent (2006) and 22.2 per cent cover (2011) following the 2010 bleaching event (Phongsuwan et al. 2013). The coral bleaching event in 1998 resulted in a significant decline in live coral cover in the Indo-Pacific Region (Bruno & Selig 2007), notably *Acropora* spp. at the Koh Kut Island group (Yeemin et al. 2013).

Subsequently, the 2008 and 2010 coral bleaching events caused further declines in the already low levels of *Acropora* spp. (Yeemin et al. 2013).

b. Cambodia

Cambodia's coastal shoreline is 435 km in length with four coastal provinces (Koh Kong, Kep, Kampot and Preah Sihanouk) and 69 islands (van Bochove et al. 2006) (Figure 2.7). The seaward boundary of the coastal zone is the outer limit of the Exclusive Economic Zone comprising an area of 55,600 km² (FAO 2011). The total area of coral reef in Cambodia is estimated at approximately 2,807 hectares (Vo et al. 2013).

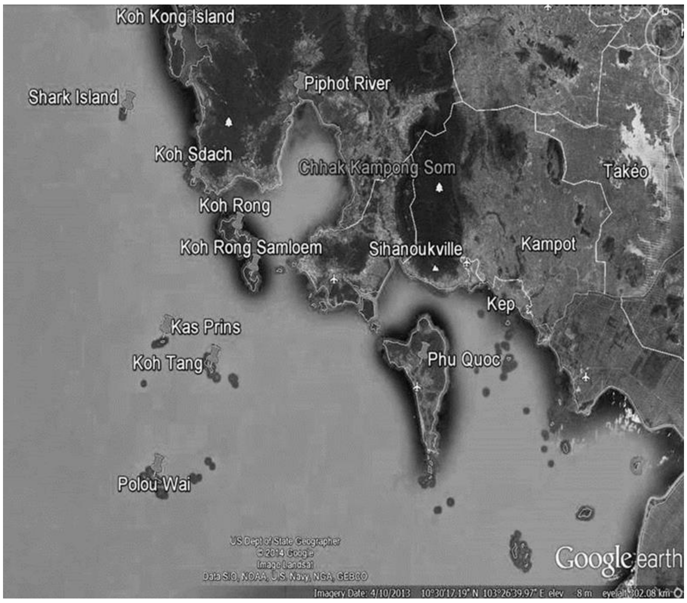


Figure 2.7 Cambodia and Vietnam Provinces and locations

Although Cambodia is rich in fringing coral reefs and reef biodiversity, the status and health of reefs is not well understood (van Bochove et al. 2011b). In 2003, the Cambodian Department of Fisheries surveyed seven coral reefs across the coastal provinces (Vibol 2007). The survey used Global Coral Reef Monitoring Network methods developed by IUCN and reported at least 70 coral species in 33 genera and 11 families (Vibol 2007). The percent live coral cover for reefs varied between 23.1 and 53.8 per cent (Table 2.2). In most cases, percentage cover was considerably higher than that found for nearby reef areas in Thailand (e.g., 33.3 per cent in 2006).

Table 2.2 Percentage cover of benthos types on selected reefs in Cambodia

	Koh Kong Province		Preah Sihanouk province			Kampot-Kep Provinces	
Benthos type (%)	**Koh Kong**	**Koh Sdach**	**Koh Rong**	**Koh Takiev**	**Koh Tang**	**Prek Ampil**	**Koh Poh**
Live coral	47.4	29.3	23.1	58.1	38.3	53.8	41.0
Dead coral	29.6	35.6	44.9	0.6	13.1	0.0	19.2
Other benthos	4.2	2.2	5.1	3.1	4.2	5.6	2.4
Algae	1.6	17.5	0.6	0.0	0.6	0.6	10.1
Abiotic	17.2	15.4	26.4	38.1	43.8	40.0	27.4

Studies conducted in Koh Rong, Koh Kong and Koh Rong Samloem in 2010 and 2011 indicated the percentage live hard coral cover was between 25 per cent and 40 per cent, with a dominance of massive coral morphological life forms and a lack of foliose and branching corals (van Bochove et al. 2011a; van Bochove et al. 2012). Coral species diversity was generally low with dominant coral species recorded as *Porities* spp. and *Diploastrea heliopora* and between two and nearly five per cent cover for *Pavona decussata*, *Favia* spp., *Galaxea* spp., *Pocillopora* and *Goniopora* spp. Less abundant were the foliose *Turbinaria* and *Montipora* spp. with less than one per cent cover (van Bochove et al. 2011a). High sediment loads were noted at these reefs.

Koh Rong Island is designated for a large tourism development, potentially posing a significant threat to coral reefs adjacent to the development site. Current anthropogenic impacts to corals are considered to be relatively low, although garbage, anchor damage and abandoned fishing nets and traps have been observed at some sites (van Bochove et al. 2011a) and pollution is increasing from coastal tourism and untreated sewage.

c. Vietnam – Phu Quoc Island

The Institute of Oceanography, Vietnam[5] reports 260 species of 49 genera of reef-building corals in the Phu Quoc archipelago. Coral reefs are located mainly south of the island (An Thoi islands) and the north-western part of Phu Quoc archipelago, with an estimated 474 hectares of coral reefs, of which 362 hectares are adjacent to An Thoi islands in the south (Figure 2.7). In 2004, coral reef surveys reported biodiversity to be similar to other areas within the South China Sea (Latypov 2003). One hundred and thirty-three scleractinian species were recorded for the Gulf (Latypov 2003). Low and patchy live coral cover was dominated by *Porities* sp., with high sediment loads and turbidity reported.

A 2010 survey revisited a number of coral reefs for the Namsu Island group adjacent to Phu Quoc and reported approximately 100 species of coral, less than that of the South China Sea waters of eastern Vietnam (Latypov & Selin 2011). This was considered to be due to shallow water and siltation from highly eutrophic waters derived from currents entering the gulf from the South China Sea (Latypov & Selin 2011). Coral-algal communities comprising *Turbinaria decurres* and *Palisada* sp., the hydroid coral *Millepora platyphylla*, and scleractinian corals *Acropora digitfera*, *Psammocora contigua*, *Goniastrea peltata* and *Leptoria phrygia* were reported with benthic cover exceeding 20 per cent (Latypov & Selin 2011). Coral dominated communities had patchy distribution with reduced live coral cover between 20 and 45 per cent; similar to Cambodian reefs. Dominant coral species included *Acropora* spp. (15 to 40 per cent), *Galaxea* spp. (14 to 30 per cent), *Leptoria* spp. (10 to 20 per cent) and *Montipora* spp. (10 per cent) and the hydroid *Millepora* spp. (8 to 14 per cent). Large colonies of *Porities* spp. and *Acropora* spp. measuring approximately 1m^2 created almost continuous cover in small individual patches. Other species such as *Acropora cytherea* and *Galaxea fascicularis* formed mono-specific colonies of relatively small size. Reef slope with greater light attenuation was dominated by *Acropora millepora*, *Montipora hipida*, *P. decussata*, *Porities lutea*, *Favia speciosa*, *Platygyra daedalea* and *Goniastrea fasciculahs* (Latypov & Selin 2011). Dominance of *Porities* spp. was considered to be a result of the highly turbid nature of the coastal water and the ability of *Porities* spp. to produce a firm bacterial mucous envelope to withstand environmental stress from high turbidity levels, light attenuation and salinity fluctuations (Latypov 2003).

2.3.5 Coral reef fish

Coral reef fish are an ancient group of vertebrates that evolved 70 to 50 million years ago in conjunction with the dominance of modern scleractinian reef-building corals. The biology of both coral reefs and coral reef fishes has evolved in unison and are closely associated (Hallacher 2003; Sale 1991). The strong interdependence between coral reef fish assemblages and coral reef habitat has been well documented globally (Bruno et al. 2009; Chong-Seng et al. 2012; Feary et al. 2007b; Feary et al. 2007a; Feary et al. 2009; Jones et al. 2004; Mumby et al. 2008; Noonan et al. 2012; Van Wynsberge et al. 2012). Coral reef health, size and structural complexity has a direct relationship with the population structure of reef fish assemblages (Graham & Nash 2013; Hixon & Beets 1993;

[5] http://vnexplorer.jimdo.com/: accessed 2 June 2014

Jones et al. 2004) and single species fish population dynamics (Noonan et al. 2012) and particularly reef fish species that display size-related dominance hierarchies (Kelly 1994).

Corallivorous fish species depend directly on live coral cover and are the most susceptible to losses from coral bleaching, diseases and other causes of live coral cover reduction (Pratchett et al. 2008; Wilson et al. 2006a). Reef-associated species, including holothurians, mollusks, crustaceans and pelagic mackerels, are also susceptible to changes in food availability from declines in live coral cover. Long term effects of coral bleaching are poorly understood as few studies have measured changes in reef fish assemblages greater than three years after a bleaching event (Bellwood et al. 2004; Graham et al. 2006; Jones et al. 2004), with no studies greater than ten years. Delayed effects of coral bleaching on reef fishes may result in reduced recruitment by fish that require coral at settlement (Feary et al. 2009; Jones et al. 2004); reductions in survivorship and reproductive output of fish that lead to gradual declines in population sizes and gene flow (Feary et al. 2009); and secondary declines in the abundance of piscivorous species due to declines in coral dependent prey species.

The Gulf of Thailand's fish fauna consists largely of widely distributed cosmopolitan species including species associated with the Indo-west Pacific (56.8%), west Pacific (21.2%), west Pacific-eastern Indian Ocean (14%), Indo-Australian (3.8%) or Indo-Malayan (2.5%) (Satapoomin 2000). Coral reef fish families include lethrinids, lutjanids, haemulids, labrids, scarids, siganids, chaetodontids, pomacentrids and pomacanthids, among others (Satapoomin 2000). Surveys indicate that the Gulf's species richness is comparatively impoverished, although it is similar to the Indo-Malayan and western-Pacific assemblages (Satapoomin 2000).

Coral reef fish surveys at Koh Rong, Koh Kon, and Koh Rong Samloem in Preah Sihanouk province indicate groupers and snappers were rarely seen at most sites, although densities of snapper were generally higher than grouper and sweetlip at all sites (van Bochove et al. 2011a). Parrotfish (Scarid) densities were generally low and butterflyfish (Chaetodontids) densities varied between sites (van Bochove et al. 2011a). Koh Kon island and some sheltered sites at Koh Rong and Koh Rong Samloem showed relatively high densities when all commercial species were pooled (1.2 – 1.6 ind/m^2) (van Bochove et al. 2011a). Data from surveys conducted in 2003 and 2009 indicate a general decline in grouper and snapper densities between years, although these data are to be treated with caution (van Bochove et al. 2011a). The relatively rare barramundi or humpback cod (*Chromileptes altivelis*) has been observed in the marine protected area at Koh Rong Samloem.

In the Phu Quoc archipelago, over 152 species of 71 genera of coral reef fish, 47 species of mollusks and 23 species of echinoderms have been recorded[6]. Coral reefs in Phu Quoc demonstrate a wide variety of groupers, abalones, scallops, oysters, giant clams, sea cucumbers, sea urchins, starfish, sponges and butterflyfishes.

2.3.6 Coral spawning and larval dispersal

Daytime spawning of *Pavona* sp. was recorded in Chumphon National Park, Gulf of Thailand on 27 August 2003, the third day after the full moon and during low tide (Plathong et al. 2006). Broadcast spawning of *Favia* sp. around inshore reefs in the inner and east Gulf of Thailand was observed following the full moons of February and March (Kongjandtre et al. 2010). *Porites* sp. displayed earlier and extended spawning periods in the southern part of the east Gulf of Thailand in Vietnam coastal waters (Latypov 2003). These reports indicate a wide variation in coral spawning periods within the Gulf of Thailand.

[6] Institute of Oceanography, Vietnam; Website http://vnexplorer.jimdo.com/: Accessed 10/12/2013

Due to the seasonal alternation in currents entering the gulf waters, coral and coral reef fish larval supply from the South China Sea vary (Satapoomin 2000). Currents entering the Gulf from the northern half of the South China Sea would possibly carry larvae from the North Equatorial Current through the Luzon Strait, the Philippines and the Sulu Sea (Satapoomin 2000). The south-west monsoonal period generates a clockwise gyre in the Gulf, creating in-flow along the Malaysian Peninsula. These waters carry a western Pacific coral reef fish assemblage (Satapoomin 2000).

2.3.7 Seagrass

Surveys conducted by UNEP indicate that one of the largest known areas of seagrass meadows in the South China Sea is located in the coastal waters between Cambodia and Vietnam (Vo et al. 2013). These seagrass meadows comprise 37,000 hectares, with 25,200 hectares located between Kampot and Kep Provinces in Cambodia and 12,500 hectares around Phu Quoc and neighboring islands of Vietnam (Mam 2002; Vibol undated; Vo et al. 2013). This habitat consists of approximately ten seagrass species providing significant fisheries refugia and a reported dugong population (Beasley & Davidson 2007).

2.3.8 Mangroves

The greatest species diversity of mangroves are found in Malaysia with 41 species (Fisheries 2009), followed by Indonesia and Vietnam with 37 species and lesser diversity found in Thailand (26 to 28 species) (UNEP 2004). Species diversity of mangroves shows latitudinal variation, with greater numbers of species occurring at the lower latitudes. Thailand's Trat Province is reported to have approximately 9,500 hectares of mangroves. Species diversity is reported to be lower on the eastern side of the Gulf than the western side, where Cambodia and Vietnam are reported to have 16 and 18 mangrove species respectively (Vo et al. 2013).

The Pream Krasaop Wildlife Sanctuary in Koh Kong Province, Cambodia has extensive mangrove communities critical for fisheries nursery grounds, with 25,800 hectares of mangroves (Nong undated; Vo et al. 2013). These mangroves are protected under the Cambodian government laws in a co-management arrangement. Immigration into the area increased after the end of the Khmer Rouge regime in 1979 (approximately 16 per cent annually) resulting in 10,000 local residents now living in the sanctuary (Nong undated). This has increased pressure on the mangroves with unprecedented destruction for large scale charcoal production, shrimp aquaculture and rice farming (Nong undated). Although local knowledge is limited due to high immigration levels, locals report that fish catch has declined over time.

The impact from aquaculture water quality in-flows to the receiving marine waters around Phu Quoc Island, Vietnam results in low pH and dissolved oxygen and high levels of iron, nitrogen, total suspended solids, total coliforms and chemical oxygen demand (Carter 2012a). Disturbance of soils for coastal development results in the exposure of acid sulfate soils further lowering the pH of receiving waters (Carter 2012a). This in turn affects the ecological integrity of the marine ecosystem including the reproduction and growth of marine flora and fauna, in particular the germination and growth of the pioneer *Avicennia* mangrove seedlings (Carter 2012a).

2.3.9 Fishing activities

The Gulf of Thailand is a tropical multi-species fishery. Pelagic species (mackerels, scads and tuna) were traditionally caught in inshore waters using non-motorized vessels; a practice that changed with the rapid rise in the number of large Thai purse seining vessels entering the fishery from 1972 (Noranarttragoon et al. 2013) (Figure 2.8). Fish aggregating devices were also used with purse seining vessels to attract fish, resulting in catch of juvenile fish below size at first maturity (Noranarttragoon et al. 2013).

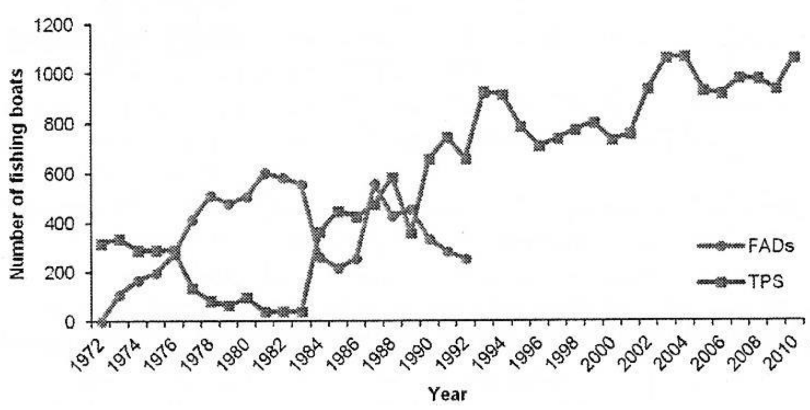


Figure 2.8 Thai purse seine (TPS) fishing vessels and Fish Aggregating Devices (FADs) in the Gulf of Thailand, 1972 – 2010 [7]

Exploitation of fish is now considered to be above the maximum sustainable yield (Cheevaporn & Menasveta 2003b; Pauly & Chuenpagdee 2003; Stobutzki et al. 2006a). Surplus Production Models indicate over-fishing in the Gulf of Thailand (Ahmed et al. 2007) with a reported decline in catch rate from 300kg/hr to 30kg/hr (Cheevaporn & Menasveta 2003b). Recent statistical data from the Food and Agricultural Organisation of the United Nations (FAO) on fish catch between 2002 and 2011 indicates Thailand's catch is declining substantially, while Vietnam's catch is increasing and Cambodia's catch remains relatively constant (Figure 2.9).

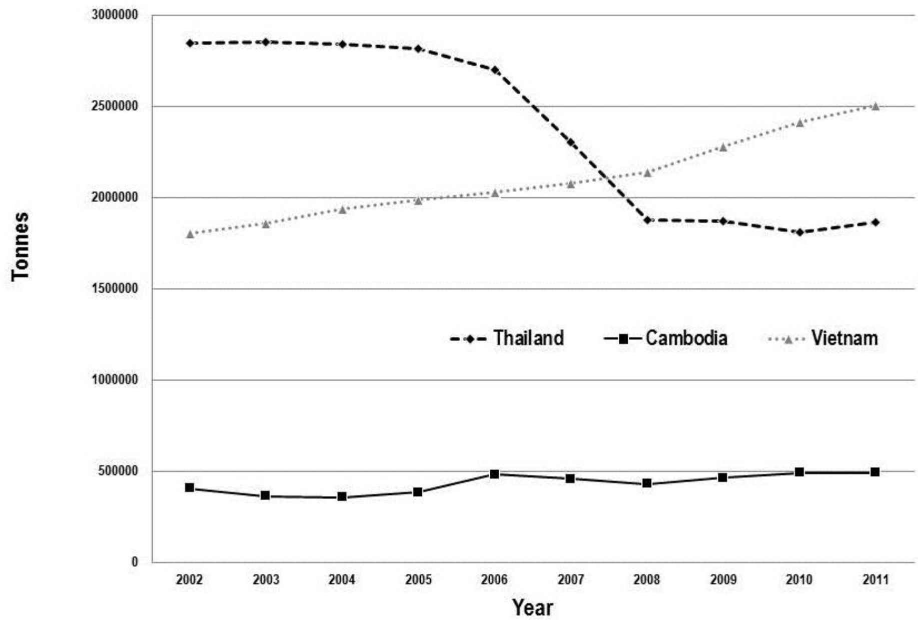


Figure 2.9 FAO reported marine capture of fish, crustaceans, mollusks and other species [8]

It is highly likely that Cambodian catch estimates are not based on actual landed weights of product. Cambodia tends to use an estimate of ten kilograms per boat per day to calculate fish catch. This is likely to be the case for Thailand and Vietnam as well, particularly for older data. Total catch of marine fisheries in 2005 was reported at 60,000 tonnes, representing a 33.3 per cent increase on the planned 45,000 tonnes for 2004 (MAFF 2006). These data contrast with the FAO fish catch data (Figure 2.9) where fish catch in Cambodia shows a slight decline for that year.

[7] Source: Noranarttragoon et al. 2013
[8] ftp://ftp.fao.org/FI/STAT/summary/a1c.pdf

As an example of the multi-species nature of the reef fishery in Cambodia in 2011, the largest catch of over 30 tonnes comprised primarily yellow dot sweetlip (*Plectorinchus* sp.), followed by red big eye (species unknown), shrimps and crabs (Figure 2.10).

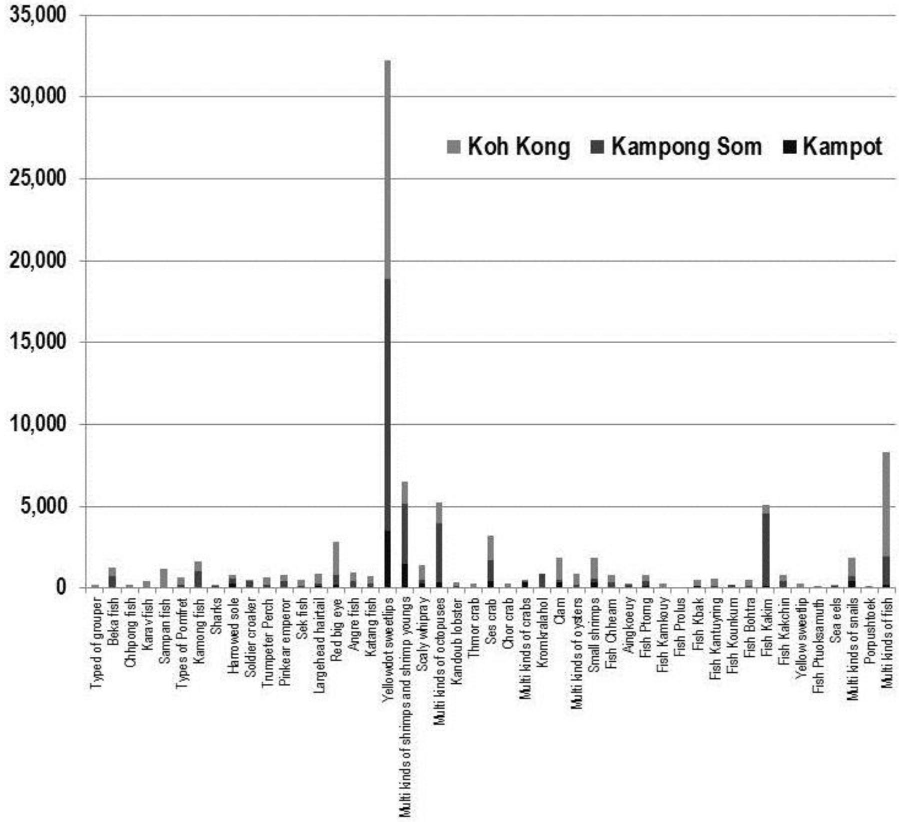


Figure 2.10 Marine catch estimates (tonnes) for coastal provinces of Cambodia in 2011[9]

Engine capacity of boats in Kampong Som Bay, Preah Sihanouk province was reported to vary between 10CC to 50CC vessels, most likely due to the variety of offshore and inshore fishing vessels based in Sihanoukville fishing port. Koh Kong Province and Kampot Province were reported to have a higher number of the smallest 10CC and 10-30CC fishing vessels (Figure 2.11).

[9] Source: Fisheries Report 2011 and Direction Setting 2012, 31 December 2011, Ministry of Agriculture, Forestry and Fisheries

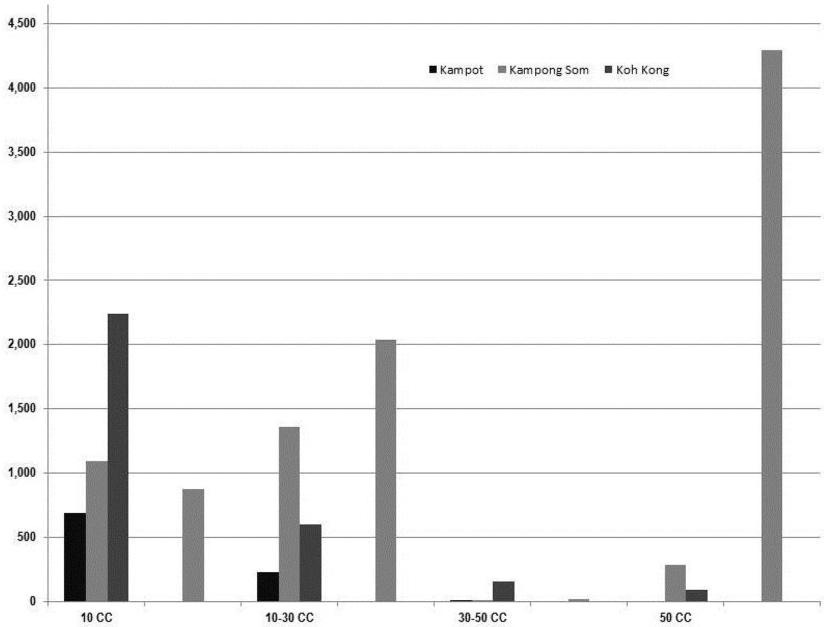


Figure 2.11 Engine capacity for marine vessels in Cambodia's coastal provinces in 2011[10]

2.4 Current management measures

The United Nations Environment and Protection launched a broad study in 2004 aimed at reversing environmental degradation on coastal habitats in the South China Sea and the Gulf of Thailand (UNEP 2004). Outputs included national reports on the status of the four priority habitats in the region (coral reefs, mangroves, seagrass and coastal wetlands), which indicate the Gulf of Thailand as areas of global biodiversity significance (Vo et al. 2013). The study focused on the specific threats to coastal habitats that are causing degradation and loss and the recommendation to develop National Action Plans and a Strategic Action Programme for the South China Sea (Vo et al. 2013). The study concluded that planning based on science was essential for developing agreement on regional targets and priority actions in the transboundary Gulf of Thailand (Vo et al. 2013).

However, co-management measures, in particular community-based fisheries management, has been effective in some circumstances in Thailand, Cambodia and Vietnam (Nasuchon & Charles 2010; Nuon & Gallardob 2011). Some co-management measures, particularly for the seagrass meadows between Cambodia and Vietnam, have been implemented with reasonable success (Nasuchon & Charles 2010; Vo et al. 2013). The combination of science-based planning and a transnational co-management approach may be beneficial for the coral reef ecosystem that exists in the east Gulf of Thailand.

2.7.1 Co-management

a. Thailand

Community based fisheries management in Thailand began following a move towards decentralization in 1992. This policy became effective in 1999 when the Mandate for Decentralization gave local areas the right to self-govern with independent power on policy formulation, administration, finance and personnel management (Nasuchon & Charles 2010). An example of effective co-management in Thailand was developed through cooperation between the Department of Fisheries and the Southeast Asia Fisheries Development Centre (SEAFDEC), which led to the Integrated Coastal Fisheries Management Program in Patthew District. A maritime territorial project site was declared and divided for aquaculture activities and total closure to fishing vessels

[10] Source: Fisheries Report 2011 and Direction Setting 2012, 31 December 2011, Ministry of Agriculture, Forestry and Fisheries

and dredging. Also, a Crab Bank Fishermen's Group was established to protect the spawning population by separating gravid crabs from the catch as well as change fishing gear to increase the mesh size on the bottom of traps. Conflicts were handled by the community members. Seven sub-groups were developed to address each type of fishing gear used in the sub-district. The project staff and fishermen engaged in regular meetings to address issues, including conflict between the different user groups. Training was conducted by the Department of Fisheries to support monitoring and conservation work resulting in an 80% decline in illegal poaching over a one year period (Nasuchon & Charles 2010). Information was shared between the sub-groups, mangrove restoration projects were initiated and fishers were engaged in collection of catch and effort data. Some lack of cooperation between government and sub-groups created problems; however, the overall effectiveness was deemed to relate to more resources for patrolling. The lack of community responsibility for policing and enforcement continues to result in reduced engagement from the fishing community.

b. Cambodia

In Cambodia, community co-management is only beginning; however, the government is involved in a 'learning by doing' approach due to the general low levels of education within the fishing communities (Nasuchon & Charles 2010). This approach transfers knowledge to the community using tours, meetings and seminars to disseminate information on fisheries co-management measures. Each village has a Village Management Committee responsible for developing management plans and solving problems. A nation-wide decentralization process began in 2002, resulting in democratically elected local councils. The Ministry of Agriculture, Forestry and Fisheries created a sub-decree with guidelines for community-based fisheries. Community prepared agreements are required to be signed by the Chief of Community Fisheries Committee and the local commune chief (Nasuchon & Charles 2010). Just how democratic this process is remains to be seen and there is currently no clear mandate or policy directive for the community-based fisheries. A 2011 study of local community perceptions of the outcome of community fishery management in Krala Peah village suggested that the development of a community fishery has led to a more equitable and efficient fishery (Nuon & Gallardob 2011). Although this approach did not lead to improving fishing habitats or catch, it was reported to be successful in achieving one of the main goals of local fishers, to reduce illegal fishing (Nuon & Gallardob 2011).

Fisheries laws and legislation frameworks were reformed in 2005 to strengthen sustainable fisheries and coastal zone management, fishing communities and fish sanctuaries. The Cambodian National Coastal Steering Committee (NCSC) was established to improve coastal peoples' livelihood through effective coordination between regional and national institutions and non-government organizations (NCSC 2005). The Committee recommends monitoring, and advises the Royal Cambodian Government on policies, plans and legal frameworks for sustainable fisheries and coastal zone management.

c. Vietnam

The Vietnamese Ministry of Fisheries developed a co-management strategy for near-shore and estuarine management that involved local organizations and fishers for monitoring and enforcement. Three problems arose from this process: lack of funds; traditional customary 'top-down approach', and lack of clear legislation determining the role of local governments in the decision making process (Nasuchon & Charles 2010). In Vietnam, strong cultural fabric controls the residential proximity rights, primary fishing rights and the right to sell, transfer or lease fishing rights. Where traditional rules are in place, one must wait for ten years before a fishery right may be granted, apart from the normal transferal to the eldest son, or daughter (in the event there are no sons). Although there are difficulties in conflict resolution arising from different user groups (or fishing gear types), increasing populations, habitat destruction and traditional practices, the communities have a history of respecting the sustainability of the resource over a long period of time. Their level of engagement is strong as they have a sense of ownership over the resource and the right to fish, which assists in more effective management of the resource, dispute resolution and problem-solving techniques (Nasuchon & Charles 2010).

d. The potential for co-management

There are many strengths as well as weaknesses in co-management approaches to fisheries management. Government intervention, well defined legislation and policies, appropriate training, project evaluation, regular communication and traditional approaches all affect the effectiveness of a community-based fisheries management model. Co-management practices in Cambodia and Thailand were found to result in minimal user organizations at the village level and led to unclear roles and authority at the local level (Wilson et al. 2006). Although fishers may be part of the consultation process, there is no obligation to include them in the management process. Further, the common practice of leasing resources to international consortiums, that provides revenue to investors and government (particularly in Cambodia), results largely in the alienation of local communities, rather than inclusion. Also, lack of funds generally creates the need for fishers to obtain loans from a middle man for fuel and other equipment. This leads to the middleman then buying product from the fishermen at a reduced price, resulting in a loss of market power.

Proximity to marine territories and governance strategies restricting use and access to non-fishing community members was found to positively correlate with more effective enforcement and reduced poaching in the Solomon Islands (Aswani & Sabetian 2010). Community-based marine parks in the Solomon Islands designed around customary management principles and under customary custodianship were shown to be more effective in enhancing ecological processes and fisheries management than traditional science driven marine reserves (Aswani & Sabetian 2010). Cooperative management and proximity to fishing grounds were shown to be effective for small customary marine tenures in Papua New Guinea in enhancing fisheries sustainability and the long-term persistence of a locally dispersed coral grouper meta-population (Almany et al. 2013).

It seems that engagement and effectiveness of the co-management approach is strongly correlated with initial provision of effective and clear directives based on traditional customs and values relevant to each particular area. Perhaps success lies in incorporating flexibility into the fisheries co-management framework based on a 'case-by-case' basis that considers social, cultural, economic and ecological factors.

2.8 Threats

The Gulf of Thailand has reportedly lost 80% of the mangroves compared to 20% loss in the Andaman Sea (Vo et al. 2013). Natural threats to mangrove loss from climate change include sea level rise, storm surge and cyclones. Conversion of coastal land for shrimp aquaculture is significant for Thailand and Vietnam, whereas charcoal production for trade to Thailand is the main cause of mangrove loss is Cambodia; and conversion of coastal lands in Vietnam (Vo et al. 2013). Charcoal production in Cambodia has slowed over the last five years due to availability of cheap natural gas. The Vietnamese value their mangrove communities for coastal stabilization and buffering from storms and flooding (Vo et al. 2013).

Seagrass meadows are under threat largely from push netting and shallow water bottom trawling. Although these activities are illegal, they are on-going due to a lack of enforcement. Declining seagrass meadows are also known to occur from increased levels of sedimentation from poor land use practices and flooding events (Preen & Marsh 1995). No data are available for seagrass loss in

Cambodia; however, 25 per cent loss is reported for Thailand's seagrass meadows and 45 per cent loss for Vietnam (Vo et al. 2013).

Using a scoring approach, Vo et al. (2013) ranked the threats to coral reefs for Thailand, Cambodia and Vietnam. Generally, Cambodian and Vietnamese reefs are scored and ranked as most vulnerable to direct threats, while Thai reefs are more vulnerable to indirect threats (Table 2.3).

Table 2.3 Threats to coral reefs for Thailand, Cambodia and Vietnam in the Gulf of Thailand[11]
(1 is the most serious and 9 is the least)

Threats	Thailand	Cambodia	Vietnam
	Rank	Rank	Rank
Direct			
Over-fishing	7	1	1
Destructive fishing	5	2	2
Sedimentation	4	5	3
Pollution	6	4	4
Bleaching	1	8	5
Indirect			
Unsustainable fishing and aquaculture	8	3	8
Coastal development	3	6	6
Unsustainable tourism	2	9	9
Deforestation of upland areas	9	7	7
Total area of coral reefs (hectares)	90,000	2810	110,000

Over-fishing and use of destructive fishing gear is ranked as the greatest threat to coral reefs in Cambodia and Vietnam, followed by sedimentation, pollution, unsustainable fishing practices, coastal development, coral bleaching, unsustainable tourism and deforestation on upstream areas (Vo et al. 2013). Destructive and illegal fishing activities are occurring in this habitat, including motorized push netting, shallow water trawling and bottom trawling. Dynamite and blast fishing are ongoing in the coastal waters of Cambodia and Vietnam. Coral bleaching was ranked as the greatest threat to coral reefs in Thailand.

2.8.1 Over-fishing

Fishing activities are largely unregulated and unmanaged and declining fish stocks in the Gulf of Thailand is attributed to over-fishing, the degradation and loss of fisheries coastal habitat and land-based pollution. It is considered that poverty contributes to over-fishing (Stobutzki et al. 2006a). Poverty is an issue in fishing communities, particularly in the small-scale fishing sectors of Thailand, Cambodia and Vietnam. Depletion of marine resources and over-fishing is reported to result in small-scale fishers increasing their fishing effort with more destructive gear. Malthusian over-fishing occurs when poorer fishing communities that lack other economic alternatives, tend to increase their fishing effort to maintain their incomes, even though catch is declining, resulting in destruction of the resource (Pauly 1994). Pauly (1994) concludes that this type of over-fishing is not able to be resolved by fisheries management interventions and requires alternative, land-based livelihood opportunities.

Shallow water demersal trawling and motorized push netting is considered to be highly destructive to seagrass meadows and benthic habitats, particularly for the seagrass meadows adjacent to Kep Province, Cambodia and Phu Quoc, Vietnam (Beasley & Davidson 2007). Although, community-based regulation and fishing activities are practiced in Cambodia under the *Cambodian Fisheries Law 2006*, Vietnam and Thai fishing vessels access Cambodian waters with minimal to no fisheries regulation enforcement occurring. There are currently minimal enforced fisheries management laws

[11] Source: Vo et al. 2013

or regulations in Thailand, Cambodia or Vietnam, presenting problems for the development of sustainable fisheries management across the contiguous coastal waters in the east Gulf of Thailand.

2.8.2 Climate change

Bleaching is considered the greatest threat to the health of coral reefs in Thailand (Table 2.3). Fluctuations in coral cover in the Indo-Pacific region have occurred from mass coral bleaching during climatic El Niño events between 1996 and 1998 (Bruno & Selig 2007). More recent coral bleaching events occurred in 2008 and 2010 in the Gulf of Thailand resulting in the loss of some coral species, particularly large branching *Acropora* sp. (Sutthacheep et al. 2013; Yeemin et al. 2013). Multiple stressors to coral reefs affect the resilience of coral reefs to withstand natural and human induced perturbations and remain a coral-dominated reef. The number of mass coral bleaching events has increased globally since late 1970 causing focus to shift towards climate change and global warming as the most influential cause of coral reef degradation (Hoegh-Guldberg et al. 2007; Hughes et al. 2003). Coral reef bleaching is exacerbated by rising sea temperatures, the effects of degraded water quality and increased storm events (Veron et al. 2009). Ocean acidification caused by saturation of the oceans with excess levels of CO_2 results in lowered pH levels of marine water and reduced coral and coralline algal growth (Veron et al. 2009). In particular, shallow water reefs are most affected by rising sea temperatures, degraded water quality and storm events resulting in greater levels of reduction in biodiversity (Wilkinson 2004).

2.8.3 Water quality

Eutrophication of marine water is of concern in the Gulf of Thailand with large amounts of untreated industrial and domestic waste being released into the receiving marine waters (Cheevaporn & Menasveta 2003b). Unregulated coastal and tourism development is rapidly expanding through intensive aquaculture farming, rice farming and land reclamation, resulting in the loss of mangrove habitat in the east Gulf of Thailand. Loss of mangrove habitats and their ecosystem services as a nutrient and sediment sink exacerbate the potential for environmental pollution impacts and enhance the potential for smothering of coral reefs and seagrass.

Eutrophication from increased nutrients, high levels of organic wastes, suspended solids, heavy metals and bacteria occurs annually in the inner Gulf. The Chao Phraya river in Thailand carries an estimated 60 to70 per cent of untreated domestic waste into the inner Gulf (Cheevaporn & Menasveta 2003b), with similar figures likely for Thailand's other main rivers. Water sampling between 1981 and 1984 identified elevated levels of chromium, copper, iron, mercury, manganese, lead and zinc in estuarine waters of all the major rivers that release into the Gulf of Thailand (Cheevaporn & Menasveta 2003b). Pesticide contamination was also reported in estuarine waters of the Tha Chin, Petchaburi and Pan Buri rivers from agricultural run-off (Cheevaporn & Menasveta 2003b).

Cambodian farmers applied between zero to 8,000 tonnes of organic fertilizer (NPK) between 1960 and 1990; while 40,000 tonnes of fertilizer were reported for 1991 and 1992 (FAO unpublished data in National Coastal Steering Committee, 2005). In addition, intensive pig and cattle farming in coastal areas of Koh Kong, Kep and Preah Sihanouk Provinces are contributing to the release of nutrients, pesticides and herbicides into the Gulf of Thailand.

Large scale dredging of river and coastal sand is occurring at the northern tip of Koh Kong Island and in the Piphot River, with no environmental monitoring of the dredging activities. Cambodia's Piphot River flows from Koh Kong Province into Champbang Som Bay adjacent to Sihanoukville City, carrying sedimentary deposits from the dredging activities. Freshwater flows and water quality in the east Gulf of Thailand from Vietnam is currently not well understood, although degraded water is entering the gulf from Kien Giang Province, mostly through farm expansion of the aquaculture industry.

Oil and gas exploration and drilling activities in the South China Sea have the potential to release petrochemicals and other heavy metals from drilling activities and flow into the Gulf of Thailand (Figure 2.12). Mercury content analysis in fish indicates that five to ten per cent of larger fish surveyed around two natural gas platforms in the Gulf were found to contain the maximum permissible concentration of mercury for consumption set by the Food and Agriculture Organisation (Cheevaporn & Menasveta 2003b). Investigations into the correlation between mercury levels found in Cobia (*Rachycentron canadus*) and natural gas platforms showed significantly higher levels of mercury in fish caught in the Gulf than those caught in the Andaman Sea (Pongplutong, 1999 in Cheevaporn and Menasveta (2003b).

Figure 2.12 Oil and gas resources in the South China Sea

2.9 Social and economic setting

2.9.1 Demographics

a. Thailand

The Thailand population is approximately 65 million, with an annual growth rate of 0.3 per cent[12]. Thailand people include three main ethnic groups: Ethnic Thai (75%), Thai Chinese (14%) and Ethnic

[12] http://en.wikipedia.org/wiki/Demographics_of_Thailand#CIA_World_Factbook_demographic_statistics

Malay (3%). The remainder (8%) includes minority groups of Indigenous hill tribes, Khmers and Mons[13]. Theravada Buddhism is the dominant religion, with an Islamic minority, mostly in southern Thailand, adjacent to the Myanmar border. Bangkok is the largest city with a population of around 14 million living in the Bangkok Metropolitan Region[17]. The land area of Trat Province is 2819 km^2 with an estimated population of 222,000 people. Provincial islands include Koh Chang, Thailand's third largest island, Koh Kut, Koh Mak and Koh Phi. Koh Chang is a protected marine park area and a popular tourist destination for local Thai people and a growing international clientele.

Thailand is currently facing two population problems: an aging population and urbanization. Urbanization is mostly concentrated around Bangkok and its surrounding areas. While many educated Thai people are moving overseas, less educated migrants from neighboring countries, such as Myanmar and Cambodia, are reported to be immigrating into the country.

b. Cambodia

The Kingdom of Cambodia's population of approximately 15 million is a relatively homogeneous Khmer population but includes Vietnamese (5%) and Chinese (1%) as other ethnic groups. Cambodia's largest city is the capital Phnom Penh, with a population of 2.2 million in the metropolitan area. Sihanoukville (ca. 300,000 people) is the largest coastal town, followed by Koh Kong, Kampot and Kep (ca. 40,000 each). With its deep seaport facilities, Sihanoukville is considered to be one of the economic centers based on the port, tourism and road access to the coastal provinces, Vietnam and Thailand borders. Theravada Buddhism is the official religion practiced by 95 per cent of the population. Islam is the main religion of the Malay and Chams minorities, with about one per cent identified as Christian.

Cambodia is currently experiencing population growth of 1.8 per cent, with a projected population estimate of 18.7 million in 2020 [14]. There are currently considerable challenges to sustainable population and economic growth and poverty reduction in Cambodia. Approximately 30 per cent of Cambodia's population is considered by the Asia Development Bank (ADB) to be living below the poverty line [15]. Poverty issues relate to a narrowly based economic structure, high costs and shortages of infrastructure, limited access to social services, inadequate access to land, natural resources, and affordable finance, human capital and skills shortages, and poor governance.

c. Vietnam

The Socialist Republic of Vietnam's population is estimated at around 92 million[16]. Vietnam's ethnicity is diverse, with the Vietnamese government recognizing 54 ethnic groups. The Kinh group is the most numerous (over 87 per cent of the population). The majority of the population has no formal religious affiliation; however, a strong influence on the beliefs and practices of the Vietnamese is a combined religion of Mahayana Buddhism, Confucianism and Taoism.

Approximately 1,705,500 people live in Kien Giang Province (Carter & Nguyen 2012). Phu Quoc island (also known as Dao Ngoc) has a resident population of over 100,000, and is located in the lower east Gulf of Thailand. It is the largest island of Vietnam with an area of 589.23 km^2. The district capital Duong Dong (ca. 20,000 residents) is the most populated city in the An Thoi archipelago which has 22 village communities. The closest cities to Phu Quoc are Rach Gia (ca. over 200,000 residents), 120 kilometers east of the island on the Vietnam mainland, and Ha Tien (ca. 40,000 residents), located 45 kilometers to the north-east. Rice farming and fishing provide the economic basis for people residing in the province (Carter & Nguyen 2012). Approximately 66 per

[13] http://worldpopulationreview.com/countries/: accessed 16 December 2013
[14] http://worldpopulationreview.com/countries/cambodia-population/: accessed 16 December 2013
[15] http://www.adb.org/countries/cambodia/main/: accessed 12 December 2013
[16] http://worldpopulationreview.com/countries/vietnam-population/

cent of the province is cultivated for agriculture and aquaculture and 19 per cent is forested (Carter & Nguyen 2012).

In 2006, the coastal areas of the province and its islands were recognized as a biosphere reserve by UNESCO [17]. Phu Quoc Island is a major tourist destination targeting the Russian market, mainly due to no visa requirements to enter Vietnam and short travel times.

2.9.2 Fishery dependency in the east Gulf of Thailand

Apart from cultural difference in the consumption of dolphin meat, there are similarities in rates and levels of pollution, illegal and unregulated fishing activities and unregulated coastal development in Thailand, Cambodia and Vietnam. However, social and cultural settings for the three countries are relevant towards developing effective conservation co-management measures.

Fishing is the most dominant source of employment and economic value for South-east Asian countries (Macusi et al. 2011). Fishing and related activities employ more than six million people in South-east Asia and contribute approximately 20 per cent of Gross Domestic Product (Fisheries 2009; Macusi et al. 2011). The fisheries sector is vital for cultural and social developments within these countries. The coastal resources of South-east Asia have a gross value of US$ 37 billion dollars; however, this is reported to be in decline due to degradation of habitat and resources from rapid urbanization, population growth, coastal developments, over-fishing and destructive fishing activities (Macusi et al. 2011). The net balance of exported and imported fish products for Thailand and Vietnam are relatively similar (Figure 2.13).

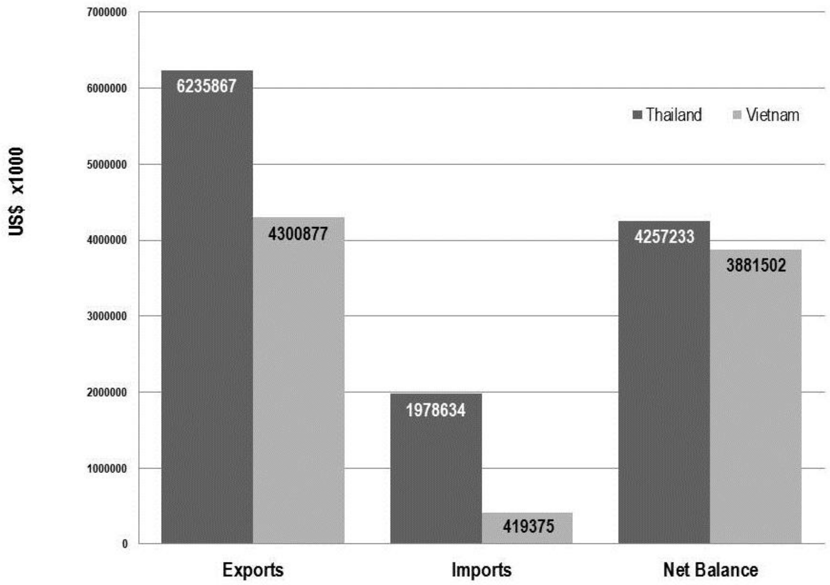


Figure 2.13 Relative importance of trade in fisheries products 2009 – Thailand and Vietnam [18, 19]

However, Cambodia relies on exporting fish products for income and imports comparatively little (Figure 2.14). Note the export and import $US x 1000 are reduced by several orders of magnitude for Cambodia.

[17] Institute of Oceanography, Vietnam; Website http://vnexplorer.jimdo.com/.
[18] ftp://ftp.fao.org/FI/STAT/summary/a7ybc.pdf
[19] Net balance = exports – imports.

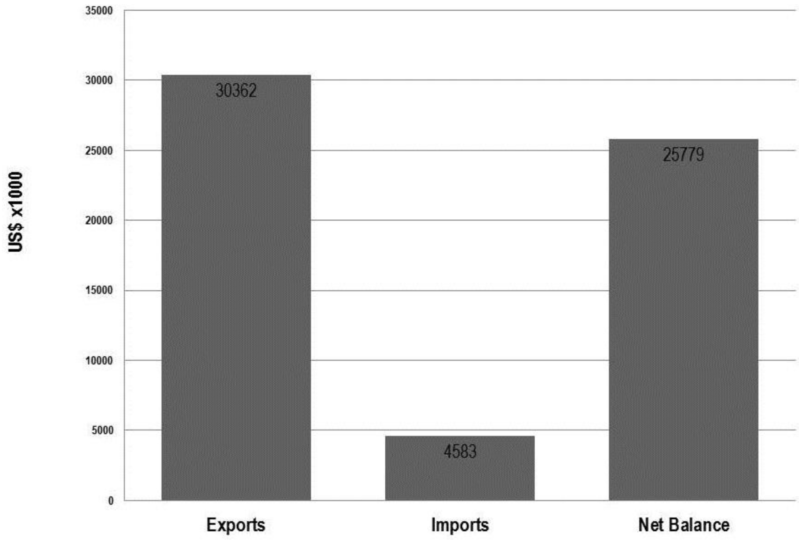


Figure 2.14 Relative importance of trade in fisheries products 2009 – Cambodia [20]

Of all agricultural exports, Vietnam has the highest proportion of exported fish products compared to Cambodia, with Thailand exporting the least (Figure 2.15). In terms of all exported merchandise, Vietnam has the highest proportion of exported agricultural products compared to Thailand, with Cambodia's exports hardly registering.

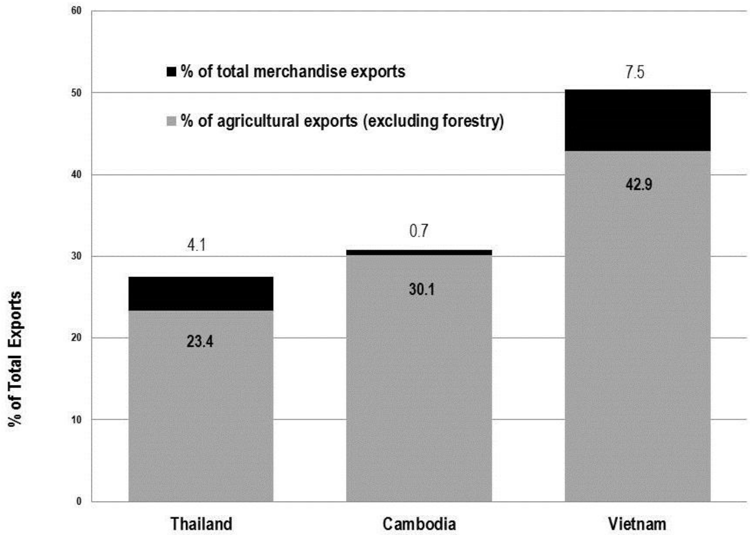


Figure 2.15 Fishery exports as a percentage of agricultural exports and as a percentage of total merchandise exports [21, 14]

[20] ftp://ftp.fao.org/FI/STAT/summary/a7ybc.pdf

[21] Agricultural & fishery products, excluding forest products. Source of total merchandise and agricultural trade is FAOSTAT.

Part three: **Methods**

3.1 Research paradigms for interpreting coral reef status

3.1.1 Four inter-related concepts explaining reef status

Coral reefs are considered to be in decline globally and are considered heterogeneous and fragile, stressed ecosystems (Bellwood et al. 2004; Graham et al. 2006; Hughes et al. 2003; Mumby & Steneck 2008). Explanations of coral reef dynamics have developed from the 1970s when it was often promulgated that reefs were robust, spatially uniform, stable and predictable in terms of organization (Endean 1977). Recent research suggests there is a lack of evidence to support coral reefs remaining in a stable coral-dominated state at all times, particularly after disturbance. It is suggested that reefs fluctuate, when algae may dominate before a successional return to a 'stable' coral-dominated reef (Dudgeon et al. 2010). Following a documented collapse of the coral reef ecosystem in the Caribbean between 1983 and 1984, reefs are now considered to be fragile and unstable and susceptible to phase-shifts following perturbation. Phase-shifts in coral-dominated ecosystems occur when disturbance leads to an algae-dominated or other ecosystem (Bruno et al. 2009; Hughes 1994; Hughes et al. 2007b). The resilience concept for coral reefs has emerged to refer to the capacity of a reef ecosystem to adapt to change and absorb recurrent disturbances without switching to a different stable state such as an algae-dominated system (Hughes et al. 2010).

New research paradigms emerged between 1980 and 2000 focusing on reproduction, recruitment, herbivory and predation (Blaber 2011; Hughes 1994; Mumby & Steneck 2008). Bellwood et al. (2005) reported a reduction in live coral cover, which resulted in a shift in reef fish community assemblage from habitat and trophic specialists to generalists. This led to the consideration of structural complexity of coral reefs and their role in maintaining fish population densities, particularly for small-bodied fish (Graham et al. 2006), the foraging efficiency of predators (Bruno et al. 2009) and invertebrate taxa (Wynne & Cote 2007). Drivers of coral reef degradation are grouped into proximate causes such as disease, bleaching and algal competition and ultimate drivers such as climate change, trophic-level dysfunction, eutrophication and land-use practices (Mumby & Steneck 2008). Since 2000, overfishing has also become a focus as the leading activity negatively impacting coral reef ecosystem processes (Mumby & Steneck 2008; Pandolfi et al. 2003).

Coral reef research paradigms focus on the relative dominance of coral reef species and trophic groups, coral reef resilience, phase-shifts and stable states, community ecology, ecosystem connectivity and the benefits or otherwise of marine protected areas (Dudgeon et al. 2010; Hughes et al. 2005; Hughes et al. 2007a; Hughes et al. 2007b; Littler et al. 2006; Mangel & Levin 2005). The importance of larval dispersal and connectivity of reefs for replenishment, resilience and gene flow for corals and coral reef fish is also evident (Ayre & Hughes 2004; Baird et al. 2009; Hughes et al. 2010; Hughes et al. 2007b; Jones et al. 2009). Cumulative impacts of climate change are also considered as important for coral reef ecosystem health and resilience (Bellwood et al. 2004; Goldberg & Wilkinson 2004; Hoegh-Guldberg et al. 2007; Hughes et al. 2003). It is now considered that coral bleaching events directly affect the diversity and abundance of reef fish species, particularly those that depend on live coral for settlement, habitat or food (Jones et al. 2004; Munday 2004).

a. Relative dominance paradigm

The Relative Dominance Paradigm hypothesizes that 'top-down control' (herbivory) or 'bottom-up control' (nutrients) determine the community structure and distribution of benthic organisms on coral reefs (Littler et al. 2006). This concept first emerged in 1985 to describe factors controlling the dominance of primary producers on reefs where the distribution of corals and coralline or fleshy algae results from variations in herbivorous grazing, wave shock and nutrient levels (Littler & Littler

1985). Manipulative experiments determined high herbivory levels combined with low nutrient levels maintained a coral-dominated system. Levels of herbivory were considered to directly reduce fleshy algal biomass that resulted in an indirect positive effect on reef-building corals and coralline algae. With the introduction of high levels of nutrients, algal blooms and fleshy algal growth are stimulated, inhibiting space for reef-building coral settlement and growth. Nutrient levels are considered to act directly as limiting factors (physiological stressors) or stimulatory factors (algal growth) and indirectly by changing the competitive balance on a coral-dominated reef. The resilience of a scleractinian-dominated reef is particularly vulnerable to reductions in herbivory from fishing and increasing nutrient levels from pollution (Littler et al. 2006).

In the east Gulf of Thailand, coral reefs are subject to over-fishing and increased pollution levels. The removal of herbivorous fish species from the reef by small- and large-scale fishing operations is most likely occurring, due to high fishing pressure and the lack of effective fisheries management. The dense coastal populations, aquaculture farms and intensive agriculture are resulting in high levels of nutrients entering Gulf waters from untreated sewage, release of waste and surface water run-off upstream. It is therefore probably that 'top-down herbivory' and 'bottom-up nutrients' are influencing the status and health of coral reefs in the east Gulf of Thailand.

b. Phase-shifts and the stable-state hypothesis

Phase-shifts in coral-dominated reef systems occur when a coral-dominated reef changes to an algal-dominated or other type of reef following disturbance, and is unable to return to its previous state of coral-dominane (Bruno et al. 2009; Hughes 1994; Hughes et al. 2007b). It is hypothesized that 'top-down herbivory' is important in driving the settlement and growth of algae on coral reefs and possible phase-shifts that may occur (Hughes 1994). Coral reefs are thought to switch between stable alternative community states of coral and macroalgae (Dudgeon et al. 2010).

Coral reefs in the Caribbean shifted from a coral-dominated to a macroalgae-dominated ecosystem in 1984 (Hughes 1994). Herbivorous fish were targeted by small-scale fishers following the removal of predatory fish species by commercial fishers. A population explosion of the herbivorous sea urchin *Diadema* resulted, followed by a mass pathogen-induced dieback of *Diadema*. *Diadema* is efficient in controlling algae on the reef and bio-erodes reef-building corals through its foraging actions. Continual bio-erosion of scleractinian corals results in a reduction in the resilience or health of corals. Furthermore, the removal of *Diadema* resulted in the successful settlement and growth of fleshy algae and a phase-shift occurred from a coral-dominated to an algal-dominated system. Sufficient long-term studies (greater than 10 years) have not been conducted on coral reefs that have undergone such change, so it is currently unknown whether a coral reef is capable of returning to a coral-dominated state.

In the Gulf of Thailand, a large rain event in August 2011 caused reduced salinity levels in the inner Gulf resulting in a decline in population numbers of the sea urchin *Diadema setosum* (Sangmanee et al. 2012). This occurred after the 2010 mass coral bleaching and low salinity levels were thought to cause further bleaching around Khang Kao and Koh Kut Island, particularly for *Pocillopora damicornis* and *Acropora* spp. (Sutthacheep et al. 2013; Yeemin et al. 2013). Bivalve and sea cucumber populations were also reported to have declined (Sangmanee et al. 2012). Disturbances from fishing activities are altering the trophic balance of reef fish assemblages. Long term over-fishing has resulted in the removal of predatory reef fish species and targeting of herbivorous fish by large- and small-scale fishers. It is likely that herbivorous fish populations are being depleted at a rapid rate. Without the competition from herbivorous fish species, algal biomass may increase and become more available for sea urchins, promoting high population numbers of sea urchins in the coral reef system. Considering the high bioerosion that sea urchins cause to corals, it is likely that this is an important factor influencing the health and status of coral reefs in the east Gulf of Thailand. Records of *Diadema* die-back from lowered salinity in the inner Gulf of Thailand are indicative of the possibility of a wide-spread *Diadema* die-back and reduction in levels of herbivory on the reef system. The coral reefs in the east Gulf of Thailand may well be on a tipping point considering the pressure already occurring from fishing and pollution.

c. Community ecology paradigm

The Community Ecology Paradigm hypothesizes that community ecology and the interactions occurring in multi-species fish assemblages within an ecosystem are the keys to understanding fisheries science rather than single-species population dynamics (Mangel & Levin 2005). This is particularly relevant in a multi-species fishery such as the Gulf of Thailand. Fisheries science has largely focused on single species population dynamics; however, in a multi-species temperate marine system, Mangel & Levin (2005) found that the removal of one apex predator resulted in a trophic cascade and habitat shifts that were not recoverable even when fishing pressure ceased. In the example, the initial presence of cod, which preyed on sea urchins, was important for maintaining the balance of sea urchin numbers and protecting critical nursery habitat. The removal of cod created a trophic shift and disturbed the inherent ecosystem balance. Even in this marine system where species are equal and competing in terms of colonizing habitat, removal of the target fish species (cod) possibly altered the larval pool and created a shift in its ability to compete.

The community ecology paradigm is particularly important in the Gulf of Thailand's multi- species coral reef ecosystem. Interactions that result following the removal of one fish guild are complex and not pair-wised. Also, the phenotypic and genetic characteristics of marine biota may be important in determining the reefs' resilience through absorbing disturbance and returning to a stable state. Although beyond the scope of this study, this emphasizes the important role that the ecology of the marine communities have in the maintenance of stable states and the connectivity to other communities on natal and neighboring reefs for larval supply.

d. Ecosystem connectivity

Connectivity of reefs between disturbed and undisturbed sites is important for coral reef resilience, through coral and fish larval replenishment and gene flow (Almany et al. 2009; Jones et al. 2009; Munday et al. 2009). The concept of ecosystem connectivity hypothesizes that habitat corridors provide connectivity between habitats critical for biota at different stages of their life history. While also allowing for the migration of species between and among habitats, successful reproduction, settlement and growth is enhanced at a range of spatial scales (Mumby 2006; Mumby & Steneck 2008). Many marine species undergo ontogenetic migrations from one type of habitat to another during their life history due to different food, shelter and reproduction requirements as they grow. Although it is not well understood, ontogenetic 'ecosystem connectivity' has been shown to be important to reef dwelling organisms where linkages between different marine habitat types, such as seagrass, mangroves and coral reefs, offer the greatest chance of survival, growth and reproduction (Mumby 2006).

The importance of mangroves and seagrass in offering refugia and nursery habitat for fish species has been well documented (Coles et al. 1989; Dorenbosch et al. 2004; Rasheed 2003; Robertson & Duke 1987; Watson et al. 1993). Successful recruitment of fish species relies on the ability of viable larvae to reach nursery habitats for growth, survival and protection. The relationship between freshwater rivers and streams and marine fisheries productivity is well understood and requires equally important habitat connectivity measures to allow for the migration and spawning patterns (Halliday & Robins 2007).

Species-specific preferences for mangrove habitats during early life history phases were reported in the Caribbean coral reef ecosystem where increases in fish biomass were shown to improve following the connection of protected reef to extensive mangrove habitats (Mumby 2006). Larval retention (self-recruitment) and habitat connectivity (dispersal) between coral reefs has been shown to be important for larval supply of coral (Baird et al. 2009; Connolly & Baird 2010; Graham et al. 2008) and coral reef fish (Jones et al. 2009; Planes et al. 2009). Long-distance dispersal, survival and settlement of coral and coral reef fish larvae may occur on neighboring reefs over 100 kilometers in distance (Baird et al. 2009; Connolly & Baird 2010; Graham et al. 2008; Jones et al. 2009; Planes et al. 2009; van Oppen et al. 2008), indicating that coral spawn can survive for long periods and travel large distances.

Fringing reefs along the east Gulf of Thailand are connected by oceanographic currents that are driven by freshwater flows, storm activity and wind forcing. The study area extends over 500 kilometers with a connected system of coastal coral reef, seagrass and mangrove habitats. The relative importance of these offshore and fringing reefs in providing larval supply of corals and coral reefs fish to natal and neighboring reefs is currently unknown for the study area.

Also, little is known about fish spawning behavior in the study area. However, broadcast spawning corals are reported to spawn mainly between March and April, at the beginning of the wet season when salinity is usually altered by rainfall events, particularly in coastal waters. This paradigm emphasizes the importance of protecting critical mangrove, seagrass and coral reef habitats in the east Gulf of Thailand to ensure that trophic functioning, growth and reproduction of marine species and biodiversity is ongoing. The provision of measures to support, maintain and enhance the integrity of the existing marine and coastal ecosystem connectivity appears to be critical.

The ongoing growth, survival and reproduction of marine species in the east Gulf of Thailand will most likely rely on the application of the precautionary principal to protect critical marine habitats for marine species during their life history phases. The development of a network of no-take areas in a data poor environment may need to be based primarily on the already known high fisheries values of mangroves, seagrass and coral reef habitats for corals and coral reef fish species for the different life history phases. Application of the ecosystem connectivity concept is likely to be essential in the development of future protection measures for enhancing resilience for fisheries marine habitats, coral reefs and coral reef fish species and for the ongoing security of biodiversity values and the ecosystem goods and services they provide for the benefit of human well- being.

3.1.2 Integrating concepts to explain and predict status

The inter-related theoretical concepts a. to d. discussed above appear to be relevant for establishing the factors influencing the status and health of the coral reefs within the study area. The Relative Dominance Paradigm considers that variations in herbivorous grazing, wave shock and increasing nutrient levels result in the segregation of corals and coralline or fleshy algal reef distribution. In applying this concept to the study area, the 'top down' removal of herbivorous fish species and the 'bottom up' increased levels of nutrients may be affecting the space available for coral settlement and also influencing the spatial and temporal coral distribution and abundance reported. Assessment of fish species, fish guilds and relative abundance and *in situ* water quality parameters will help explain the status of coral reef fish assemblages and water quality in relation to the per cent and variability of live coral cover and coral species observed within the study area.

The variability in live coral cover, algal cover, dead coral and other benthic substrate types will provide baseline information on the status and health of coral reefs for each site within and between locations. From the existing evidence, over-fishing and destructive fishing activities are occurring in the study area, with herbivorous fish species targeted by commercial and small-scale fishers. Die-back of *Diadema* sp. has also occurred in the inner Gulf of Thailand. Field observations of herbivorous fish species and relative abundance and the per cent cover of live coral and fleshy algae may indicate that the coral reefs in the east Gulf of Thailand are indeed close to a tipping point for a phase-shift to algal-dominated reefs. This information is important for identifying future monitoring approaches and targeting environmentally sensitive areas for protection.

In terms of community ecology, tropical coral reef ecosystem dynamics are complex and not based on simple pair-wised interactions between prey and predator and competitor and predator. The level of resilience that coral reefs have to remain in a coral-dominated state may depend on the level of genetic diversity, sourced from natal and neighboring reefs. This emphasizes the need to identify areas of coral reef within the study area that are high in coral species richness and structural complexity. As structural complexity of coral reefs is correlated with reef fish assemblages and abundance, identification of these areas assists in possible future protection of critical coral reef habitat. This, in turn, assists with the ongoing provision of critical coral reef ecosystem services for the benefit of human well-being.

3.1.3 Applying concepts to this study

This study does not seek to test the hypotheses inherent in the theoretical concepts discussed in Section 3.1.2. Rather, it will apply results of the evaluation of coral reef and water quality status to identify, probabilistically, the reasons for status and likely trajectories under different intervention approaches (Figure 3.1).

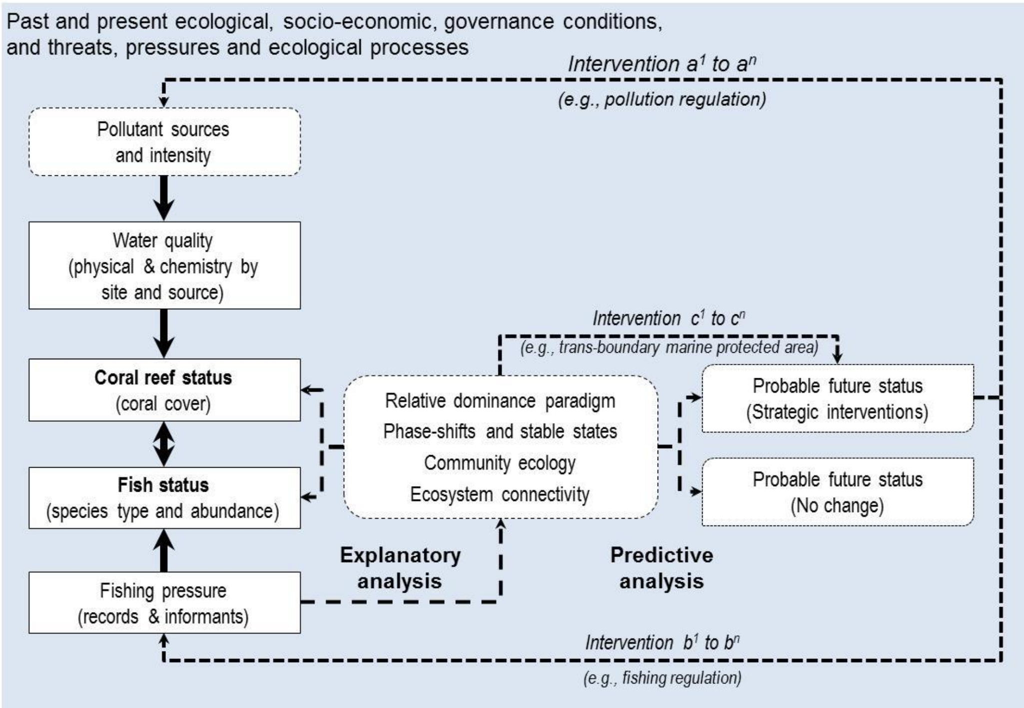


Figure 3.1 Explaining reef status and probable trajectories

As a precautionary measure, it appears that no-take marine areas may afford protection of the poorly inventoried coral reef, seagrass and mangrove habitats in the study area and enhance the likelihood of coral reef fish and coral species replenishment. The provision of connectivity between and among reefs also appears to be critical for maintaining the east Gulf of Thailand reef system. Considering the high levels of fishing pressure already occurring, the nutrient and sediment input, a system of no-take areas might be needed to ensure reef system resilience, complimented by actions to reduce land-based pollution, particularly adjacent to coral reef identified as highly biodiverse.

Ecosystem-based management and co-management measures need also be considered for their application and effectiveness across the political borders of Thailand, Cambodia and Vietnam. Ongoing and committed enforcement of no-take areas appears to be critical for successful protection of marine species and requires continual review to minimize cost and maximize effectiveness. Commitment is required from Thailand, Cambodia and Vietnam if the development of marine protected areas and other interventions are to be effective in enhancing coral reef resilience and providing ongoing ecosystem goods and services for the benefit of human well-being.

3.2 Research methods

3.2.1 Site selection

The rationale for selecting the study area was based on the contiguous nature of the coral reef system between the Koh Chang island group in Thailand, the Cambodian coastal islands and Phu Quoc in Vietnam. These reefs are connected by oceanographic currents (Aschariyaphotha et al. 2008; Latypov 2003; Singhruck 2001) and freshwater flows largely from Thailand and Cambodia (Aschariyaphotha & Wongwises 2012). Specific sites were selected based on key groups of islands and areas of fringing reef that are relatively easy to access, close to coastal land, freshwater flows and coastal population centers such as tourist and residential areas.

Eight locations were selected within the study area between and including Trat Province in Thailand, Koh Kong, Preah Sihanouk Provinces in Cambodia and Kien Giang Province in Vietnam. Sites within locations were selected based on the presence of continuous reef sufficient for conducting surveys (Table 3.1). Potential sites were initially inspected by manta towing and snorkeling to identify suitable reef to conduct the underwater surveys.

Table 3.1 Country, Province, locations and survey sites

Location No.	Site No.	Country	Province	Location Name	Site Name
1	1	Thailand	Trat	Koh Chang Island	Wai Reef Is
1	2	Thailand	Trat	Koh Chang Island	Yak Yai Is
1	3	Thailand	Trat	Koh Chang Island	SongPeeNong Is
2	4	Thailand	Trat	Koh Kut Island	Mai See Lek
2	5	Thailand	Trat	Koh Kut Island	Koh Rat
2	6	Thailand	Trat	Koh Kut Island	Ao Tum
2	7	Thailand	Trat	Koh Kut Island	Lam Chede
3	8	Cambodia	Koh Kong	Koh Sdach Island	Koh Chan
3	9	Cambodia	Koh Kong	Koh Sdach Island	Koh Chan
3	10	Cambodia	Koh Kong	Koh Sdach Island	Koh Krorsa No. 1
3	11	Cambodia	Koh Kong	Koh Sdach Island	Koh Krorsa No. 2 South
3	12	Cambodia	Koh Kong	Koh Sdach Island	Koh Krorsa No. 2 East
3	13	Cambodia	Koh Kong	Koh Sdach Island	Koh Ampel No.1
3	14	Cambodia	Koh Kong	Koh Sdach Island	Koh Ampel No.1 SE
3	15	Cambodia	Koh Kong	Koh Sdach Island	Koh Ampel No.2 S S/W
3	16	Cambodia	Koh Kong	Koh Sdach Island	Koh Andech
4	17	Cambodia	Koh Kong	Koh Kong Island	Koh Kong S
4	18	Cambodia	Koh Kong	Koh Kong Island	Koh Kong SW
4	19	Cambodia	Koh Kong	Koh Kong Island	Koh Kong SW 2
5	20	Cambodia	Koh Kong	Shark Island	Shark Is East
5	21	Cambodia	Koh Kong	Shark Island	Shark Is South
6	22	Cambodia	Preah Sihanouk	Koh Rong Island	Song Saa
6	23	Cambodia	Preah Sihanouk	Koh Rong Island	Coral Reef Island
6	24	Cambodia	Preah Sihanouk	Koh Rong Island	Misty Maze
6	25	Cambodia	Preah Sihanouk	Condor Reef	Condor Reef
7	26	Cambodia	Preah Sihanouk	Kas Prins Island	Trong Ol
7	27	Cambodia	Preah Sihanouk	Kas Prins Island	Koh Chicken
7	28	Cambodia	Preah Sihanouk	Kas Prins Island	Kas Prins
7	29	Cambodia	Preah Sihanouk	Paulo Wai Island	PW Naval Base 1
7	30	Cambodia	Preah Sihanouk	Paulo Wai Island	PW Naval Base 2
7	31	Cambodia	Preah Sihanouk	Paulo Wai Island	Rocher Saracen

Location No.	Site No.	Country	Province	Location Name	Site Name
7	32	Cambodia	Preah Sihanouk	Paulo Wai Island	PW No. 1 W
7	33	Cambodia	Preah Sihanouk	Paulo Wai Island	PW No. 1 S
7	34	Cambodia	Preah Sihanouk	Paulo Wai Island	PW No. 2 S/E
7	35	Cambodia	Preah Sihanouk	Koh Tang	Koh Tang S/W
7	36	Cambodia	Preah Sihanouk	Koh Tang	Koh Tang S
6	37	Cambodia	Preah Sihanouk	Koh Rong Island	Koh Touk
6	38	Cambodia	Preah Sihanouk	Koh Rong Island	Koh Rong Long Beach
6	39	Cambodia	Preah Sihanouk	Koh Rong Island	Koh Kon
6	40	Cambodia	Preah Sihanouk	Koh Kon Island	Koh Kon N/E
6	41	Cambodia	Preah Sihanouk	Koh Rong Island	Koh Rong Samloem
6	42	Cambodia	Preah Sihanouk	Koh Rong Island	Cobia Point
8	43	Vietnam	Kien Giang	Turtle Island	Turtle Island North
8	44	Vietnam	Kien Giang	Turtle Island	Turtle Island South

3.2.2 Data collection

a. Site descriptors

Descriptive data on coral reef species diversity and abundance, reef slope and profile were recorded for each dive site. A site description data sheet was completed for each site within locations to record proximity to population centers, freshwater flows, marine protection measures, fishing activities, relative exposure to wave and wind action and location. Site information for each dive site was recorded, including GPS co-ordinates, depth, time of survey, orientation of transects, proximity to freshwater flows and population centers, weather and site exposure, sources of pollution including daily number of boats, popular dive location and evidence of anthropogenic influence, management protection measures and fishing regulation and activities.

These data are used to aid interpretation of results for reef water quality and biotic characteristics and probable relationships with the descriptors. They also provide potential to link status assessments with management practices (Appendix 2).

b. Coral reef fish and reef benthos

A nested, fixed factor sample design was developed to assess coral reef health and status, where location is fixed and sites are nested within locations. Four by 25 meter transects were placed at a depth contour between three and nine meters on the reef slope as replicates for each site within locations. The sample design is based on the assessment of coral reef at a spatial scale sufficient to establish the variability of live coral cover within and between sites and locations.

Coral reef fish assessment

In the selection of key fish species to be counted it was necessary to ensure that they are:

- visually and numerically dominant without cryptic behavior;
- easily identified underwater; and
- associated with reef-slope habitats.

These species are identified, counted and estimated for size for each transect at each site. Predatory, herbivorous and other fish trophic guilds were identified for each transect and count estimates recorded where possible.

Fixed width transects are the commonly used method for underwater visual census and have been adopted for current monitoring programs (Hill & Wilkinson 2004; Hodgson et al. 2006). Although this methodology underestimates cryptic fish and nocturnal species abundance, it provides a quick estimate of species richness, fish abundance and length frequency distributions (English et al. 1994).

Two x 50 meter flexible tapes were placed from the shallowest point of the reef to the deepest point where reef meets sand. Reef profiles were limited by a maximum of 100 meters in width due to field equipment constraints. Reef habitat type was observed during laying the reef profile tapes to identify any transition zones within the reef slope habitat. The reef profile was recorded for each site, from shallow to deep, using the camera on video setting. Length of the profile and maximum depth was recorded for each site.

The 25 meter transects were placed along a depth profile between three and nine meters depth. Observed reef fish species and size were recorded in an imaginary belt transect 2.5 meters either side of the transect line (Figure 3.2). A minimum five meter gap was left between each transect to ensure that transects were not pseudo-replicates. This process was repeated for the remaining three transects to develop a total of four visual count belt transect fish observations per site (English et al. 1994).

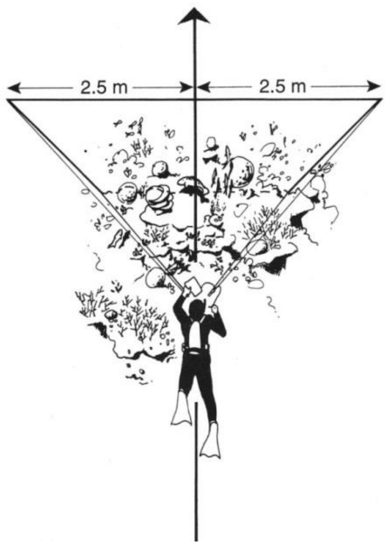


Figure 3.2 Fish visual census technique[22]

A core group of species appropriate for coral reef fish assessment was selected to quantitatively estimate density and size structure of predator and herbivore fish species that are favored 'targets' of fishermen (e.g. grouper, rabbitfish, parrotfish, snapper, trevally and sweetlips) and recorded on data sheets.

Coral reef benthic habitat

Currently accepted methods to assess coral benthic habitat on SCUBA include: line intercept transects, 1 meter x 1 meter quadrat, line point transects, video sampling and 1 meter x 1 meter photo-quadrats analyzed by point sampling (used in this study) (see Brown et al. 2004; Dumas et al. 2009; English et al. 1994; Hill & Wilkinson 2004; Kohler & Gill 2006; Leujak & Ormond 2007). Due to time and budget constraints and image clarity for identification purposes, underwater still photographs of benthic habitat was taken every meter along a 25 meter transect. This process generates a series of 0.5 to 1 meter x 1 meter photo-quadrats sufficient for point sampling techniques developed by Kohler and Gill (2006) to assess benthic communities and per cent live coral cover.

Following completion of the reef fish visual census, the transect was re-traversed taking still photographs every meter along each 25 meter transect tape, using a 12 megapixel Cannon S110 still camera with an underwater housing to obtain high quality photographic images. This generates 100

[22] English et al. 1994

still photographs per site. Evidence of coral disease, coral predators, coral bleaching, abandoned fish traps and nets, dynamite fishing and algae were recorded for each transect.

c. Water quality

Water samples and environmental parameters were taken at each site within locations. In addition, similar data were collected at identified sources of freshwater flows and population centers within each location where possible. Ambient water quality parameters were taken for sea surface temperature, water temperature at three and ten meters, salinity and dissolved oxygen using a water quality probe. Turbidity was recorded *in situ* using a Sechi disc.

Water samples were collected in Nansen bottles at the surface, taking care not to contaminate the sample. Samples were fixed with chloroform and kept on ice in cooler boxes and sent to the laboratory within seven days of collection. Testing was conducted on levels of nitrates, nitrites, phosphorous, ammonia, fecal coli form and chlorophyll *a* levels. Laboratories used were in Thailand, Cambodia and Vietnam for ease of access and freshness of samples.

d. Community-based surveys

A fishing community survey was designed to gain perceptions of the status of fisheries and marine resources in the east Gulf of Thailand. Surveys were conducted at each location by interviewing members of the local fishing community and included ordinal data on local fishing community perception of the status and health of fisheries within the study site and in-depth interviews using an interview guide. Interview questions were designed to be simple for translation purposes into Thai and Khmer languages. The questions gathered data on the length of time interviewees have been fishing in the area, vessel size used, observations on land use changes, size of fish caught now and up to ten years prior, marine water quality observations over time, and opinions on current management arrangements. Fishers were visited at boat ramps, villages and aquaculture farms for the purpose of interviews. Either men or women were selected depending on their level of agreement. A translator was used in all cases enabling information to be recorded in the native language, and then translated into English after the interview.

e. Fisheries data

Collation of available fisheries data provided an estimate of the current status of fish stocks within the study area, where possible. Field assessment of key coral reef fish species provided an independent set of data on species present, relative abundance and size for sites and locations within the study site.

Fishing catch and effort data were collected for the study area, with comments noted on the source and reliability of the data. Interviews were held with government officials from Thailand, Cambodia and Vietnam to collect current statistical data of marine fish catch and effort. Other statistical data were collected from sources including the Food and Agriculture Organisation of the United Nations.

Desktop assessment of available published and grey fisheries literature and data were conducted to develop catch and effort trends over time. Analysis of existing fisheries catch and effort data are used to validate anecdotal information and provide a description of trends over time to understand the dynamics of the fishery in the east Gulf of Thailand, with particular reference to the study area. Initial analysis of data collected is presented in Part Two of this report.

3.2.3 Data analysis

a. Coral species and benthic communities

Benthic type and percentage cover data was analyzed using Coral Point Count with Excel extensions (CPCe) software program (Kohler & Gill 2006) to generate the percentage of live coral cover, dead coral, algae, sand, rubble and rock and other for each frame, transect, site and location. The 'other' category includes all soft corals, gorgonians, barrel sponges and sea urchins. CPCe includes automatic frame-image sequencing, single-click species/substrate labelling, auto-advancement of data point focus, zoom in/out, zoom hold, and specification of random point number, distribution type, and frame border location. Customization options include user-specified coral/substrate codes and data point shape, size, and color. Using the CPCe methodology, statistical parameters of each substrate type (relative abundance, mean, standard deviation, standard error). Presence of coral disease and Crown of Thorns was also noted. Dominant coral species was analyzed with reef fish species and assemblages using correlation and regression analysis to explore the relationship between live coral cover, water quality and fish counts for sites and locations.

b. Coral reef fish species and assemblages

Fish counts were calculated per species to assess the relative abundance of predators and herbivores at sites and locations.

c. Water quality parameters

Water quality data will be correlated with the percentage of live coral cover between sites and locations to establish the relationship between degraded water quality and the health of the adjacent coral reef.

d. Fisheries community surveys

An anecdotal picture of local perception of the status of the fishery, effectiveness of current management measures and a measure of the feeling of ‘inclusion’ in management decisions and operations is then developed. Other responses on the level of satisfaction that members of the local fishing communities are experiencing in terms of access to the fishery or new fisheries, fishing rights, availability of fish stocks and pressure caused by encroachment from fishing vessels coming from other countries is collated to assist in the co-management development process.

Part four: **Summary results and discussion**

4.1 Coral reefs in the east Gulf of Thailand

4.1.1 Inshore reefs

Twenty-five species of hard coral were identified in the inshore sample sites, including: large branching and laminar *Acropora* spp., massive *Diploastrea heliopora*, *Favites* sp., *Fungid* sp., *Lobophyllia* spp. , *Goniastrea* spp., *Monitpora* spp., *Goniopora* spp., *Alveopora* spp., *Pavona cactus*, *Pavona decussata*, *Pectinia paeonia*, *Porites lutea*, *Porities lobata, Echinopora* spp., and *Turbinaria* spp. Massive *Porities* spp. were dominant at almost all inshore sites. The foliose *Turbinaria* sp., frondose *P. decussata* and encrusting *Galaxea* sp. were also dominant at some inshore sites. Large branching and laminar *Acropora* spp. were prevalent at Thai and Vietnam inshore sites. All inshore reefs showed signs of stress in terms of high levels of bioerosion (burrowing bivalves and tubeworms) particularly on *Porities* bommies, high levels of turf algae and sediment, with the exception at Koh Andech (S17). This site had wide diversity of corals with minimal algae present.

a. Benthos characteristics

The mean coral cover for all inshore reefs was nearly 40 percent, although this varied between sites and between countries. However, the differences are unlikely to be significant (Table 4.1). There was little dead coral recorded (3%) and highest cover percent was found on Thai reefs, but there was considerable variation between sites. Algal cover was around 17% across all sites, with again considerable variation between sites, particularly in Thailand (Table 4.1). Vietnamese sites had the highest percentage cover of algae (25%), which aligns with the low levels of sand and rubble (35% across all sites) (Table 4.1).

Table 4.1 Benthos cover and water quality parameters of eastern Gulf of Thailand sample sites

	Benthos cover (%)					**WQ parameters**								
	Coral live	**Coral dead**	**Algae**	**Sand/rubble**	**Other**	**TDS**	**DO**	**Turbidity**	**Nitrate**	**Nitrite**	**Ammonia**	**Phosphate**	**TSS**	**Total coliform**
Mean Inshore Thai	41.3	3.4	16.2	35.5	3.4	2.8	4.9	5.1	1.8	0.0	3.7	1.8	17.9	17.0
SD	11.6	4.7	15.0	14.3	3.9	0.4	1.7	1.4	2.3	0.0	2.1	2.2	5.5	26.2
Mean Inshore Cambodia	35.4	2.7	16.7	39.3	5.2	18.7	7.5	4.0	1.7	1.7	2.7	3.7	31.6	9.1
SD	10.7	2.3	9.4	18.0	4.9	17.0	1.2	1.0	0.2	0.8	0.5	2.0	31.5	4.3
Mean Inshore Vietnam	49.6	1.1	25.6	16.0	7.6	33.8	7.6	5.0	2.4	0.1		0.6		
SD	7.2	1.6	11.8	0.4	5.8									
Mean Inshore all	**39.5**	**2.9**	**17.1**	**35.6**	**4.5**	**9.3**	**5.9**	**4.7**	**1.9**	**0.3**	**3.6**	**1.9**	**20.1**	**15.8**
SD	11.4	3.6	12.5	16.2	4.4	13.1	2.0	1.3	2.0	0.6	1.9	2.1	12.7	24.2
Mean Offshore (Cambodia)	**17.2**	**4.4**	**0.8**	**68.4**	**9.0**	**25.9**	**9.4**	**7.3**	**1.6**	**1.4**	**25.7**	**7.6**	**57.5**	**23.0**
SD	14.5	4.1	1.6	11.9	9.8	15.3	1.4	3.7		0.6	27.2	6.8	64.4	11.3

b. Water quality

While dissolved oxygen (DO) levels were low and total suspended solids (TSS) high, the mean value for all other water quality parameters measured were below accepted upper-limit standards for enclosed offshore marine waters. However, variability was high for total dissolved solids (TDS) (except for Thai sites), nitrate, nitrite and ammonia (driven by the Thai data), phosphate, total suspended solids (driven by the Cambodian data), and total coliforms (driven by the Thai data) (Table 4.1). This suggests that some sites sampled are exceeding or approaching the minimum standard for marine water quality.

There was no strong correlation found between any water quality parameter and benthos characteristics. However, higher levels of dissolved oxygen were associated with higher per cent coverage of live coral (R^2=0.63). In addition, algal cover tended to decline with total dissolved solids and turbidity (R^2=0.32), and consistently increased with increasing levels of each nutrient, although the correlations were very weak. The data suggest that while some sites might be affected currently by nutrient levels in terms of coral cover, the resilient *Porites* spp. is largely unaffected.

Seventy-seven per cent of sites gave pH readings for surface water of less than 7.5, and 34 per cent had pH levels of less than 7. Given that the preferred pH level for corals is greater than 7.5, these figures create concern for the resilience of corals; particularly should other stressors be affecting the ecosystems.

4.1.2 Offshore reefs

a. Benthos characteristics

Offshore reefs sampled had much lower coral cover (17%) than the inshore reefs and much higher percentage cover of sand and rubble and rock (68%) (Table 4.1). Offshore reefs consist of corals settling on a rock base. *Acropora* spp., *Tubastrea* spp., large gorgonians, corallimorphs and Crown of Thorns were found specifically at these offshore locations. Offshore sites in Cambodia exhibited several thickets of large branching *Acropora* spp. recovering from storm damage. Significant storm damage on staghorn corals (Acropora spp.) was noted on the reefs by large areas of dead staghorn coral rubble. Corals found at offshore fringing reefs were largely settling on and around large rock platforms and boulders, and therefore not reef-building corals. The structure of coral reefs varied greatly between inshore and offshore reefs, including a notable absence of algae at offshore sites.

b. Water quality

As with the inshore water quality, all water quality parameters measured in offshore sites were at acceptable levels, although there was considerable variation between sites for ammonia, phosphates and total suspended solids (Table 4.1).

4.1.3 Key findings

Percentage live coral cover from our sampling is similar to findings of Vibol (2007) and van Bochove et al. 2011a and 2012) and the small increase in live coral cover between 2007 and 2011 may be persisting. We found no change in the corals dominating the benthos. However, our finding that algal cover was considerably higher (around 16%) than that recorded by van Bochove (generally much less than 10%, except for around Koh Sdach), may be cause for concern. The increase in algal cover suggests increased nutrients or loss of algal grazing species may be resulting in algal colonization of rock and rubble areas, and may ultimately reduce the space available for corals to recruit and grow. The lack of any clear correlation between nutrients and coral cover may be explained by the current resilience of the dominant inshore *Porities* spp. to both nutrients and sediments. However, *Porities* spp. is showing signs of stress, and perhaps reduced resilience, through high levels of bioerosion from burrowing bivalves and tubeworms. *Acropora* spp., which are more sensitive to lowered salinity, rising sea temperature and Crown of Thorn outbreaks are generally less abundant on all inshore reefs in the study area.

The consistent finding of pH values less than 7.5 suggests the coral reefs are already stressed from ocean acidification. Coupled with possible background chronic nutrient stress, although low level, and seasonal sedimentation and lowered salinity stress, the dominance of more resilient coral species at inshore sites and the absence of more sensitive species is understandable.

4.1.4 Potential responses

Coral reef systems in the enclosed waters of the Gulf of Thailand have developed in the context of seasonally low salinity and high sediment loads as a result of freshwater runoff and winds that generate currents re-suspending sediments. What is different for the coral reefs is the stress that additional nutrients and sediments bring from pollutants (nutrients, chemicals and sediments) entering the receiving marine waters as a result of human activity. Impacts from climate change may include more frequent and intense storm activities, further lowering salinity levels in the Gulf waters and increasing mechanical damage to the reefs. While this increasing background level of stress requires national and regional attention (regulation and enforcement), protection of local reef quality requires ensuring that point source pollution (e.g., release of wastewater from human development) is minimized. The dominant massive *Porities* corals are tolerant, but perhaps will be less so if coral reef communities shift to include a greater percentage cover of algae.

Like background water quality issues, the possibly declining pH level of the waters of the Gulf cannot be easily addressed at local or even national levels alone. Acidification may be attributable, in part, to increased atmospheric CO_2 levels, with fish-pond effluent and untreated sewage probably adding to the change. If coral reefs are important for local fisheries and tourism, again, local action must ensure there is no additional stress applied that might tip the already stressed coral reef system to collapse.

4.2 Coral reef fish in the east Gulf of Thailand

4.2.1 Variation between predators and grazer fish guilds

The numbers of large commercial or artisanal fish species were recorded from each site. The variation between sites was high. Fifteen predatory species (predominantly groupers, snappers and pelagic species) and nine grazing species (parrotfish and rabbitfish) were identified (Table 4.2).

Table 4.2 Large commercial or artisanal fish recorded from survey sites

Predators		**Grazers**	
Species	**Common name**	**Species**	**Common name**
Carangoides sp.	([1]Bar cheek) trevally	*Chlorurus sordidus*	Daisy parrotfish
Cephalapholis formosa	Bluelined hind (grouper)	*Scarus sp.*	Parrotfish
Cephalopholis boenak	Chocolate hind (grouper)	*Scarus ghobban*	Bluebarred parrotfish
Cromileptes altivelis	Humpback grouper	*Scarus rubroviolaceus*	Ember parrotfish
Epinephalus fasciatus	Blacktip grouper	*Siganus corallines*	Blue-spotted spinefoot
Epinephalus quoyanus	Longfin grouper	*Siganus guttatus*	Goldlined spinefoot
Epinephalus sp.	([1]Orange-spotted) grouper	*Siganus javus*	[1]Streaked spinefoot
Lutjanus luatjnus	Bigeye snapper	*Siganus lineatus*	Golden-lined spinefoot
Lutjanus russelli	Moses' snapper	*Siganus vulpinus*	Foxface rabbitfish
Lutjanus sp.	Snapper		
Lutjanus vitta	Brownstripe red snapper		
Plectorhinchus sp.	Sweetlip		
Plectropomis areolatus	Squaretail coralgrouper		
Rachycentron canadum	Cobia (black kingfish)		
Sphyraena sp.	([1]Pickhandle) barracuda		

[1] Species identified in the community surveys, Section 4.4.

For inshore reefs, the mean number of grazer species per site was higher than predatory species, and the opposite for offshore reefs, although there was high variability in fish abundance between sites (Table 4.3). Grazers outnumbered predators in inshore reef sites, except for Vietnamese sites, where the mean number of grazer fish species per site was low. This low number of grazer fish per site is what might be expected if the population was under intense fishing pressure. It might also simply reflect chance, given the low number of sample sites (2). Cambodian sites had the greatest abundance of both predator and grazer fish species per site, followed by Thai and Vietnamese sites (Table 4.3).

Table 4.3 Mean number of fish species per site

	Predators	Grazers
Mean Inshore Thai	17.1	33.4
SD	15.3	50.8
Mean Inshore Cambodia	31.7	35.5
SD	46.5	56.9
Mean Inshore Vietnam	19.0	0.5
SD	21.2	0.7
Mean Inshore all	**22.4**	**30.9**
SD	31.6	51.3
Mean Offshore (Cambodia)	**217.6**	**7.3**
SD	351.3	6.2

For inshore reefs, there was a weak relationship between live coral cover and the abundance of both predators and grazers (Figures 4.1 and 4.2). The absence of the expected strong correlation and the variability in the sites reflects what might be anticipated of a suite of coral reefs subject to intensive fish catch.

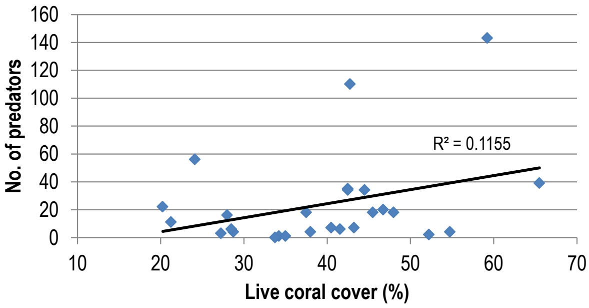


Figure 4.1 Per cent live coral cover vs predator abundance

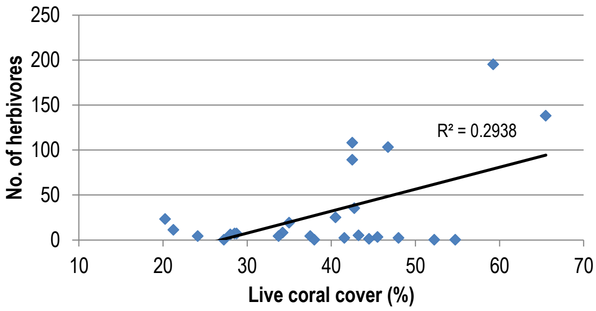


Figure 4.2 Per cent live coral cover vs grazers abundance

4.2.2 Variation in species

a. Predatory species

Barracuda, snapper and trevally and schooling and reef-associated pelagic species dominate predatory fish species recorded for inshore sites, rather than the reef-dependant cryptic carnivores such as grouper (*Epinephelus* spp., *Plectropomus* spp. and *Cephalopholis* spp.). Some of the data may reflect the cryptic behavior of grouper and underwater visual census technique that typically underestimates these species. Offshore reefs were characterized by large schools of barracuda and snapper, and relatively few cryptic carnivores (Table 4.3). This reflects the absence of reef habitat for reef-dependent species, with the substrate comprising mainly rock boulders, sand and rubble with some patches of *Acropora* spp. and other sub-massive and foliose coral species. Collectively, the data suggest overfishing may have resulted in the low numbers of reef-dependent predatory species. Inshore Cambodian sites had the greatest abundance of predatory species, followed by Thai and then Vietnamese sites (Table 4.3). This again suggests that the abundance data reflects intense fishing pressure at these inshore sites.

Table 4.3 Mean number of commercial predator fish species per site

	Sphyraena sp.	*Lutjanus vitta*	*Lutjanus lutjanus*	*Carangoides* sp.	*Lutjanus russelli*	*Cephalopholis boenak*	*Cephalopholis formosa*	*Epinephelus fasciatus*	*Plectorhinchus* sp.	*Epinephelus* sp.	*Epinephelus quoyanus*	*Plectropomus areolatus*	*Lutjanus* sp.	*Cromileptes altivelis*	*Rachycentron canadum*
Mean Inshore Thai	20	12	6	1	6	5	5	1	1	2	1	1	1	1	1
SD		21	8		4	5	5		1	1		1			
Mean Inshore Cambodia	4	19	65	24	10	5	3	1	2	1	2	2	2		
SD	5	16		34	8	4	3		1		1	1	1		
Mean Inshore Vietnam		30				4									
SD															
Mean Inshore all	**8**	**16**	**21**	**13**	**8**	**5**	**5**	**1**	**2**	**1**	**1**	**1**	**1**	**1**	**1**
SD	9	18	30	28	6	4	4		1	1		1	1		
Mean Offshore (Cambodia)	**501**	**185**	**4**			**2**	**1**	**4**	**1**	**1**		**1**	**2**		
SD	706	239				2							2		

b. Grazer species

Parrotfish and rabbitfish (spinefoots) were the only large commercial grazing fish species recorded for the sites, with very few present on offshore reefs, although species diversity was similar to inshore reefs (Table 4.4). Again, this may reflect the nature of the habitat, obvious lack of turf algae at offshore sites and resultant exposure to predation. In contrast with the predator data, Thai coral reefs tended to have greater abundance and diversity of grazer fish species than Cambodian reefs, while Vietnam was almost devoid of grazer species. This further suggests that the inshore coral reefs of the east Gulf of Thailand, in particular, may be more intensely fished and under a higher level of stress. That is, the continual human take of grazer species, plus predation by reef-associated pelagic carnivores combine to suppress grazer species abundance.

Table 4.4 Mean number of commercial grazer fish species per site

	Scarus sp.	*Scarus ghobban*	*Siganus guttatus*	*Siganus corallinus*	*Chlorurus sordidus*	*Siganus javus*	*Scarus rubroviolaceus*	*Siganus lineatus*	*Siganus vulpinus*
Mean Inshore Thai	35	34	14	6	2	4	1	1	1
SD	44	57	24	4	1	4			
Mean Inshore Cambodia	33	8	12	6	14	3		1	
SD	55	6	18	6	26	2		0	
Mean Inshore Vietnam						1			
SD									
Mean Inshore all	**35**	**15**	**13**	**6**	**6**	**3**	**1**	**1**	**1**
SD	46	30	19	5	15	3		0	
Mean Offshore (Cambodia)	**3**	**3**	**2**		**3**	**1**		**1**	**4**
SD	2	2	2		4	1			3

4.2.3 Key findings

The fish data suggest coral reefs under stress, probably from a combination of stressors affecting the health of coral, reducing diversity, and fishing pressure. Commercial fish species diversity and abundance is not high, except for a small number of reef-associated and reef-dependent carnivores, especially on offshore reefs. Fish abundance appears to be associated with live coral cover, but the weak correlation suggests other factors are masking the expected relationship.

The data suggest that the human take of predatory and grazer fish species is maintaining a system of low diversity and low fish abundance. This is reflected in the community responses to perceived change in catch (Section 4.3).

4.2.4 Potential responses

The status of coral reef fish populations in the east Gulf of Thailand is probably the result of multiple factors affecting the health and nature of the live coral benthos, predator prey relationships and the impact of artisanal and commercial fishing that appears to have targeted both predatory and grazer species. If the coral reefs and associated fish populations are to be supported to become resilient and continue to be of value to subsistence and tourism, then conservation measures are essential. The evidence suggests that while there are exceptions, most coral reef areas and fish populations may be at a tipping point where further change may cascade through the system to reduce production of ecosystem services for humanity.

Significant reduction in fish catch is essential, as previous research suggests (Stobuzki et al., 2006) for the ongoing protection of sustainable local artisanal fishing. Large scale commercial fishing operations need to be removed from inshore reefs. This will require unified increased regulatory efforts by all countries. Locally, in the context of already declining catch, bag-limits, seasonal closures, seem to be unrealistic and would bring serious hardship to artisanal fishing communities, especially in Cambodia. Initially, a network of small no-take areas may be a suitable trade-off to permit localized fish recovery and migration between reefs. However, these areas will likely have to be expanded with the long term goal of substituting high take of small sized, low value fish for low take of large size, high value fish. This will need to occur across the three nations and involve the development of community stewardship programs.

4.3 Community perceptions of fishery status

4.3.1 Thailand communities

Interviews were conducted in Salukpetch community, Koh Chang (seven interviews) and Koh Kood, two communities (ten interviews). While the interviewees in Koh Chang generally had spent more time in the area, their years of fishing was less than interviewees from Koh Kood (Table 4.#). The horsepower of boats used has possibly increased in both communities, and considerably in Koh Kood. This has been associated with an increase in the number of boats (Table 4.5).

Table 4.5 Thai interviewee summary statistics

	Koh Chang				Koh Kood			
	Years lived in area (n=7)	**Years fished in area** (n=7)	**Boat hp past** (n=1)	**Boat hp present** (n=1)	**Years lived in area** (n=10)	**Years fished in area** (n=10)	**Boat hp past** (n=3)	**Boat hp present** (n=9)
Mean	30	15	8	10	30	22	13	48
Median	41	12	8	10	30	20	16	26
Max	51	32	8	10	44	40	16	168
Min	2	2	8	10	20	4	6	8

a. Change in recent years

Land use changes reported included increased area of land under rubber plantations (30%), tourism development, especially homestays (25%), and additional shrimp ponds and improved roads and access to electricity. However, 25 percent of respondents identified no change.
Marine use changes identified included increased tourism activity (40%), trawler fishing by non-local

boats and the shift in crabbing practice from nets to traps. Forty percent of respondents identified no change.

Fishery changes reported were a decrease in catch (53%), and seasonal change in species caught, increased tourism use and changes in fishing gear used (18% combined).

b. Trends in fish catch

Ten species were reported as being caught (Table 4.6). The fisheries were largely based on crustaceans and squid, although some fishers supplemented their livelihoods with inshore and offshore fish catch, largely depending on the availability of suitable fishing vessels. All interviewees reported large declines in catch over the last 5-10 years (Table 4.6). For the principal fisheries, catch of blue swimmer crab was reported to be nearly six times less than 5-10 years ago and for bigfin reef squid, nearly four times less (Table 4.6). No interviewee reported a change in catch size.

Table 4.6 Species caught and decline in catch from Koh Chang and Koh Kood

Species	Per cent reported as catching (n=17)	Catch 5-10 years ago x catch today
Blue swimmer crab (*Portunus pelagicus*)	76	5.7
Bigfin reef squid (*Sepioteuthis lessoniana*)	41	3.6
Anchovy (Family Engraulidae)	12	3.3
Shrimp (*Penaeus merguentis*)	18	1.5
Grouper (Family Serranidae)	12	1.5
Mud crab (*Scylla* sp.)	18	
Squaretail mullet (*Ellochelon* sp.)	6	
Mantis shrimp (*Oratosquillina* sp.)(as by-catch)	6	
Pickhandle barracuda (*Sphyraena* sp.)	6	
Crucifix crab (*Charybdis* sp.)	6	

The decline in catch was attributed to overfishing (82%) through increased boat numbers and engine capacity (35%), number of crab traps set (24%), commercial fishing (12%), and the increasing practice of using lights to attract squid. Other contributing factors were pollution and resource use from population growth and poor conservation management (e.g., non-release of gravid female crabs). Two interviewees attributed the change to changes in season (e.g., climate change).

c. Perceived reef and water quality status

Most interviewees reported no change in reef quality (53%). However, coral bleaching (18%) and tourism impacts through anchor damage and reef walking (24%) were identified as affecting reefs.

The main change reported for marine waters was sea level rise (53%), commonly estimated at 10cm over the last 10 years, and mainly observable from October to January. Thirty per cent of interviewees identified declining water quality, which they attributed to pollution from population growth, siltation from land clearing and fish ponds ("when water is released, all fish die"). Twenty-four per cent of interviewees identified no change in the marine waters.

Most of the interviewees (59%) identified no change in stream water quality. Those that did, attributed sedimentation from land clearing as the cause of declining water quality (30%).

d. Explanatory comments of interviewees

The resource depletion cycle

Many interviewees identified the circular implications of the deteriorating fisheries. Decrease in catch is responded to with bigger and more powerful boats, greater catch effort and more effective catch methods, which all lead to further declines in catch per effort. The following quotes indicate the cycle:

The catch

> "*I used to catch 30-35kg/day five years ago, now I catch 5kg/day*" (5-10kg/day was commonly given for current catch levels).
>
> "*Five years ago, I caught 30-40kg on 1000 traps, now I catch 7kg with 900 traps*".
>
> "*Years ago, I caught more than 100kg of squid a day, now I catch 5-6kg*".

Fisher response

> "*I have changed my motor from 16hp to 40hp*".
>
> "*I used to trap three nights a week. Now I trap four nights, and fish for squid or mullet on at least one or two other nights*".
>
> "*I know I am contributing to overfishing, but I need to feed my family*".
>
> "*I reduced the number of traps from 1500 to 900 because of trawler damage. Now I have to fish more nights inshore*".
>
> "*Unlike others, I use small motors to save on fuel. I remember when diesel was THB3bht, now it is THB45bht. It is not about how much you catch, but what you make*".

Bigger and better

> "*With a 16hp boat, I was catching 30kg of squid a day. With my 168hp boat, I catch 70-80kg per day with 30 traps. But I fish four nautical miles off the coast*".
>
> "*I get THB180 per kg for big crabs and only THB100 per kg for small sizes*".

Marketing alternatives

> "*I catch less, but if I sell to tourists I can charge 70% more for my crabs*".
>
> "*I now sell to a middle-man who on-sells to the tourism sector. They add 10-20% … I make slightly less, but the costs of selling are less.* ".

Transition with tourism and retail

> "*I am happy with my homestay business. From eight people per month, I now have 200 coming at THB600 per person. This supplements my fishing income*".
>
> "*My shop is better. I get 70% of my income from the shop, 30% from fishing … 80% of the shop income is from locals, 20% from tourists*".

4.3.2 Cambodian community

Interviews were conducted in Salukpetch community, Koh Sdach, Koh Kong Province (twenty interviews). Unlike the Thai communities interviewed, which were largely based on crab and squid fishing, the Koh Sdach community focused on fish species. While there has been a considerable increase in the horsepower of boats, there appears to be no increase in the number of boats used (Table 4.7). The comparatively low number of years living and fishing in the area possibly relate to youthfulness of the Cambodian population and the effect of the Khmer Rouge era (1975-79), when communities were displaced.

Table 4.7 Cambodian interviewee summary statistics

	Years lived in area (n=20)	Years fished in area (n=20)	Boat hp past (n=19)	Boat hp present (n=18)
Mean	19	21	14	28
Median	20	23	6	17
Max	20	30	75	130
Min	16	6	5	7

a. Change in recent years

Land use change reported by all interviewees was increased settlement and housing for fishing families as the village population grows. Some (20%) identified land clearing for agriculture as a recent land use change.
Marine use changes identified were associated with the growing fisher population (90%), although many (25%) highlighted that some community members had emigrated to Thailand for work, while others had sold their fishing business to work for others. There was a view that the fisher population was actually decreasing as community members also took up jobs away from the village. There was concern expressed for natural resource depletion and, ironically, the increase in numbers of researchers interviewing fishers and undertaking coral reef studies (30%).
Fishery changes reported were a decline in fish yield (95%) (e.g., one of the few squid fishers reported a decline in catch from 20-30kg/day to 4-5kg/day), and smaller fish being caught (80%), increasing rarity of some species being caught (40%). Without prompting, one interviewee estimated that catch was now half of what it was 4-5 years ago. Another suggested that catch each year is decreasing by 20 percent and fishers have to travel further.

b. Trends in fish catch

Thirteen species were reported as being caught (Table 4.8). All interviewees reported at least a halving of catch when compared with 5-10 years ago. The largest declines were reported for bigfin reef squid, mud crab, island mackerel, and yellow tail scad. All interviewees reported a decrease in the size of fish caught, irrespective of species, but no change for crabs and squid.

Table 4.8 Species caught and decline in catch from Koh Sdach

Species	**Per cent reported as catching** (n=20)	**Catch 5-10 years ago x catch today**
Mud crab (*Scylla* sp.)	10	2.5
Bigfin reef squid (*Sepioteuthis lessoniana*)	15	2.7
Island mackerel (*Rastrelliger* sp.)	15	2.5
Yellow tail scad (*Atule* sp.)	75	2.4
Pickhandle barracuda (*Sphyraena* sp.)	25	2.2
Bar cheek trevally (*Carangoides* sp.)	80	2.1
Red mouth grouper (*Aethaloperca* sp.)	55	2.0
Scaley whipray (*Himantura* sp.)	35	2.0
Squaretail mullet (*Ellochelon* sp.)	10	2.0
Agujon needlefish (*Tylosurus* sp.)	10	
Streaked spinefoot (*Siganus* sp.)	10	
Orange-spotted grouper (*Epinephelus* sp.)	5	
Slender scad (*Decapterus* sp.)	5	

All interviewees attributed the decline in catch to an expanding number of local and outsider fishers (Thai and Vietnamese). This included recognition of illegal fishing generally, including poison use, methods using light attractants, and bombing. Large scale Vietnamese and Thai fishing boats were commonly identified as being illegal (60%). Only a small percentage (10%) raised concern for habitat loss and destruction.

c. Perceived reef and water quality status

Twenty per cent of interviewees identified no change in reef quality. The balance identified destruction of reefs through use of explosives for fishing (70%), the use of poisons (65%) and impacts from the warming of sea temperatures (55%).

Only 10 per cent of interviewees thought that marine water quality had not changed. The balance reported the water as getting dirtier (85%), and causing itches and becoming smelly (75%): "*some* *years dirty, some years clean*". They attributed this deterioration to increased levels of liquid and solid waste entering the system (60%). Sixty percent reported they had become aware of the frequency of 'irregular' high tides.

No interviewee identified changes in stream water quality.

d. Perceived needed action

There was a high degree of similarity both in responses to specific questions and ideas on how to address concern for declining fish catch. This suggests that the Koh Sdach community is well aware of issues and have discussed them at the community level. Most identified the need to establish a fishery committee to self-regulate their own fishing behaviors (85%). They believed that those outside their community should not be allowed to fish commercially alongside community members (95%) and that large fishing vessels should not be allowed to fish within the area used by the community (90%). To achieve the latter, they acknowledged the need for a higher authority to regulate outsider use by Cambodians and the illegal use of Thai and Vietnamese fishers.

4.3.3 Key findings

Community members, especially fishers, are well aware of and concerned by declining catch in all targeted species and therefore their livelihoods. Their local (ecological) knowledge of deteriorating fisheries in the east Gulf of Thailand reflects Vo et al. (2013) ranking of threats (Section 2.8) for Cambodia and concern of others who have undertaken studies of reef status (Sections 2.3.5 and 2.3.9). However, Thai community insights, with those of their Cambodian counterparts, to trends in marine species catch, at least for crabs and squid, suggest that Vo et al.'s (2013) assessment of the degree of threat overfishing plays in reef sustainability is possibly under-estimated.

While the threat of overfishing to sustainable fisheries and livelihoods is clear to communities, there appears to be limited understanding of marine ecosystem dynamics and the link between healthy fisheries, clean marine waters, and the ecological integrity and maintenance of mangroves, seagrass meadows and coral reef systems. The result is that declining fish catch is perceived as a local problem, which of course it is if your livelihood depends on artisanal fishing; but acting locally is likely to be insufficient to address overfishing and marine system quality decline that extends beyond local boundaries and national borders.

From the Cambodian interviews, there appears to be a willingness to address their own unsustainable fishing practices, but there emerged a sense of helplessness to address the unsustainable practices of outsiders, especially large fishing vessels crossing borders. Given that their fishing is largely for subsistence, the community is most vulnerable to staying in a state of poverty. External intervention and financial support seems to be inevitable.

In contrast, Cambodia's fishing peers in Thailand appear to have the economic and human capital to adapt to declining fish catch. Entrepreneurial skill and capacity seems higher and individuals are acting to transition to reduce exposure to decline in fisheries through diversifying their sources of income. Tourism is providing the opportunity to buffer the impact of deteriorating fisheries.

4.3.4 Potential responses

Fishing communities have sound knowledge of the status of fisheries they exploit. They have detailed empirical knowledge of trends in fish populations, which may be more accurate at the local scale than data collected by government; but their knowledge lacks ecological context. Within their capacity, local fishers respond to threats to their livelihoods to maintain their well-being, but the actions, driven by self-interest, may exacerbate the threat in the long term and have negative implications to others in a community and beyond.

The capacity of communities in the east Gulf of Thailand to address fishery sustainability by their actions alone does not exist. Neither does it exist in any one provincial or national government. The achievement of sustainable fisheries in the east Gulf of Thailand requires consistent and enforced fisheries policies across Thailand, Cambodia and Vietnam, that is endorsed and supported by all lower levels of governance. It requires a coordinated top-down trans-border—bottom-up approach, with fishing communities empowered to adapt the fishing and marketing practices and given opportunities to diversify their economies. Given the Thai experience, tourism may well be a partner in achieving sustainable fisheries and for transitioning communities to sustainable livelihoods, especially for the poor.

Part five: **Conclusions**

5.1 The status of coral reef communities in the east Gulf of Thailand

a. Benthos

The fringing coral reefs along the coast of the east Gulf of Thailand are dominated by massive corals tolerant to many anthropogenic and background stressors that can challenge the resilience of coral ecosystems. The result is inshore coral communities dominated by *Porites* spp. with 'good' benthos cover, but low biodiversity. This is probably the result of a background of seasonally turbid waters and reduced salinity as flood waters enter the enclosed waters of the Gulf.

Placing additional stress on these reefs is acidification of the waters, possibly increasing water temperature and probable seasonal increases in anthropogenic derived pollutants. The relative dominance paradigm suggests that the bottom-up effect of additional nutrients has shifted the balance of corals (and may continue to do so at an increasing rate) from less resistant (and resilient) branching corals to massive corals with greater cover of algae. Community ecology indicates that the removal of herbivorous species directly through catch and take of carnivorous species reduces the pressure on algae as well as bio-eroding species such as echinoderms. A prognosis is for many of the coral reefs to become algal dominated systems and ultimately a phase shift towards a system where corals are a small part of the benthos cover. Without connectivity to areas that can 're-seed' the communities, return to a coral state is likely to be, at best, delayed.

b. Fish

Partly reflecting the low biodiversity (and structural diversity) of the coral reefs of the east Gulf of Thailand is fish diversity and abundance. However, overfishing appears to be significantly removing both predators and prey; reducing the grazing pressure on algae and bio-eroding species. Again, the diversity and abundance of reef fish, except for reef associated pelagic carnivores, is low. Community ecology principles suggest that this situation supplements fishery take to reinforce suppression of biodiversity and a shift to all but the more resilient and ubiquitous fish species.

5.2 The status of marine waters in the east Gulf of Thailand

The marine waters of the Gulf of Thailand are naturally seasonally turbid with periods of low salinity. While clear, nutrient poor marine waters with a pH more than 7.5 would foster the growth of corals, this is not the case in the east Gulf. However, generally, water quality remains within acceptable limits for coral growth, at least during the dry season. Without further human influence, the prognosis for the future of the coral reefs is uncertain because of the impact of climate change (increased sea water temperatures and acidification leading to coral bleaching). With the added effects of increased nutrients through inflows from mainland rivers and point sources (e.g., from untreated sewage from population growth and tourist development), it is probable that local increases in nutrient levels will have significant impacts on coral communities, with probable phase shifts to algal dominated systems.

5.3 Community perception of coral reef and fishery status

It appears that local fishing communities are well aware of declining fish populations and are currently suffering the consequences of unsustainable fish take. However, their knowledge of reef systems and the interdependency of coral reefs, mangroves, marine grass communities and fishery health is limited. They are also aware of the impact of large fishing boats and they possibly rightly propose that curtailing their fishing practices will make minimal difference to the sustainability of fisheries without addressing large scale poaching and the excesses of large fishing boats. Without interventions, the prognosis for local fishing communities is on-going poverty, decline in fishing as a livelihood option, and on-going migration away from existing communities. However, provided the quality of marine resources can be maintained and improved, there is opportunity of some members of the community to transition to a tourism economy that may advantage the whole community. Capacity building seems essential to improve understanding of coral reef ecological dynamics, alternative livelihoods to fishing, stewardship approaches to management of fisheries. However, the goals for such capacity build will not be realized without higher level government interventions.

5.5 Strategic action

Addressing the status of coral reefs in the east Gulf of Thailand is a wicked problem for management that has gone unaddressed for many years. Reversing trends will require multiple actors from community level to national initiatives that include transnational cooperation and coordination and probably with the support of international aid agencies. Many required actions are known. Here we concentrate on new initiatives and reinforce known needs that have failed to be addressed.

1. **Relax the degrading pressures on coral reefs** through: (a) enforcing existing fisheries regulations; (b) require major tourism developments to install tertiary treatment of waste water; (c) ensure vegetated buffers to waterways to trap sediment on islands and the mainland; (d) maintain the ecological integrity mangroves and seagrass meadows; (e) progressively install sewage treatment plants to service all coastal communities; and (f) install gross pollutant traps to prevent solid waste entering the marine system.
2. **Encourage coral reef natural resilience** through: (a) maintaining connectivity between coral reefs, healthy mangroves and seagrass meadows; (b) reduce fishery take; (c) reduce water pollution; and (d) ceasing destructive fishing activities such as blast fishing.
3. **Provide stock to ensure capacity for reef recovery** through: (a) implementation of a broader suite of fisheries management measures (e.g., minimum size limits and short term fishery closures); (b) designation of no-take zones (e.g., marine protected areas).
4. **Foster alternative livelihoods** that are not resource exploitive or environmentally polluting (e.g., poorly managed aquaculture) through: (a) providing community capacity building and seed funding to support supplementary income generation; and (b) demonstrating alternative sustainable livelihood options.
5. **Develop sustainable, feasible and enforceable regulations** that include traditional fishers in the policy making process.
6. **Establish collaborative governance** for marine resources across the east Gulf of Thailand, including: (a) development of an integrated marine area plan that uses a zoning approach akin to that prepared for the Great Barrier Reef Marine Park Area; (b) consideration of extending the Kien Giang Man and the Biosphere Reserve to include marine waters off the coast of Cambodia and Trat, Thailand; and (c) engagement of local fishery communities and others in a stewardship approach to marine resource management.
7. **Monitor success** through the collection of fishery-dependent data on targeted fish species, including the use of community and local knowledge.

References

Adger, W. N., P. M. Kelly, and N. H. Ninh 2001. Living with environmental change: social vulnerability, adaptation and resilience in Vietnam. Routledge.

Ahmed, M., P. Boonchuwongse, W. Dechboon, and D. Squires. 2007. Overfishing in the Gulf of Thailand: Policy challenges and bioeconomic analysis. Environment and Development Economics **12**:145-172.

Almany, G. R., R. J. Hamilton, M. Bode, M. Matawai, T. Potuku, P. Saenz-Agudelo, S. Planes, M. L. Berumen, K. L. Rhodes, and S. R. Thorrold. 2013. Dispersal of grouper larvae drives local resource sharing in a coral reef fishery. Current Biology.

Aschariyaphotha, N., and S. Wongwises. 2012. Simulations of Seasonal Current Circulations and Its Variabilities Forced by Runoff from Freshwater in the Gulf of Thailand. Arabian Journal for Science and Engineering **37**:1389-1404.

Aschariyaphotha, N., P. Wongwises, S. Wongwises, and U. W. Humphries. 2007. Simulation of current circulations in the gulf of Thailand. Pages 61-66, Beijing.

Aschariyaphotha, N., P. Wongwises, S. Wongwises, U. W. Humphries, and X. You. 2008. Simulation of seasonal circulations and thermohaline variabilities in the Gulf of Thailand. Advances in Atmospheric Sciences **25**:489-506.

Aswani, S., and A. Sabetian. 2010. Implications of Urbanization for Artisanal Parrotfish Fisheries in the Western Solomon Islands. Conservation Biology **24**:520-530.

Baird, A. H., J. R. Guest, and B. L. Willis. 2009. Systematic and biogeographical patterns in the reproductive biology of scleractinian corals. Annual Review of Ecology, Evolution, and Systematics **40**:551-571.

Baird, I. 1999. Towards sustainable co-management of the Mekong River inland aquatic resources, including fisheries. Proceedings of the International Workshop on fisheries co-management, Penang, Malaysia.

Ban, N. C., G. J. A. Hansen, M. Jones, and A. C. J. Vincent. 2009. Systematic marine conservation planning in data-poor regions: Socioeconomic data is essential. Marine Policy **33**:794-800.

Barbier, E. B. 2003. Habitat-fishery linkages and mangrove loss in Thailand. Contemporary Economic Policy **21**:59-77.

Beasley, I. L., and P. J. A. Davidson. 2007. Conservation Status of Marine Mammals in Cambodian Waters, Including Seven New Cetacean Records of Occurrence. Aquatic Mammals **33**:368-370,372-379.

Bellwood, D. R., and T. P. Hughes. 2001. Regional-scale assembly rules and biodiversity of coral reefs. Science **292**:1532-1535.

Bellwood, D. R., T. P. Hughes, C. Folke, and M. Nyström. 2004. Confronting the coral reef crisis. Nature **429**:827-833.

Bellwood, D., T. Hughes, S. Connolly, and J. Tanner. 2005. Environmental and geometric constraints on Indo-Pacific coral reef biodiversity. Ecology Letters **8**:643-651.

Blaber, S. J. M. 2011. 8.09 - Removals (Wild Harvesting) of the Biological Resources from Systems. Pages 253-275 in E. Wolanski, and D. McLusky, editors. Treatise on Estuarine and Coastal Science. Academic Press, Waltham.

Boonyapiwat, S. 1999. Distribution, abundance and species composition of phytoplankton in the South China Sea Area I: Gulf of Thailand and East Coast of Peninsular Malaysia. SEAFDEC. Proceedings of the First Technical Seminar on Marine Fishery Resources Survey in the South China Sea Area I: Gulf of Thailand and East Coast of Peninsular Malaysia:111-134.

Boonyatumanond, R., A. Jaksakul, P. Puncharoen, and M. S. Tabucanon. 2002. Monitoring of organochlorine pesticides residues in green mussels (Perna viridis) from the coastal area of Thailand. Environmental Pollution **119**:245-252.

Booth, D. J., and G. A. Beretta. 2002. Changes in a fish assemblage after a coral bleaching event. Marine Ecology-Progress Series **245**:205-212.

Brown, C., E. Corcoran, P. Herkenrath, and J. Thonell 2006. Marine and coastal ecosystems and human well-being: a synthesis report based on the findings of the Millennium Ecosystem Assessment.

Brown, E. K., E. Cox, P. Jokiel, S. K. u. Rodgers, W. R. Smith, B. N. Tissot, S. L. Coles, and J. Hultquist. 2004. Development of benthic sampling methods for the Coral Reef Assessment and Monitoring Program (CRAMP) in Hawai'i. Pacific Science **58**:145-158.

Bruno, J. F., and E. R. Selig. 2007. Regional decline of coral cover in the Indo-Pacific: timing, extent, and subregional comparisons. PLoS one **2**:e711.

Bruno, J. F., H. Sweatman, W. F. Precht, E. R. Selig, and V. G. W. Schutte. 2009. Assessing Evidence of Phase Shifts from Coral to Macroalgal Dominance on Coral Reefs. Ecology **90**:1478-1484.

Carter, R. W. 2012. Guidelines for integrated planning for conservation and development of Dong Ho lagoon Viet Nam. Australian AID-GIZ Conservation and Development of the Kien Giang Biosphere Reserve Project. GIZ, Rach Gia, Viet Nam.

Carter, R. W., and D. M. Nguyen. 2012. Realising the tourism potential of Kien Gieng Province and strategic actions for Dong Ho lagoon Viet Nam. GIZ-Australian AID Conservation and Development of the Kien Giang Biosp'here REserve Project, GIZ Rach Gia, Viet Nam.

Carter, R. W., K. Kelly, N. Tindale, H. Beazley, S. Worachananant, and P. Worachananant. 2013a. Water and Coral Reef Quality in the east Gulf of Thailand. APN Science Bulletin:101-103.

Carter, R. W., V. O'Rourke, T. Livingstone, T. McKenzie, M. Lyell, J. Brown, P. Marsden, J. Gray, F. McMackin, J. Knight, K. Kelly, and A. Roiko. 2013b. Strategic Guidelines for sustainable tourism on the Khmer Coast - Report to the Ministry of Tourism, Royal Government of Cambodia. Page 84. University of the Sunshine Coast, Sippy Downs, Qld Aus, University of the Sunshine Coast, Sippy Downs, Qld Aus.

Cheevaporn, V., and P. Menasveta. 2003a. Water pollution and habitat degradation in the Gulf of Thailand. Marine Pollution Bulletin **47**:43-51.

Chong-Seng, K. M., T. D. Mannering, M. S. Pratchett, D. R. Bellwood, and N. A. J. Graham. 2012. The influence of coral reef benthic condition on associated fish assemblages. PLoS ONE **7**.

Cinner, J. E., T. R. McClanahan, T. M. Daw, N. A. J. Graham, J. Maina, S. K. Wilson, and T. P. Hughes. 2009. Linking Social and Ecological Systems to Sustain Coral Reef Fisheries. Current Biology **19**:206-212.

Coles, R., I. Poiner, and H. Kirkman. 1989. Regional studies–seagrasses of northeastern Australia. Biology of Australian Seagrasses-an Australian perspective:261-278.

Connolly, S. R., and A. H. Baird. 2010. Estimating dispersal potential for marine larvae: dynamic models applied to scleractinian corals. Ecology **91**:3572-3583.

Dao, M. S., and T. Pham. 2011. Management of coastal fisheries in Vietnam. The WorldFish Center Working Papers.

Dara, A., K. Kimsreng, H. Piseth, and R. Mather. 2009. An Integrated Assessment for Preliminary Zoning of Peam Krasop Wildlife Sanctuary, Zoning of Peam Krasop Wildlife Sanctuary, Southwestern Cambodia.

Dayton, P. K., S. F. Thrush, M. T. Agardy, and R. J. Hofman. 1995. Environmental effects of marine fishing. Aquatic conservation: marine and freshwater ecosystems **5**:205-232.

Dorenbosch, M., M. Van Riel, I. Nagelkerken, and G. Van der Velde. 2004. The relationship of reef fish densities to the proximity of mangrove and seagrass nurseries. Estuarine, Coastal and Shelf Science **60**:37-48.

Doshi, A., S. Pascoe, O. Thébaud, C. R. Thomas, N. Setiasih, J. T. C. Hong, J. True, H. Z. Schuttenberg, and S. F. Heron. 2012. Loss of economic value from coral bleaching in SE Asia.

Dudgeon, S. R., R. B. Aronson, J. F. Bruno, and W. F. Precht. 2010. Phase shifts and stable states on coral reefs. Marine Ecology Progress Series **413**:201-216.

Dumas, P., A. Bertaud, C. Peignon, M. Léopold, and D. Pelletier. 2009. A “quick and clean” photographic method for the description of coral reef habitats. Journal of Experimental Marine Biology and Ecology **368**:161-168.

Dung, P. H. 2006. Status of leatherback turtles in Viet Nam. Assessment of the conservation status of the leatherback turtle in the Indian Ocean and South East Asia:156.

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

Fabricius, K. E. 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. Marine Pollution Bulletin **50**:125-146.

Fabricius, K. E., and G. De'Ath. 2004. Identifying Ecologcal Change and Its Causes: A Case Study on Coral Reef's. Ecological Applications **14**:1448-1465.

FAO. 2011. National Fishery Sector Overview - Cambodia March 2011. Food and Agriculture Organization of the United Nations.

Feary, D. A., G. R. Almany, G. P. Jones, and M. I. McCormick. 2007. Coral degradation and the structure of tropical reef fish communities. Marine Ecology-Progress Series **333**:243-248.

Feary, D. A., G. R. Almany, M. I. McCormick, and G. P. Jones. 2007b. Habitat choice, recruitment and the response of coral reef fishes to coral degradation. Oecologia **153**:727-737.

Feary, D. A., M. I. McCormick, and G. P. Jones. 2009. Growth of reef fishes in response to live coral cover. Journal of Experimental Marine Biology and Ecology **373**:45-49.

Fisheries Administration, Ministry of Agriculture, Forestry and Fisheries.

Fisheries, F. 2009. The State of World Fisheries and Aquaculture: 2008.

Flaherty, M., and C. Karnjanakesorn. 1993. Commercial and subsistence fisheries conflicts in the Gulf of Thailand: the case of squid trap fishers. Applied Geography **13**:243-258.

Foale, S., D. Adhuri, P. Aliño, E. H. Allison, N. Andrew, P. Cohen, L. Evans, M. Fabinyi, P. Fidelman, C. Gregory, N. Stacey, J. Tanzer, and N. Weeratunge. 2013. Food security and the Coral Triangle Initiative. Marine Policy **38**:174-183.

Gluckman, R. 2009. Saving the seahorses. Far Eastern Economic Review **172**:77.

Graham, E., A. Baird, and S. Connolly. 2008. Survival dynamics of scleractinian coral larvae and implications for dispersal. Coral Reefs **27**:529-539.

Graham, N. A. J., and K. L. Nash. 2013. The importance of structural complexity in coral reef ecosystems. Coral Reefs **32**:315-326.

Graham, N. A. J., P. Chabanet, R. D. Evans, S. Jennings, Y. Letourneur, M. A. MacNeil, T. R. McClanahan, M. C. Ohman, N. V. C. Polunin, and S. K. Wilson. 2011. Extinction vulnerability of coral reef fishes. Ecology Letters **14**:341-348.

Graham, N. A. J., S. K. Wilson, S. Jennings, N. V. C. Polunin, J. P. Bijoux, and J. Robinson. 2006. Dynamic fragility of oceanic coral reef ecosystems. Proceedings of the National Academy of Sciences **103**:8425-8429.

Hábitats de Arrecifes de Coral como Sustitutos de Especies, Funciones Ecológicas y Servicios de Ecosistemas. Conservation Biology **22**:941-951.

Hallacher, L. E. 2003. The Ecology of Coral Reef Fishes. Manuscrito). Universidad de Hawaii en Hilo.(Modificado para Quest).

Halliday, I., and J. Robins 2007. Environmental flows for sub-tropical estuaries: understanding the freshwater needs of estuaries for sustainable fisheries production and assessing the impact of water regulation. Departmentof Primary Industries and Fisheries.

Hill, J., and C. Wilkinson. 2004. Methods for ecological monitoring of coral reefs. Australian Institute of Marine Science, Townsville:117.

Hines, E., K. Adulyanukosol, P. Somany, L. S. Ath, N. Cox, P. Boonyanate, and N. X. Hoa. 2008. Conservation needs of the dugong Dugong dugon in Cambodia and Phu Quoc Island, Vietnam. Oryx **42**:113.

Hixon, M. A., and J. P. Beets. 1993. Predation, prey refuges, and the structure of coral-reef assemblages. Ecolo. Monogr. **63**:77-101.

Hodgson, G., J. Hill, W. Kiene, L. Maun, J. Mihaly, J. Liebeler, C. Shuman, and R. Torres. 2006. Reef Check Instruction Manual: A Guide to Reef Check Coral reef Monitoring. Reef Check Foundation, California.

Hoegh-Guldberg, O., P. J. Mumby, A. J. Hooten, R. S. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. F. Sale, A. J. Edwards, K. Caldeira, N. Knowlton, C. M. Eakin, R. Iglesias-Prieto, N. Muthiga, R. H. Bradbury, A. Dubi, and M. E. Hatziolos. 2007. Coral Reefs Under Rapid Climate Change and Ocean Acidification. Science **318**:1737-1742.

Hoeksema, B. W., C. Scott, and J. D. True. 2013. Dietary shift in corallivorous Drupella snails following a major bleaching event at Koh Tao, Gulf of Thailand. Coral Reefs **32**:423-428.

Hughes, T. P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science-AAAS-Weekly Paper Edition **265**:1547-1551.

Hughes, T. P., A. H. Baird, D. R. Bellwood, M. Card, S. R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J. B. C. Jackson, J. Kleypas, J. M. Lough, P. Marshall, M. Nyström, S. R. Palumbi, J. M. Pandolfi, B. Rosen, and J. Roughgarden. 2003. Climate Change, Human Impacts, and the Resilience of Coral Reefs. Science **301**:929-933.

Hughes, T. P., D. R. Bellwood, C. S. Folke, L. J. McCook, and J. M. Pandolfi. 2007a. No-take areas, herbivory and coral reef resilience. Trends in Ecology & Evolution **22**:1-3.

Hughes, T. P., M. J. Rodrigues, D. R. Bellwood, D. Ceccarelli, O. Hoegh-Guldberg, L. McCook, N. Moltschaniwskyj, M. S. Pratchett, R. S. Steneck, and B. Willis. 2007b. Phase Shifts, Herbivory, and the Resilience of Coral Reefs to Climate Change. Current Biology **17**:360-365.

Hughes, T. P., N. A. J. Graham, J. B. C. Jackson, P. J. Mumby, and R. S. Steneck. 2010. Rising to the challenge of sustaining coral reef resilience. Trends in Ecology & Evolution **25**:633-642.

Ibrahim, H. M. 1999. Overfishing in the Gulf of Thailand: Issues and resolution. SEAPOL Integrated Studies of the Gulf of Thailand **2**:55-93.

ISRS. 2004. Sustainable fisheries management in coral reef ecosystems. Page 14. Briefing Paper.

Jones, E., T. Gray, and C. Umponstira. 2009. The impact of artisanal fishing on coral reef fish health in Hat Thai Mueang, Phang-nga Province, Southern Thailand. Marine Policy **33**:544-552.

Jones, G. P., M. I. McCormick, M. Srinivasan, and J. V. Eagle. 2004. Coral decline threatens fish biodiversity in marine reserves. Proceedings of the National Academy of Sciences of the United States of America **101**:8251-8253.

Jones, G., G. Almany, G. Russ, P. Sale, R. Steneck, M. Van Oppen, and B. Willis. 2009. Larval retention and connectivity among populations of corals and reef fishes: history, advances and challenges. Coral Reefs **28**:307-325.

Kelly, K. 1994. The effects of behaviour and habitat on the populatiopn structure of a coral reef damselfish. Marine Biolgy. James Cook University, Townsville.

Kohler, K. E., and S. M. Gill. 2006. Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. . Computers and Geosciences **32**:1259-1269.

Kongjandtre, N., T. Ridgway, S. Ward, and O. Hoegh-Guldberg. 2010. Broadcast spawning patterns of Favia species on the inshore reefs of Thailand. Coral Reefs **29**:227-234.

Latypov, Y. Y. 2003. Reef-building corals and reefs of Vietnam: 1. The Gulf of Thailand. Russian Journal of Marine Biology **29**:S22-S33.

Latypov, Y. Y., and N. I. Selin. 2011. Current status of coral reefs of islands in the Gulf of Siam and Southern Vietnam. Russian Journal of Marine Biology **37**:255-262.

Leujak, W., and R. F. G. Ormond. 2007. Comparative accuracy and efficiency of six coral community survey methods. Journal of Experimental Marine Biology and Ecology **351**:168-187.

Littler, M. M., D. S. Littler, and B. L. Brooks. 2006. Harmful algae on tropical coral reefs: bottom-up eutrophication and top-down herbivory. Harmful algae **5**:565-585.

Littler, M., and D. LITTLES. 1985. factors controlling relative dominance of primary producers on biotic reefs facteurs qui controlent la dominance relative des producteurs primaires dans les recifs coralliens. Page 35. Proceedings of the Fifth International Coral Reef Congress: Symposia and seminars. Antenne Museum-EPHE.

Longhurst, A. R., and D. Pauly 1987b. Ecology of tropical oceans. Academic Press San Diego.

Luckhurst, B., and K. Luckhurst. 1978. Diurnal space utilization in coral reef fish communities. Marine Biology **49**:325-332.

Lunn, K. E., and P. Dearden. 2006. Monitoring small-scale marine fisheries: An example from Thailand's Ko Chang archipelago. Fisheries Research **77**:60-71.

Macusi, E. D., R. E. Katikiro, K. H. M. Ashoka Deepananda, L. A. Jimenez, C. A.R., and N. Fadli. 2011. Human induced degradation of coastal resources in Asia Pacific and implications on management and food security. . Journal of Nature Studies **9/10**.

MAFF. 2006. Summary MAFF Annual Report 2005-2006 in F. a. F. Ministry of Agriculture, editor. Kingdom of Cambodia, Phnom Penh, Cambodia.

MAFF. 2012. Fisheries REport 2011 and Direction Setting 2012 in F. Administration, editor. Ministry of Agriculture, Forestry and Fisheries, Cambodia.

Mam, K. 2002. Coral reef and seagrass in Cambodia. The Society of Wetland Scientists Bulletin **19**:18-21.

Mangel, M. 2000. On the fraction of habitat allocated to marine reserves. Ecology Letters **3**:15-22.

Mangel, M., and P. S. Levin. 2005. Regime, phase and paradigm shifts: making community ecology the basic science for fisheries. Philosophical Transactions of the Royal Society B: Biological Sciences **360**:95-105.

Mapstone, B. D., C. Davies, L. Little, A. Punt, A. Smith, F. Pantus, D. Lou, A. Williams, A. Jones, and A. Ayling 2004. The effects of line fishing on the Great Barrier Reef and evaluations of alternative potential management strategies. CRC Reef Research Centre Townsville.

Marschke, M., and A. J. Sinclair. 2009. Learning for sustainability: Participatory resource management in Cambodian fishing villages. Journal of Environmental Management **90**:206-216.

MCC. 2011. Seahorse Population Assessment: June-July 2011. Marine Conservation Cambodia.

McCook, L. J., T. Ayling, M. Cappo, J. H. Choat, R. D. Evans, D. M. De Freitas, M. Heupel, T. P. Hughes, G. P. Jones, and B. Mapstone. 2010. Adaptive management of the Great Barrier Reef: A globally significant demonstration of the benefits of networks of marine reserves. Proceedings of the National Academy of Sciences **107**:18278-18285.

McKenzie, L. J., and J. E. Mellors. 2007. Seagrass-Watch: Guidelines for Monitoring Seagrass Habitats in the Burdekin Dry Tropics Region. Proceedings of a Training Workshop. in N. F. Centre, editor. Seagrass-Watch HQ, Cairns.

MEA 2005. Millenium Ecosystem Assessment: Ecosystems and human well-being. Island Press Washington, DC.

Moberg, F., and C. Folke. 1999. Ecological goods and services of coral reef ecosystems. Ecological economics **29**:215-233.

Monyneath, V. undated. The Status of Cambodia's Coastal and Marine Environment: "Emerging Policies and Management Strategies". International Symposium on Protection and Management of Coastal Marine Ecosystem. Ministry of Environment and Danaida.

Mumby, P. J. 2006. Connectivity of reef fish between mangroves and coral reefs: algorithms for the design of marine reserves at seascape scales. Biological Conservation **128**:215-222.

Mumby, P. J., A. J. Edwards, J. E. Arias-González, K. C. Lindeman, P. G. Blackwell, A. Gall, M. I. Gorczynska, A. R. Harborne, C. L. Pescod, and H. Renken. 2004. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. Nature **427**:533-536.

Mumby, P. J., and R. S. Steneck. 2008. Coral reef management and conservation in light of rapidly evolving ecological paradigms. Trends in Ecology & Evolution **23**:555-563.

Mumby, P. J., K. Broad, D. R. Brumbaugh, C. P. Dahlgren, A. R. Harborne, A. Hastings, K. E. Holmes, C. V. Kappel, F. Micheli, and J. N. Sanchirico. 2008. Coral Reef Habitats as Surrogates of Species, Ecological Functions, and Ecosystem Services

Munday, P. L. 2004. Habitat loss, resource specialization, and extinction on coral reefs. Global Change Biology **10**:1642-1647.

Nasir, M. S., P. Rojana-anawat, and A. Snidvongs. 1999. Physical characteristics of water-mass in the South China Sea. Proceedings of the First Technical Seminar on Marine Fishery Resources Survey in the South China Sea Area I: Gulf of Thailand and East Coast of Peninsular Malaysia, 24-26 November 1997, Bangkok, Thailand:1-5.

Nasuchon, N., and A. Charles. 2010. Community involvement in fisheries management: Experiences in the Gulf of Thailand countries. Marine Policy **34**:163-169.

NCSC. 2005. Environment and Socio-Economy Report: National Coastal Steering Committee in M. o. t. Environment, editor. Kingdom of Cambodia, Phnom Penh, Cambodia.

Nelson, P. J. 2007. Human Rights, the Millennium Development Goals, and the Future of Development Cooperation. World Development **35**:2041-2055.

Nong, K. undated. Peam Krasaop Wildlife Sanctuary: Insights into life in the mangroves. International Symposium on Protection and Management of Coastal Marine Ecosystem. Ministry of Environment, Phom Penh, Cambodia.

Noonan, S. H. C., G. P. Jones, and M. S. Pratchett. 2012. Coral size, health and structural complexity: effects on the ecology of a coral reef damselfish. Marine Ecology-Progress Series **456**:127-137.

Noranarttragoon, P., P. Sinanan, N. Boonjohn, P. Khemakorn, and A. Yakupitiyage. 2013. The FAD fishery in the Gulf of Thailand: Time for management measures. Aquatic Living Resources **26**:85-96.

Nuon, V., and W. Gallardob. 2011. Perceptions of the local community on the outcome of community fishery management in Krala Peah village, Cambodia. International Journal of Sustainable Development and World Ecology **18**:453-460.

Oliver, E. C. J. 2012. Intraseasonal variability of sea level and circulation in the Gulf of Thailand: the role of the Madden-Julian Oscillation. Climate Dynamics:1-16.

Pandolfi, J. M., R. H. Bradbury, E. Sala, T. P. Hughes, K. A. Bjorndal, R. G. Cooke, D. McArdle, L. McClenachan, M. J. H. Newman, G. Paredes, R. R. Warner, and J. B. C. Jackson. 2003. Global Trajectories of the Long-Term Decline of Coral Reef Ecosystems. Science **301**:955-958.

Pauly, D. 1994. From growth to Malthusian overfishing: stages of fisheries resources misuse. Traditional Marine Resource Management and Knowledge Information Bulletin **3**.

Pauly, D., and R. Chuenpagdee. 2003. Development of fisheries in the Gulf of Thailand large marine ecosystem: analysis of an unplanned experiment. Elsevier Science.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres. 1998. Fishing down marine food webs. Science **279**:860-863.

Pho Hoang Han, M. M. M. 2007. Fisheries development in Vietnam: A case study in the exclusive economic zone. Ocean & Coastal Management **50**:699-712.

Phongsuwan, N., A. Chankong, C. Yamarunpatthana, H. Chansang, R. Boonprakob, P. Petchkumnerd, N. Thongtham, S. Paokantha, T. Chanmethakul, P. Panchaiyapoom, and O. A. Bundit. 2013. Status and changing patterns on coral reefs in Thailand during the last two decades. Deep-Sea Research Part II: Topical Studies in Oceanography.

Planes, S., G. P. Jones, and S. R. Thorrold. 2009. Larval dispersal connects fish populations in a network of marine protected areas. Proceedings of the National Academy of Sciences **106**:5693-5697.

Plathong, S., A. H. Baird, C. A. Chen, T. Chanmethakul, V. Suwonno, P. Buaphet, and S. Soontornpitakkool. 2006. Daytime gamete release from the reef-building coral, Pavona sp., in the Gulf of Thailand. Coral Reefs **25**:72-72.

Pomeroy, R. S. 2012. Managing overcapacity in small-scale fisheries in Southeast Asia. Marine Policy **36**:520-527.

Pratchett, M. S., P. Munday, and S. K. Wilson. 2008. Effects of climate-induced coral bleaching on coral-reef fishes. Ecological and economic consequences. Oceanography and Marine Biology: An Annual Review **46**:251-296.

Pratchett, M., A. Hoey, D. Coker, and N. Gardiner. 2012. Interdependence between reef fishes and scleractinian corals. 12th International Coral Reef Symposium 9 - 13 July 2012, Cairns, Australia.

Preen, A., and H. Marsh. 1995. Response of dugongs to large-scale loss of seagrass from Hervey Bay, Queensland Australia. Wildlife Research **22**:507-519.

Raakjær, J., D. Manh Son, K.-J. Stæhr, H. Hovgård, N. T. Dieu Thuy, K. Ellegaard, F. Riget, D. Van Thi, and P. Giang Hai. 2007. Adaptive fisheries management in Vietnam: The use of indicators and the introduction of a multi-disciplinary Marine Fisheries Specialist Team to support implementation. Marine Policy **31**:143-152.

Rasheed, M. 2003. Port Curtis and Rodds bay seagrass and benthic macro-invertebrate community baseline survey November/December 2002. Queensland Department of Primary Industries.

Reopanichkul, P., R. Carter, S. Worachananant, and C. Crossland. 2010. Wastewater discharge degrades coastal waters and reef communities in southern Thailand. Marine environmental research **69**:287-296.

Reopanichkul, P., T. A. Schlacher, R. Carter, and S. Worachananant. 2009a. Sewage impacts coral reefs at multiple levels of ecological organization. Marine Pollution Bulletin **58**:1356-1362.

Robertson, A., and N. Duke. 1987. Mangroves as nursery sites: comparisons of the abundance and species composition of fish and crustaceans in mangroves and other nearshore habitats in tropical Australia. Marine Biology **96**:193-205.

Russ, G. R., A. C. Alcala, A. P. Maypa, H. P. Calumpong, and A. T. White. 2004. Marine reserve benefits local fisheries. Ecological Applications **14**:597-606.

Sale, P. F. 1991. The ecology of fishes on coral reefs. Access Online via Elsevier.

Sangmanee, K., M. Sutthacheep, and T. Yeemin. 2012. The decline of the sea urchin Diadema setosum affected by multiple disturbances in the inner Gulf of Thailand. 12th International Coral reef Symposium, Cairns.

Sanpanich, K. 2011. Marine bivalves occurring on the east coast of the Gulf of Thailand. ScienceAsia **37**:195-204.

Satapoomin, U. 2000. A preliminary checklist of coral reef fishes of the Gulf of Thailand, South China Sea. Raffles Bulletin of Zoology **48**:31-53.

Sathirathai, S., and E. B. Barbier. 2001. Valuing Mangrove Conservation In Southern Thailand. Contemporary Economic Policy **19**:109-122.

Shinnaka, T., M. Sano, K. Ikejima, P. Tongnunui, M. Horinouchi, and H. Kurokura. 2007. Effects of mangrove deforestation on fish assemblage at Pak Phanang Bay, southern Thailand. Fisheries Science **73**:862-870.

Singhruck, E. 2001. Circulation features in the Gulf of Thailand Inferred from SeaWiFS data. Chulalongkorn University Thailand 10330.

Sinsakul, S. 1997. Coastal zone in Thailand. Status of Marine Scientific Study in Thai Waters:97-116.

Snidvongs, A., and P. Sojisuporn. 1999. Numerical simulation of the net current in the Gulf of Thailand under different monsoon regimes. Proceedings of the First Technical Seminar on Marine Fishery Resources Survey in the South China Sea, Area I: Gulf of Thailand and East Coast of Peninsular Malaysia, 24-26 November 1997, Bangkok, Thailand:52-72.

Son, D. M., and P. Thuoc. 2003. Management of coastal fisheries in Vietnam. Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries:1120.

Stiles, D. 2009. The Marine Turtle Product Trade in Viet Nam. Marine Turtle Newsletter:6-9.

Stobutzki, I. C., G. T. Silvestre, A. Abu Talib, A. Krongprom, M. Supongpan, P. Khemakorn, N. Armada, and L. R. Garces. 2006a. Decline of demersal coastal fisheries resources in three developing Asian countries. Fisheries Research **78**:130-142.

Stobutzki, I. C., G. T. Silvestre, and L. R. Garces. 2006b. Key issues in coastal fisheries in South and Southeast Asia, outcomes of a regional initiative. Fisheries Research **78**:109-118.

Storey, A. W., L. E. Andersen, J. Lynas, and E. Melville. 2007. Port Curtis Ecosystem Health Report Card. Port Curtis Integrated Monitoring Program (PCIMP). Centre for Environmental Management, Central Queensland University.

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

Suvapepun, S. 1991. Long term ecological changes in the Gulf of Thailand. Marine Pollution Bulletin **23**:213-217.

Tana, T. S. 2005. Review of Oceanography, natural resources and fisheries of the coastal zone of Cambodia. Ministry of Agriculture, Forestry and Fisheries, Phnom Penh, Cambodia.

Thompson, A., and B. Mapstone. 1997. Observer effects and training in underwater visual surveys of reef fishes. Marine Ecology Progress Series **154**:53-63.

Trisak, J., H. Soasung, and P. Wongkaew. 2009. Seasonal variations in catches and efforts of a small-scale swimming crab trap fishery in the Eastern Gulf of Thailand. Songklanakarin Journal of Science and Technology **31**:373-380.

UNEP. 2004. Reversing environmental degradation trends in the South China Sea and Gulf of Thailand. Report on the Fifth Meeting of the Regional Working Group on Mangroves. UNEP/GEF/SCS/RWG-M.5/3.

van Bochove, J. H., N. Vitlin, V. Bush, and P. Raines. 2006. Initial results from scientific surveys conducted on Cambodia's fringing reefs in J. H. van Bochove, editor. Coral Cay Conservation, Phnom Penh, Cambodia.

van Bochove, J. W., K. Longhurst, and A. Ferguson. 2012. Initial scientific findings to support the designation of a MPA around Koh Rong Isl., Cambodia. Page 28. Coral Cay Conservation. Coral Cay Conservation, Cambodia.

van Bochove, J. W., M. McVee, N. Ioannou, and P. Raines. 2011b. Cambodia Reef Conservation Project Year 1 Report, Feb 2010 - Feb 2011. Coral Cay Conservation

van Bochove, J. W., N. Ioannou, M. McVee, and P. Raines. 2011a. Evaluating the status of Cambodia's coral reefs through baseline surveys and scientific monitoring. Cambodian Journal of Natural History **2**:114-121.

van Oppen, M. J., A. Lutz, G. De'ath, L. Peplow, and S. Kininmonth. 2008. Genetic traces of recent long-distance dispersal in a predominantly self-recruiting coral. PLoS ONE **3**:e3401.

Van Wynsberge, S., S. Andréfouët, M. A. Hamel, and M. Kulbicki. 2012. Habitats as surrogates of taxonomic and functional fish assemblages in coral reef ecosystems: a critical analysis of factors driving effectiveness. PloS one **7**:e40997.

Veron, J. E. N. 1993. Coral of Australia and the Indo-Pacific. University of Hawaii Press.

Veron, J. E. N., O. Hoegh-Guldberg, T. M. Lenton, J. M. Lough, D. O. Obura, P. Pearce-Kelly, C. R. C. Sheppard, M. Spalding, M. G. Stafford-Smith, and A. D. Rogers. 2009. The coral reef crisis: The critical importance of <350ppm CO2. Marine Pollution Bulletin **58**:1428-1436.

Vibol, M. O. undated. Seagrass in the South China Sea.

Vibol, M. O., S. Nam, L. Puy, and P. S. Wath. undated. Seagrass Diversity and Distribution in Coastal Area of Kampot Province, Cambodia.

Vibol, O. 2007. National Reports on Coral Reefs on the Coastal Waters of the South China Sea. Page 135. Technical Publication. UNEP/GEF/SCS, Bangkok.

Vidthayanon, C., and S. Premcharoen. 2002. The status of estuarine fish diversity in Thailand. Marine and Freshwater Research **53**:471-478.

Viner, K., M. Ahmed, T. Bjørndal, and K. Lorenzen. 2006. Development of Fisheries Co-management in Cambodia: A case study and its implications. Page 39pp. WorldFish Centre, Penang, Malaysia.

Vo, S. T., and J. Pernetta. 2010. The UNEP/GEF South China Sea Project: Lessons learnt in regional cooperation. Ocean & Coastal Management **53**:589-596.

Vo, S. T., J. C. Pernetta, and C. J. Paterson. 2013. Status and trends in coastal habitats of the South China Sea. Ocean & Coastal Management (2013).

Watson, R. A., R. G. Coles, and W. L. Long. 1993. Simulation estimates of annual yield and landed value for commercial penaeid prawns from a tropical seagrass habitat, northern Queensland, Australia. Marine and Freshwater Research **44**:211-219.

Wattayakorn, G. 2006. Environmental issues in the Gulf of Thailand. Pages 249-259. The Environment in Asia Pacific Harbours. Springer.

Wen, C. K., G. R. Almany, D. H. Williamson, M. S. Pratchett, T. D. Mannering, R. D. Evans, J. M. Leis, M. Srinivasan, and G. P. Jones. 2013. Recruitment hotspots boost the effectiveness of no-take marine reserves. Biological Conservation **166**:124-131.

WEPA. 2013. State of water environmental issues - Cambodia overview.

Weterings, R. 2011. A GIS-based assessment of threats to the natural environment on Koh Tao, Thailand. Kasetsart Journal - Natural Science **45**:743-755.

Wilkinson, C. 2004. Status of coral reefs of the world. Chapter **18**:473-491.

Wilkinson, C. R. 1996. Global change and coral reefs: impacts on reefs, economies and human cultures. Global Change Biology **2**:547-558.

Wilson, D. C., M. Ahmed, S. V. Siar, and U. Kanagaratnam. 2006. Cross-scale linkages and adaptive management: Fisheries co-management in Asia. Marine Policy **30**:523-533.

Wilson, S. K., N. A. J. Graham, M. S. Pratchett, G. P. Jones, and N. V. C. Polunin. 2006a. Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient? Global Change Biology **12**:2220-2234.

Worachananant, S., R. Carter, M. Hockings, and P. Reopanichkul. 2008. Managing the Impacts of Scuba divers on Thailand's coral reefs. Journal of Sustainable Tourism **16**:645-663.

Wynne, S. P., and I. M. Cote. 2007. Effects of habitat quality and fishing on Caribbean spotted spiny lobster populations. J. Appl. Ecol. **44**.

Yeemin, T., S. Pengsakun, M. Yucharoen, W. Klinthong, K. Sangmanee, and M. Sutthacheep. 2013. Long-term decline in Acropora species at Kut Island, Thailand, in relation to coral bleaching events. Marine Biodiversity **43**:23-29.

Zhuang, W., S. P. Xie, D. Wang, B. Taguchi, H. Aiki, and H. Sasaki. 2010. Intraseasonal variability in sea surface height over the South China Sea. Journal of Geophysical Research C: Oceans **115**.

Appendix 1 Site descriptions

Site No.	Visibility (m)	Global UTM (N)	Global UTM (E)	Dominant coral species	Other coral species	Fish and invertebrates	Threats	other
1	4	0217905	1317275	*Porities* spp.	*Acropora* sp., Favid sp., *Agiceridae* sp., Faviids, *Pocillopra* sp.	Tridacna sp., tubeworms, bivalves, sea urchins	lots turf algae and sediment, white-spot disease	
2	7	0216212	1304327	*Porities* spp., *Pavona decussata*	Fungids, Galaxea sp., Echinpora sp.,Favid sp., Diploastrea heliopora, Mussids, Turbinaria sp., Pavona cactus, Goniastrea sp., Goniopora sp., Lobophyllia sp., Pectinia sp., Turbinaria sp.	Chromilpetes alvitelis, Epinephalus quoyanus, nemiipterids, Apogonids, Abedefduf bengalensis, wrasse, Barrel sponges, bivalves, tubeworms, sea urchins	lots turf algae and sediment, bleached Acropora sp., white spot disease,	
3	6	0214265	130647	*Porities* spp.	D. heliopora., P. decussata, Galaxea sp., Lobophyllia sp., Favites sp., D. heliopora, P. cactus.	C. boenak, Epinephalus sp., C. formosa. E. quoyanus, Halichoeries purperensis, Tridacna sp., large Balistoides viridescens	lots turf algae and sediment, some bioerosion in Porities, dead Acropora staghorn, bleached Favid sp.	
4	8	0207649	1324460	Pavona decussata	Lobophyllia sp., Pectinia sp., Porities spp., Asteopora sp., Galaxea sp, Favids, large Porities bommies,	P. aereolatus, large Clorurus sordidus, wrasses, Heniochus acuminatus, Tridacna sp., holothurian, sea urchins, barrel sponge, bivalves, tubeworms	abandoned fish traps, dumped outboard housing, dead Acropora staghorn, fishing net over reef, pink spots on Porities indicating trauma and susceptibility to bioerosion, White plaque disease on Montipora sp.	
5	5	0229929	1292336	Porities spp.	Acropora sp., Turbinaria sp., Pectinia sp., Galaxea sp., Fungids, D. heliopora, Goniastrea sp., Echinopora sp., Euphyllia sp., Goniopora sp., plate Acropora, Montipora sp., Lobophyllia sp., Echinpora sp.,	Tunicates, soft corals, sea urchins (abundant), barrel sponge, Tridacna sp.	turf algae abundant, rock abundant	

Site No.	Visibility (m)	Global UTM (N)	Global UTM (E)	Dominant coral species	Other coral species	Fish and invertebrates	Threats	other
6	10	0231473	285705	Porities spp.	Turbinaria sp., fungids sp., Acropora formosa staghorn (blue-tipped and white-tipped), Acropora hyacynthus, Lobophyllia sp., Pectinia sp., Echinopora sp., Podabacia crustacea, P. decussata, soft corals., D. heliopora, Galaxea sp., Montipora sp., Asteopora sp., Pectinia sp.,	Chelienus fasciatus, , D. reticulatus, schooling L. vitta., holothurians, anemones, gorgonians, sea urchins, tunicates, Tridacna sp., encrusting and barrel sponges	some bleaching, dead corals and algae, dead branching Acropora sp., white spot disease on Asteopora sp.,	Several D. heliopora >1m2, small sub-massive Porities mainly with some larger bommies, high bioerosion
7	4	0231946	1286156	Porities spp.	Lobophyllia sp., D. heliopora., P. decussata, P. cactus, Goniastrea sp., Echinopora sp., Astreopora sp., Symphyllia sp., staghorn Acropora sp., fungids, large and recruit Turbinaria sp., Pectinia sp., fungiids, Pocillopora sp., Favid recruits,	Cushion starfish, anemones, cowrie shell, Lutjanus russelli, T. lunare, S. ghobban, A. peridereion, anemones, schooling Sphyraena flavicauda, Abedefduf sexfasciatus, sea urchins	algae, dead coral, high bioerosion in Porities, white spot disease on Favid	Several D. heliopora >1m2, small sub-massive Porities with some larger bommies, high bioerosion, rock
8	8	0286744	1211629	Galaxea sp. Growing on rock	Galaxea sp., Turbinaria bifrons, small Turbinaria recruits, tabulate Acropora sp., Faviites sp., P. decussata,	anemones, C. formosa, C. boenak, A. sexfasciatus, A. peridereion, D. Trimaculatus, sponges, sot corals, rock	algae, dead coral	lots of rock and no reef building corals
9	5	0287272	1212449	Porities sp., P. decusatta	Fungids, Alveopora sp., Goniopora sp., Lobophyllia sp., Turbinaria sp. Large and recruits, Pectinia sp., Acropora grandis, Astreopora sp., P. cactus, Galaxea sp.	Epinephalus sp., nudibranch	algae, sediment, bioerosion	fishing vessels
10	4	0287	1212	D. Heliopora >1 m2	Platygyra sp., P. decussata, P. Cactus, lots Favid sp.,	Barrel sponge, C. Formosa, schooling fusiliers, nudibranch,		
11	4	0290291	1223174	Galaxea sp., Porities spp.	Acropora spp., P. decussata, Favid spp., Turbinaria sp.,	Tridacna sp., tubeworms, bivalves, sea urchins, barrel sponge	Nutrient indicator algae in shallows	

Site No.	Visibility (m)	Global UTM (N)	Global UTM (E)	Dominant coral species	Other coral species	Fish and invertebrates	Threats	other
15	6	0287121	1206983	D. heliopora, mixed species	D. heliopora, Lobophyllia sp., Galaxea sp., P. decusatta, Pectinia sp., Acropora spp., Euphyllia sp., Turbinaria sp., Echinpora sp., Montipora sp., Favid sp.,	P. areaolatus, Epinephalus merra, Siganus sp., encrusting and barrel sponges, bivalves, soft corals, Ascidians, Tridacna sp., sea urchins	Turf algae, sediment	Several D. heliopora >1m2, small sub-massive Porities, coral species growing on rock
16	12	0287348	1206054	Galaxea sp., Goniopora sp.	Acropora spp. Staghorn, Porities spp., Turbinaria sp., Lobophyllia sp., Goniopora sp., Galaxea sp., P. decusatta	Anemone, sea urchins, sponges,	algae, bivalves	Mixed species sight
17	4	0283483	1243399	Porities spp.	Galaxea sp., Turbinariaspp., laminar Acropora spp., Faviites spp., P. decussata, Coeloseris sp., Favid sp.,	Holothurian,	High sediment, algae	Large Porities bommies
18	6	0279438	1247453	Porities spp.	P. decusatta, P. cactus, Fungids, D. heliopora, Turbinaria sp., Lobophyllia sp.	barrel sponge, anemones, A. perieodon, schooling fusiliers, eels,	high sediment, algae	Fields of solitary fungids, 1 x D. heliopora >1m2, large Porities bommies
19	8	0278461	1260799	Porities spp.	Favid sp., Galaxea sp., Pectinia sp., Goniopora., P. decusatta, Goniastrea sp., Lobophyllia sp., Echinpora sp., Fungids,	L. russelli, S. lineatus, C. boenak, C. formosa, Plectorhinchus gibbosus, Tridacna sp., soft corals, bivalves, tubeworms, barrel sponge	white spot disease on Porities, algae, sediment	abundant nutrient indicator algae
20	20	0278461	1260779	soft corals, anemones	D. heliopora, Lobophyllia sp., Porities spp., P. decusatta, Acropora spp., Pocillopora spp., Turbinaria sp., Favid sp.,	Siganus guttatus, S. vulpinnus, S. ghobban, Cephalopholis boenak, Epinephelis fasciatus, Plectorhinchus gibbosus, L. vitta, Corallimorphs, echinoids, barrel and ecnrusting sponge, white-eyed eel, Bamboo shark, Ascidians, bivalves, sea urchins	Fishing net over reef (abundant), Crown of Thorns, armies of sea urchins	Minimal coral growing on rock

Site No.	Visibility (m)	Global UTM (N)	Global UTM (E)	Dominant coral species	Other coral species	Fish and invertebrates	Threats	other
22	4	10 45 12.38	103 12 46.891	Porities spp.	Galaxea spp., P. decusatta, Goniopors spp., Favid spp., Fungids, Lobophyllia spp., Acropora spp.,	Tridacna sp., sea urchins	high sediment, algae	small Porities bommies, sand
23	4	10 46 288	103 12 432	Porities spp.	Turbinaria sp., Favid sp., Pectinia spp., Lobophyllia spp., P. decusatta, Galaxea sp., Acropora spp., Fungids, Symphyllia spp.	C. boenak, Siganus spp., branching sponge,barrel sponge, sea urchins, large bivalves, tubeworms, Tridacna spp., sea whips	abandoned trawl net, high bioerosion / black spot disease on Porities	mixed species site
24	3	10 48 10.2	103 11 27.2	Mixed species	Turbinaria sp., Acropora spp., Lobophyllia sp., P. decusatta, Porities spp., Goniopora spp., Galaxea sp., Pectinia sp., Echinopora spp., Euphyllia sp., Symphyllia sp.	juvenile Plectorinchus chaetodonoides, gorgonians, sea urchins, corallimorphs, anemones,, soft coral	abundant algae and sediment	
25	10	10 43 42.2	102 51 53.1	soft corals	Turbastrea sp., Galaxea sp., Favids	Zooanthids, Sea whips, soft corals, gorgonians, anemones, sea urchins COT		clusters of sea urchins, bare rock platform, little coral settlement
26	25	10 21 37.0	102 55 32.1	Mixed species	Turbinaria sp., Favid sp., Porities sp., D. heliopora, Pocillopora sp., Acropora spp., Lobophyllia spp., Echinopora sp.	sea whips, hydroids, encrusting and barrel sponges, sea urchins, holothurians, Ascidians, echinoids	bleached/dead Acropora, fishing net over reef	coral settled on bare rock, sand, clusters of sea urchins
28	15	10 22 46.2	102 58 27.9	Mixed species	Porities spp., Favids, Pocillopora spp., fungids, Lobophyllia spp.	sea urchins, tubeworms, Tridacna sp., Holothurians, COTs, Scorpionfish, Oyster clam, barrel sponge	COTs, high bioerosion in Porities	Bare rock substrate,
29	25	9 56 05.2	102 52 46.8	Mixed species	Acropora spp. (staghorn, branching, laminar), encrusting Porities sp., Favid sp., Echinopora sp., Galaxea sp., Lobophyllia sp., Goniastrea sp., P. decusatta	Anemones, corallimorphs, encrusting sponge, Epinephalus sp., Tridacna sp., T. lunare, Cushion star, soft coral (leather, encrusting)		
30	24	09 56 124	102 54 727					

Site No.	Visibility (m)	Global UTM (N)	Global UTM (E)	Dominant coral species	Other coral species	Fish and invertebrates	Threats	other
31	20	09 56 56.5	102 54 23.5	Mixed species	Porities spp., Favids, Pocillopora spp., fungids, Lobophyllia spp., Pectinia sp., Acrpora spp. (staghorn, branching, laminar), P. decusatta, Fungids, Asteopora sp.,	Epinephalus sp., E. fasciatus, Lutjanus desussatus, hydroids, barrel sponge, Cushion star, echinoids, sea urchins, corallimorphs	high bioersoion in Porities, bleached Acropora, dead staghorn from storm damage	Bare rock substrate, corals settling on rock
34	15	09 54 50.2	102 57 09	Acropora spp.	Acropora spp (staghorn, branching, laminar), Favid sp., Pocillopora sp., P. decusatta, Porities spp., P. cactus, Turbinaria sp., Galaxea sp., Goniastrea sp., Symphyllia sp	Lutjanus russelli, Lethrinus lentjan, Siganus sp., Scarus sp., Scarus rubrorivulatus, Oyster clams, Ascidians, COTs, cushion star, sea urchins, starfish, soft corals, barrel sponge, nudibranchs	white spot disease on Favid sp., COTs, bleached Pocillopora, storm damage	lots of broken and dead staghorn Acropora from previous storm damage
35		10 16 21.3	103 08 43.7	D. heliopora	Acrpora spp (laminar, branching), Asteopora sp., Lobophyllia sp., Symphyllia sp.	L. decussatus, L. vitta, Tridacna sp., E. fasciatus, soft corals, hydroids, barrel sponge, Tridacna sp., nudibranchs, sea urchins, gorgonians, zooanthids, corallimorphs, anemones, tunicates, echinoids	high bioerosion on Porities, dead sub-massive favid, white spot disease on Favid	several large D. heliopora >1m2
36	7	10 15 34.1	103 10 11.1	Porities spp.	Favid spp., Lobophyllia sp., Favid bommies, D. heliopora	soft corals, hydroids, barrel sponge, Tridacna sp., nudibranchs, sea urchins	Storm damage,	
37	3	10 39 24.1	103 15 31.8	Porities spp., P. decusatta	Turbinaria spp., Goniopora sp., Lobophyllia sp., P. decusatta, fungids	barrel sponge, anemones, sea urchins Tridacna sp.	dead staghorn coral, abundant algae and sediment	
38	5			Mixed species	D. heliopora, Galaxea sp., Mussids, Acropora spp., Favid spp., Goniopora sp., encrusting Favid sp., Lobophylllia sp., Turbinaria sp., P. decusatta	soft corals, hydroids, barrel sponge, Tridacna sp., nudibranchs, sea urchins	algae and sediment	several D. heliopora >1m2, red algae, calcareous algae
39		10 37 44.3	103 17 42.9	Porities spp. And mixed	Lobophyllia sp., fungids, Turbinaria sp., Goniopora sp., Echinopora sp., Montipora sp., Porities sp., D. heliopora sp.	anemones, C. formosa, C. boenak, A. sexfasciatus, A. peridereion, D. Trimaculatus, sponges, soft corals, rock, sea urchins	algae and sediment	recruits of Turbinaria

Site No.	Visibility (m)	Global UTM (N)	Global UTM (E)	Dominant coral species	Other coral species	Fish and invertebrates	Threats	other
41	7	10 33 39.9	103 18 16.5	D. heliopora	Acropora spp., P. decussata, Favid spp., Turbinaria sp., Pocillopora sp., Lobophyllia sp., Goniopora sp.	Holothurian, barrel sponge, soft coral, tubeworms, bivalves, sea urchins	white spot disease and high bioerosion on D. heliopora, algae and sediment	5 large D. heliopora >1m2, calcareous algae
42	5	10 32 37.6	103 19 32.2	Porities spp.	Acropora sp., Pocillopora sp., Turbinaria sp., Lobophyllia sp., D. heliopora, Favids, P. decusatta, Porities cylindrica, Pectinia sp., Goniopora sp., Echinopora sp.	Cushion starfish, anemones, T. lunare, A. peridereion, Abedefduf sexfasciatus, sea urchins	algae and sediment	
43	6	10 19 26.9	103 50 34.9	Porities spp.	P. decusatta, Fungids, Lobophyllia sp., Acropora spp.,	barrel sponge, anemones, bivalves, tubeworms	algae and sediment	fields of solitary fungids, laminar Acropora, Porities bommies.
44		10 19 11.9	103 50 24.8	Portiies spp., Acropora spp. Branching and laminar, P. decusatta	Acropora spp., P. decusatta, Lobophyllia spp., Fungids, Pectinia sp., Favites sp., Asteopora sp., Turbinaria sp.	barrel sponges, sea urchins, soft corals, corallimorphs, bivalves, nudibranchs	algae and sediment	fields of solitary fungids, laminar Acropora, staghorn Acropora, Porities bommies.

Appendix 2 Benthos cover and water quality of sampled sites

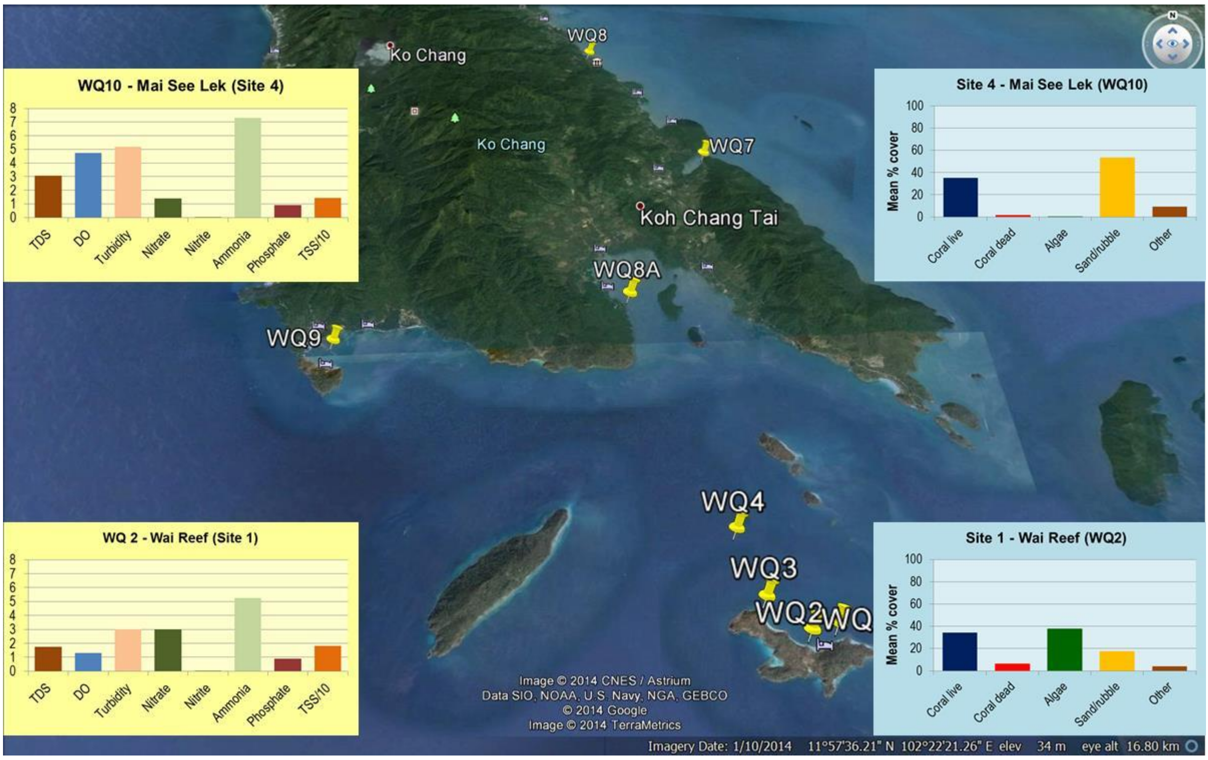


Figure A1 Inshore sample sites around Koh Chang island, Thailand

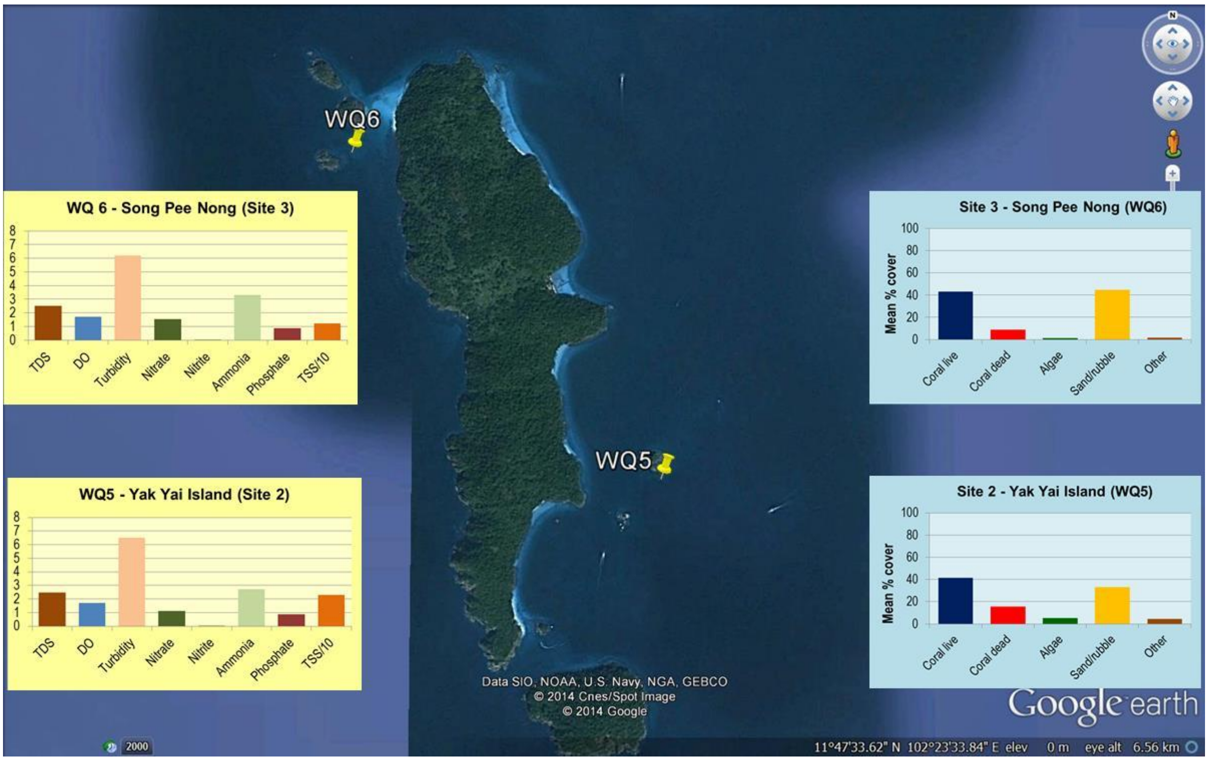


Figure A2 Inshore sample sites around Yak Yai island, Thailand

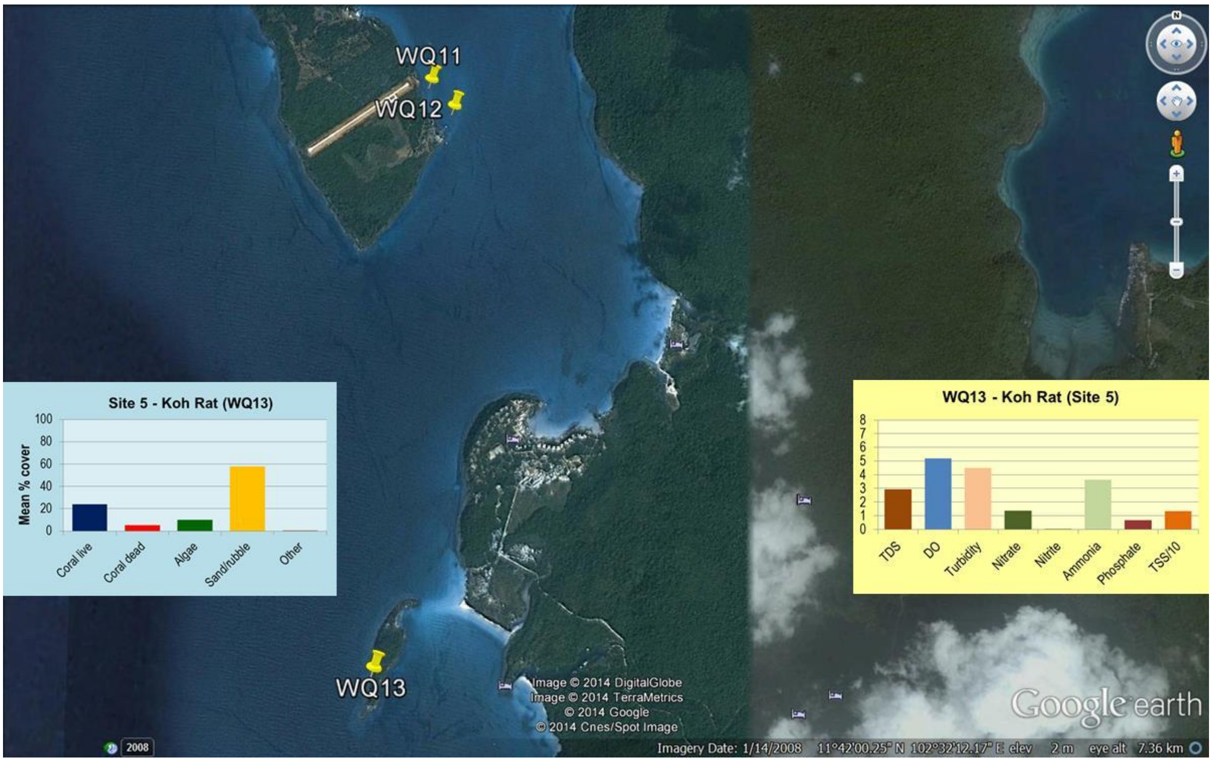


Figure A3 Inshore sample sites around Koh Rat island, Thailand

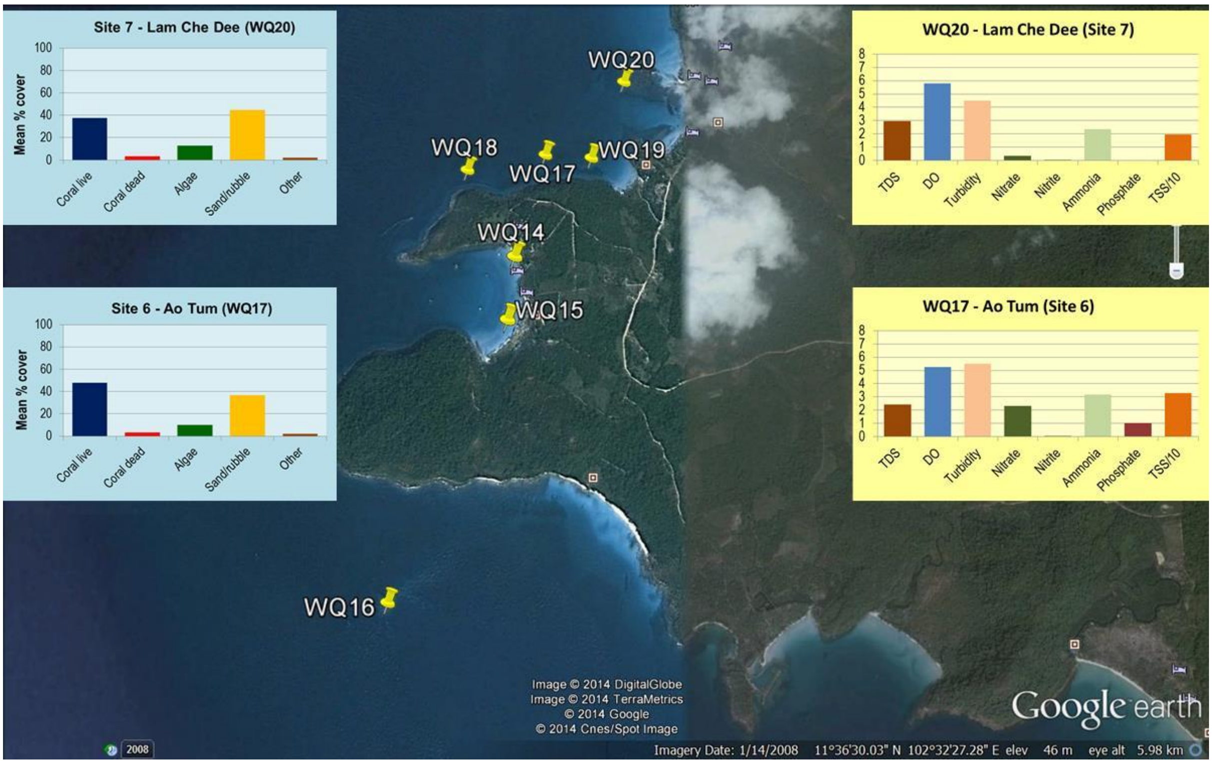


Figure A4 Inshore sample sites around Ao Tum, Thailand

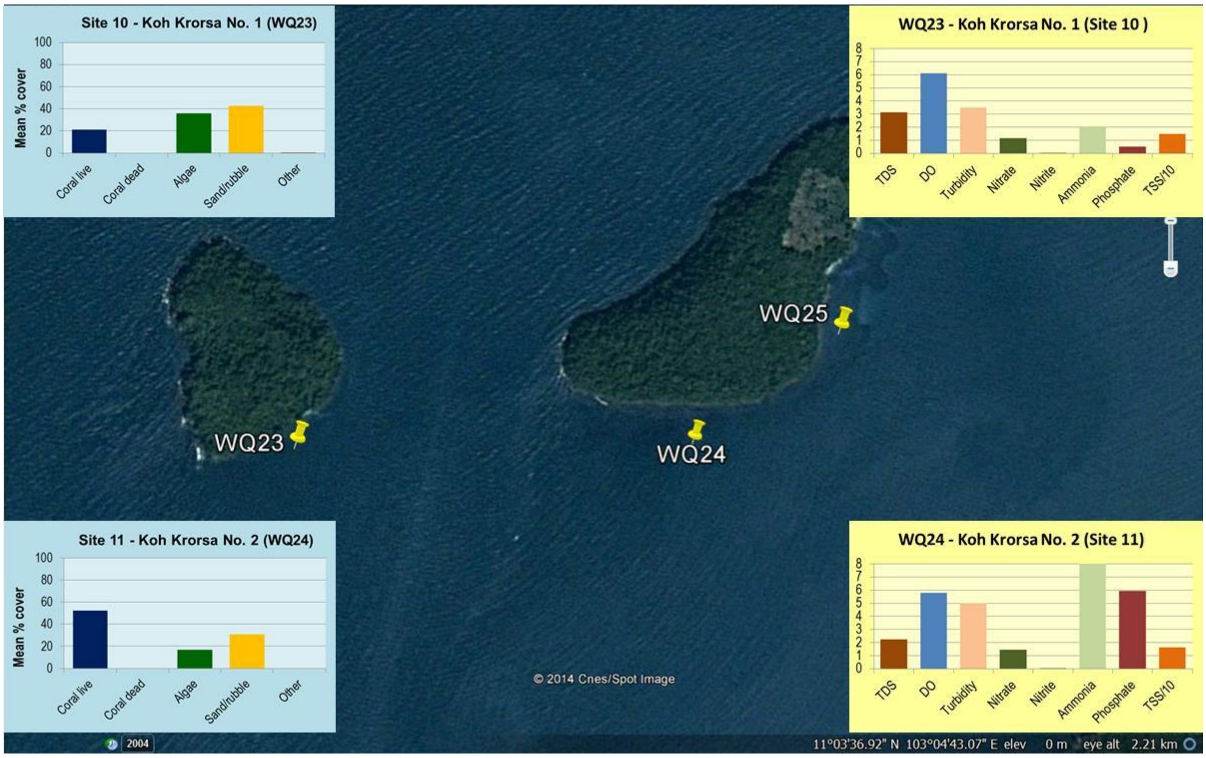


Figure A5 Inshore sample sites around Koh Krorsa, Thailand

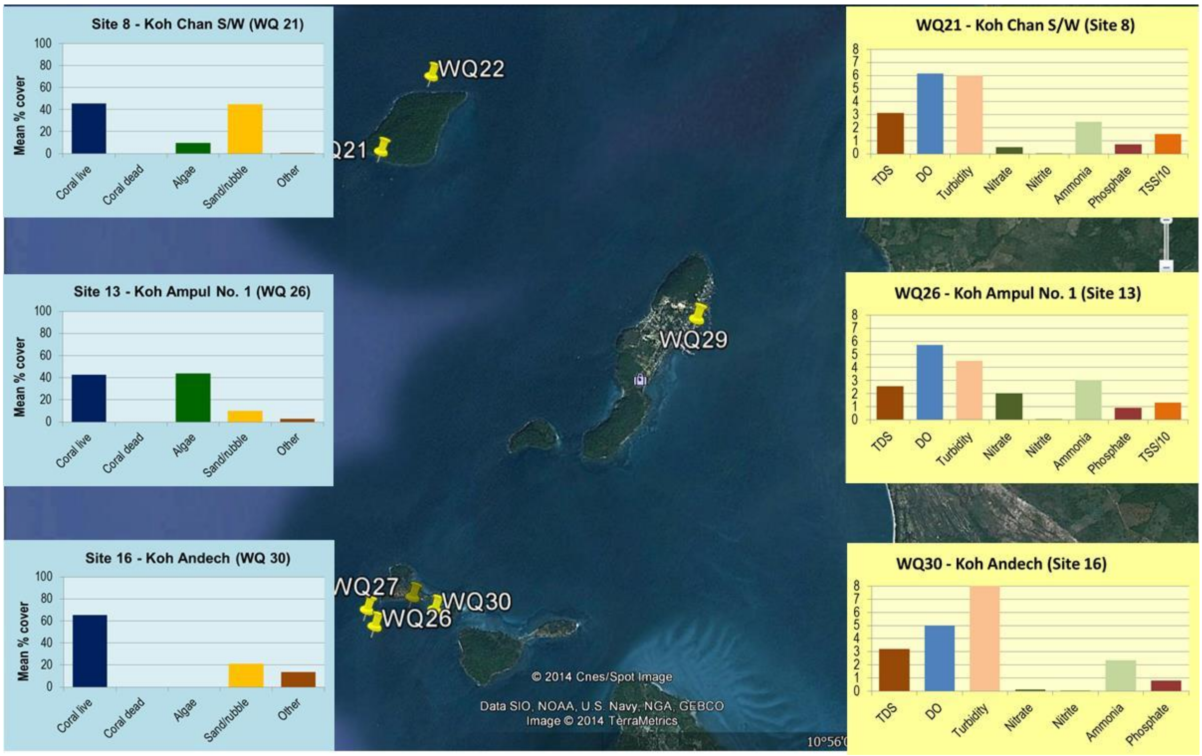


Figure A6 Inshore sample sites around Koh Ampul island, Thailand

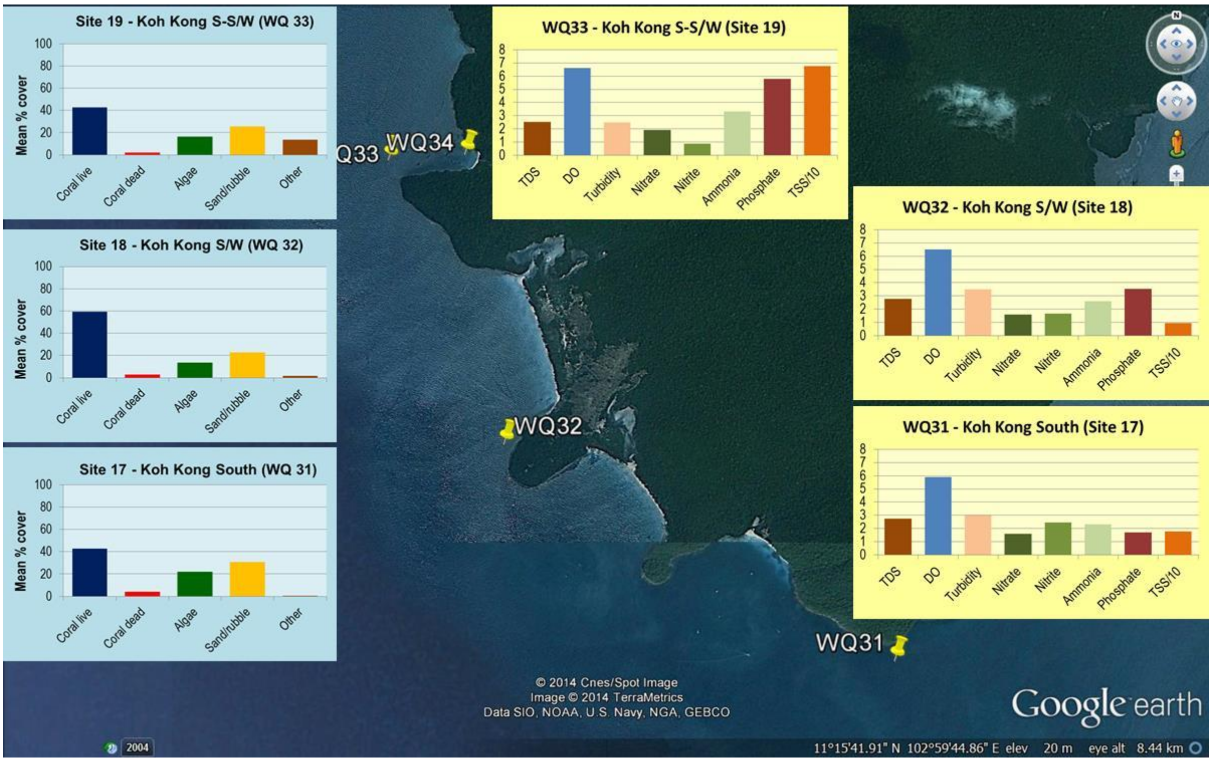


Figure A7 Inshore sample sites around Koh Kong island, Cambodia

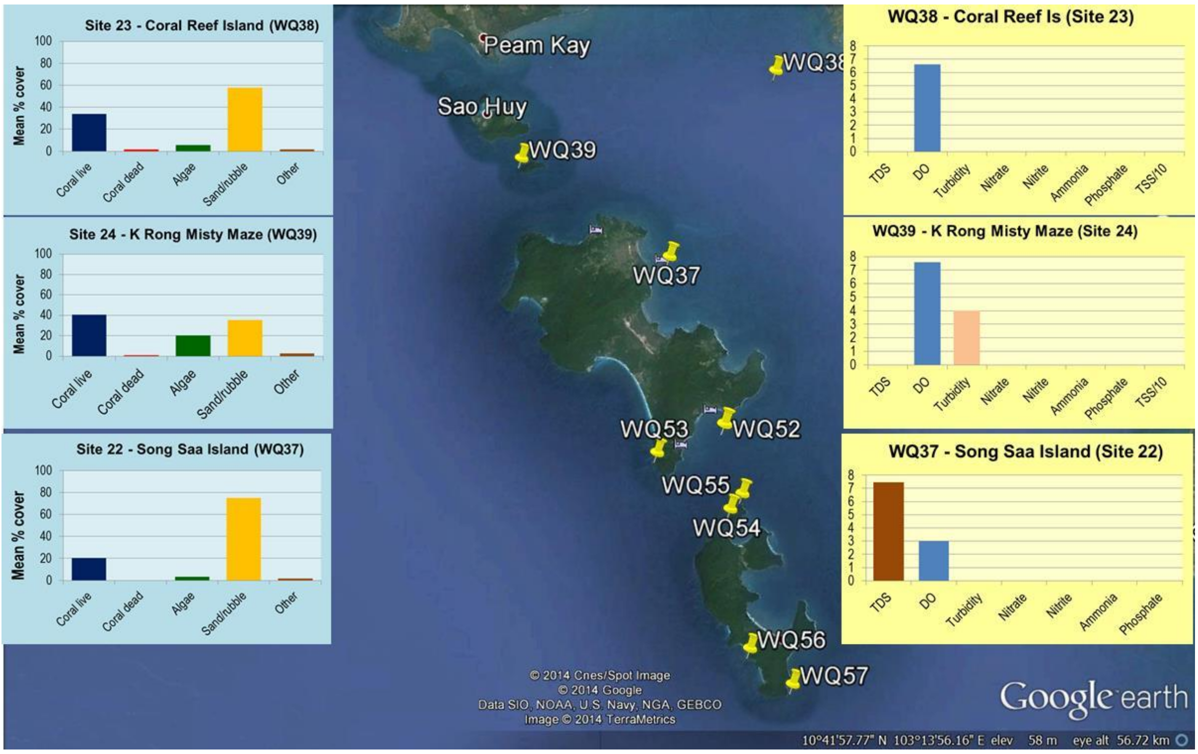


Figure A8 Inshore sample sites around Sao Huy island, Cambodia

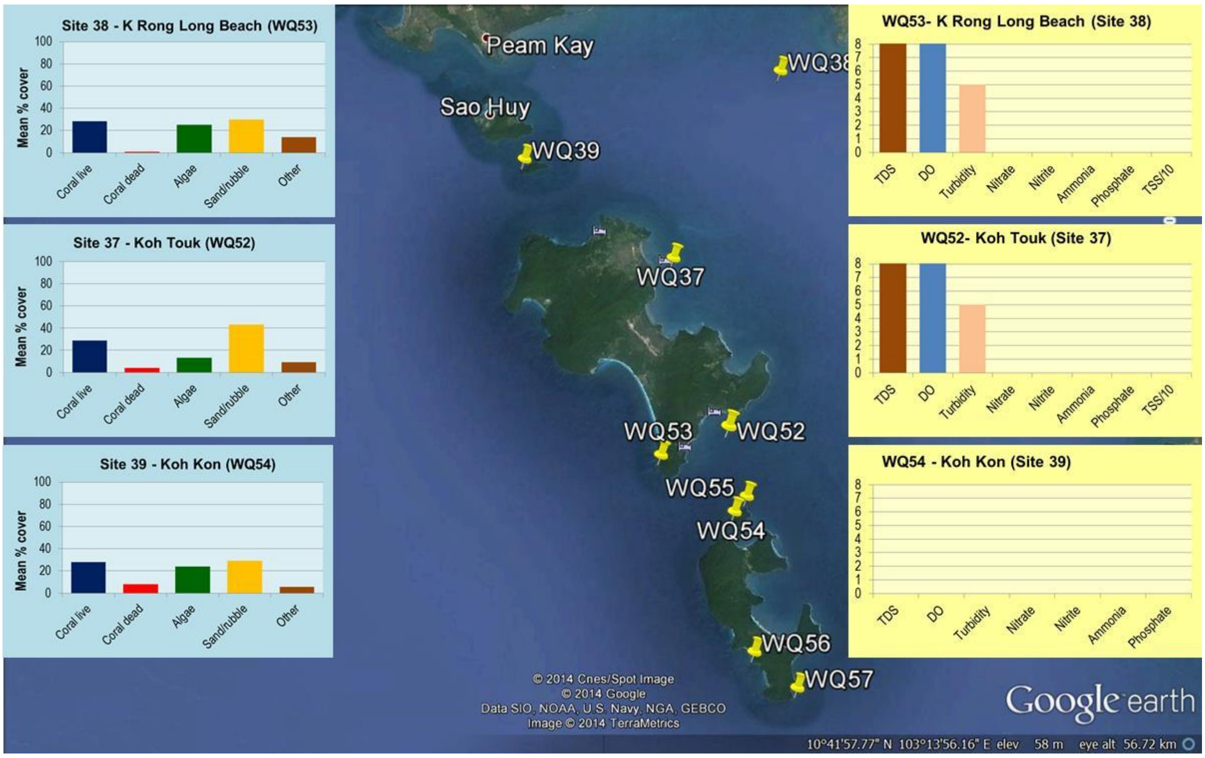


Figure A9 Inshore sample sites around Koh Rong island, Cambodia

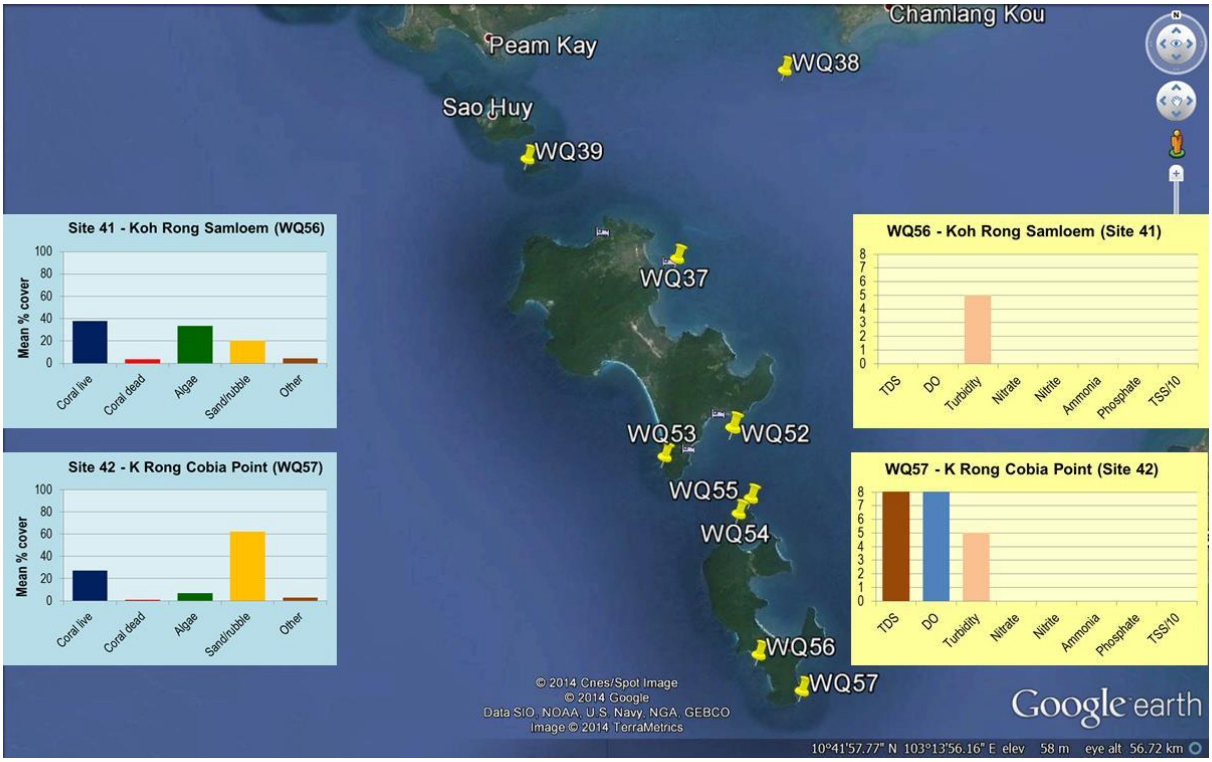


Figure A10 Inshore sample sites around Koh Rong Samloem, Cambodia

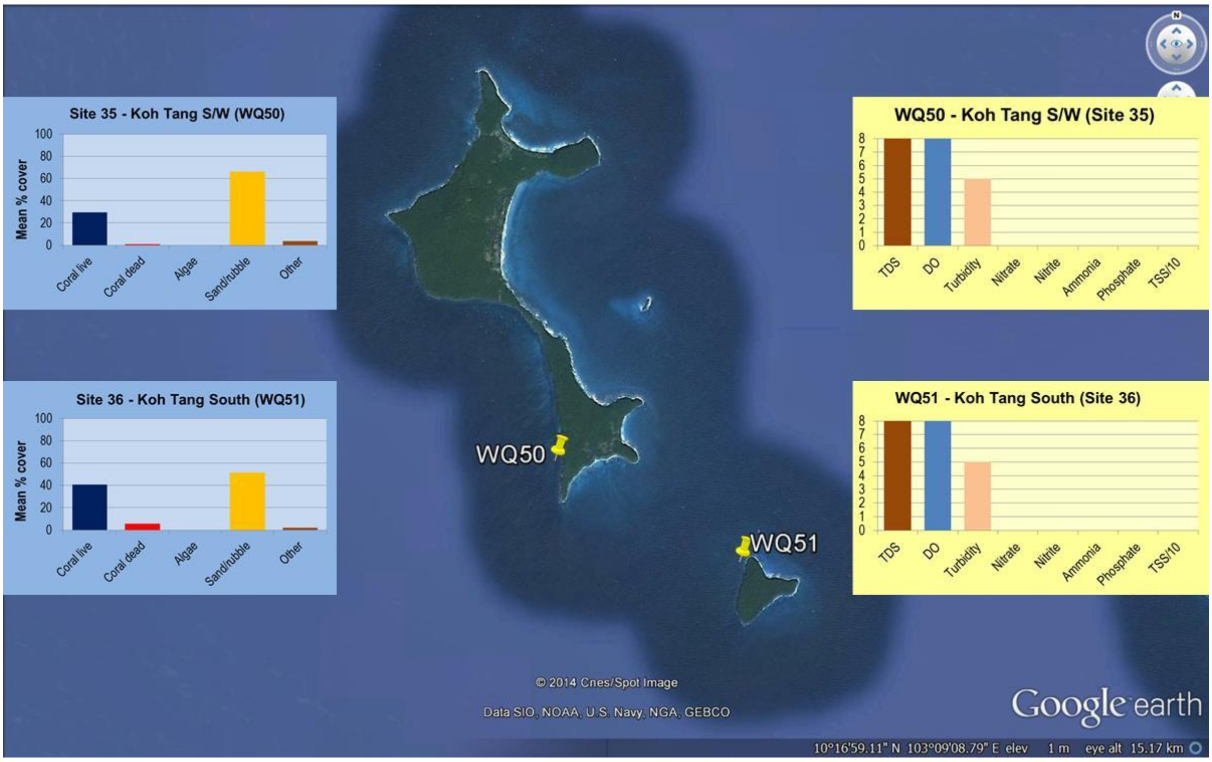


Figure A11 Inshore sample sites around Koh Tang, Cambodia

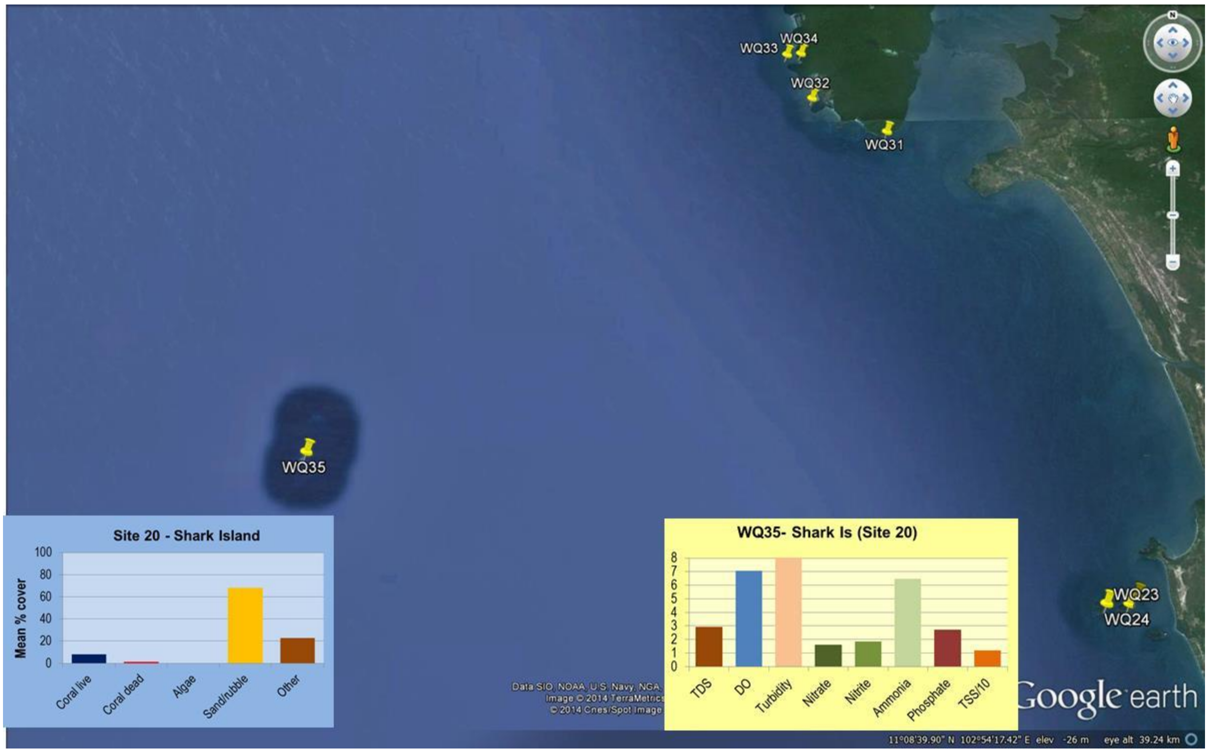


Figure A12 Offshore sample site around Shark Island, Cambodia

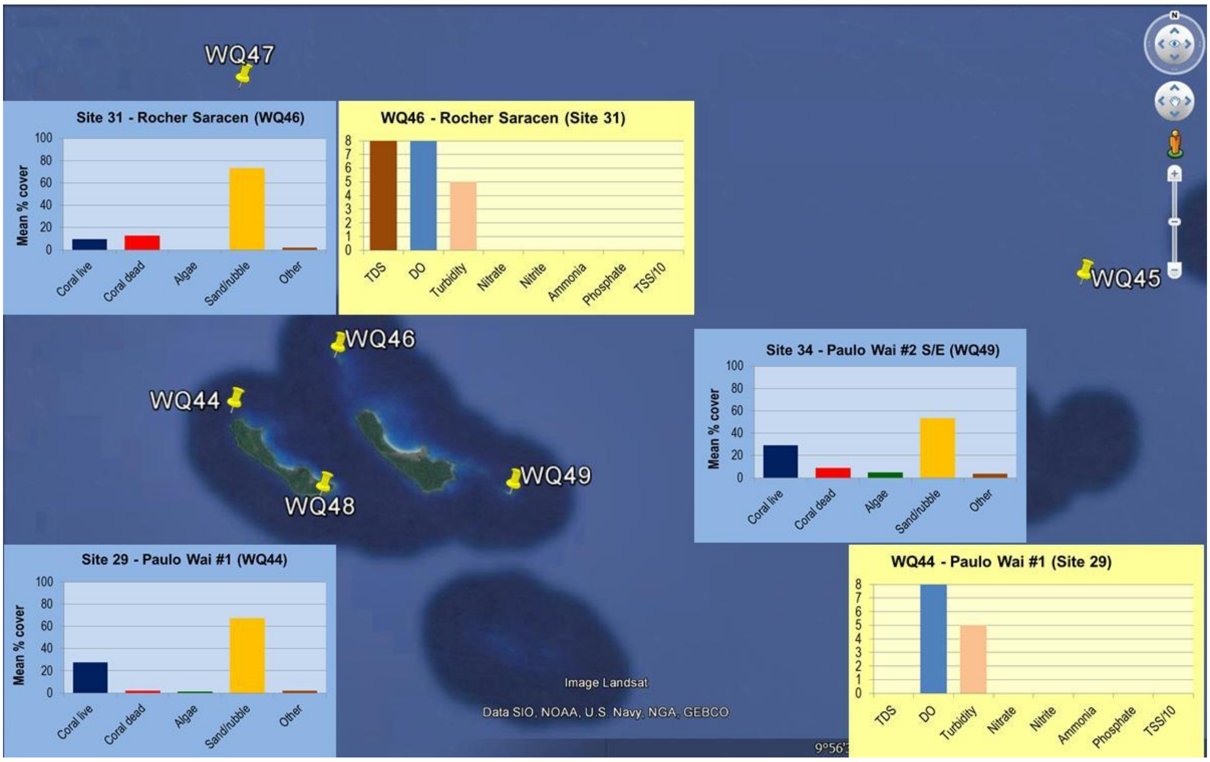


Figure A13 Offshore sample site around Paulo Wai island, Cambodia

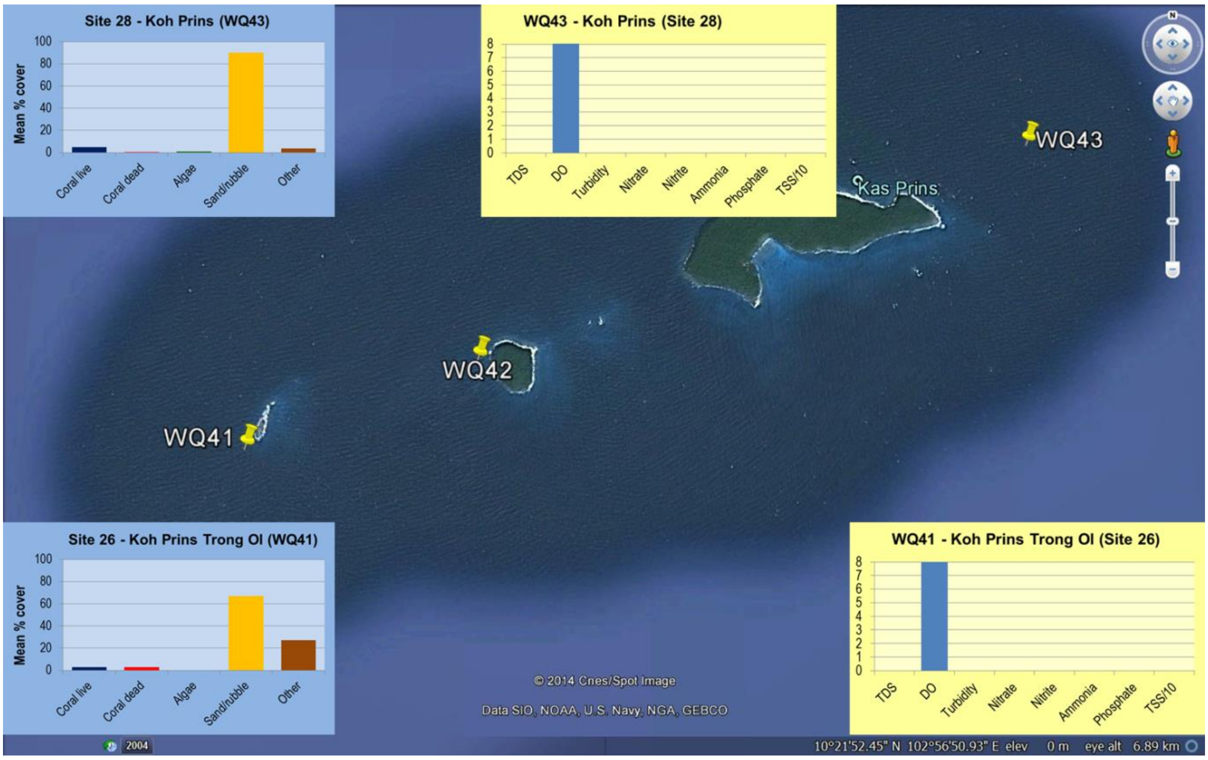


Figure A14 Offshore sample site around Koh Prins island, Cambodia

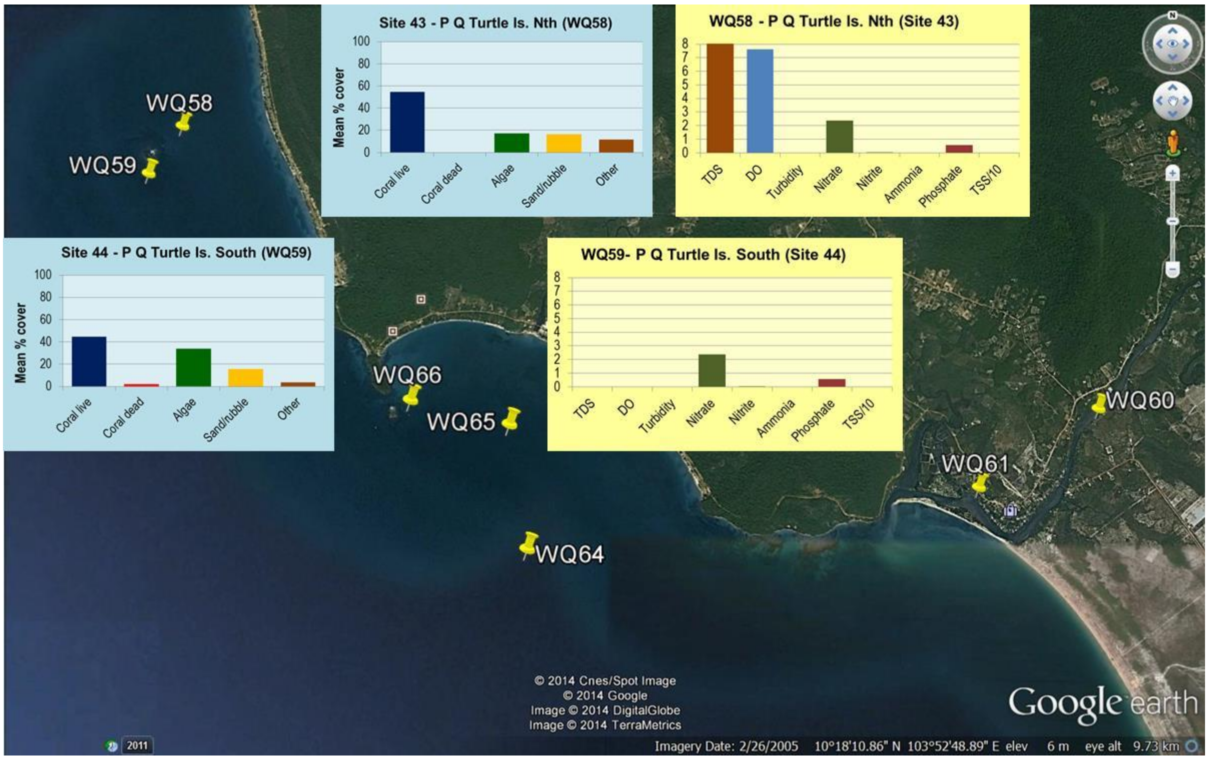


Figure A15 Offshore sample site around Phu Quoc island, Vietnam

Carter, R.W., K. Kelly, H. Beazley, N. Tindale, S. Worachananant, P. Worachananant, S. Thok (2014)
Coral reef and water quality status and community understanding of threats in the Eastern Gulf of Thailand