A Rapid Vulnerability Assessment of Coastal Habitats and Selected Species to Climate Risks

in Chanthaburi and Trat (Thailand), Koh Kong and Kampot (Cambodia), and Kien Giang, Ben Tre, Soc Trang and Can Gio (Vietnam)

Mark R. Bezuijen, Charlotte Morgan and Robert J. Mather

BUILDING RESILIENCE TO CLIMATE CHANGE IMPACTS – COASTAL SOUTHEAST ASIA

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Foreword

“Building Resilience to Climate Change Impacts – Coastal Southeast Asia (BCR)” is a four year project supported by the EU and implemented by IUCN with partners VASI, SDF and GIZ, and operating in 8 provinces of Thailand, Cambodia and Vietnam, along the stretch of the South China Sea Coast between Bangkok and Ho Chi Minh City. The project has developed an integrated community based and ecosystem based approach which it is applying on the ground in project sites (See Chinvanno and Mather, 2011). As part of this overall approach there is a need to understand the context and situation of ecosystems, habitats and species in the project area; a need to understand what is likely to happen to these ecosystems as a result of both climate and non-climate pressures; and finally a need to understand what can be done to maintain and enhance the resilience of habitats and species, and to ensure that ecosystems continue to provide the services on which local communities depend. This assessment addresses all three areas, and provides clear recommendations for priority actions. As such it provides an important contribution to developing and selecting appropriate pilot activities that will be supported in each province by the BCR project.

Robert Mather, Bangkok.

Fisherman in Cambodia

Executive summary

This report presents a rapid assessment of the vulnerability to climate change of coastal habitats and selected species in the eight focal areas of the IUCN project 'Building coastal resilience in Vietnam, Cambodia and Thailand': Koh Kong and Kampot (Cambodia), Chanthaburi and Trat (Thailand), and Ben Tre, Can Gio, Kien Giang and Soc Trang (Vietnam). The aims of this assessment were to identify coastal habitats of highest priority for adaptation planning in the project area, and management issues for some selected species of birds, mammals and reptiles, as well as to assess the sensitivity and adaptive capacity of key fisheries and aquaculture species in light of their expected exposure to climate change risks

Two trial methodologies for 'vulnerability assessment' of habitats and species to climate change were applied for this study. Both were recently developed for the Mekong River Commission by the International Centre for Environmental Management (Bezuijen, 2011; Meynell, 2011). Eight coastal habitats ('in-shore shallow marine waters', 'estuaries/inlets', 'inter-tidal mudflats', 'sandy beaches', 'rocky beaches', 'seagrass beds', 'mangrove forest', 'Melaleuca forest/seasonally flooded grassland'), ten vertebrate species (six mammals, one bird, three turtles) and three avian assemblages ('other large waterbirds', 'medium-sized colonial-nesting waterbirds', 'migratory shorebirds', totaling another 39+ bird species) were assessed using this methodology. To undertake the assessment, data was compiled on habitats, selected species, protected areas and other sites of conservation importance in the project area.

In addition, each of the selected species in the fisheries and aquaculture sector, and three habitat types – mangroves, coral reefs and see grass, were subject to a rapid literature review as to their sensitivities to a range of climate change impacts such as warming sea and air temperatures, sea level rise, changing ocean chemistry, changing ocean circulation, increase in severity/frequency of extreme events and changes in precipitation. Where appropriate, synergistic effects of multiple stressors were considered. Because the vulnerability of habitats and species to climate change is partly dependant on their degree of protection, a brief analysis of protected areas and other sites recognized to be of importance for biodiversity conservation was also conducted.

The marine and coastal habitats of the project area are of global importance for biodiversity conservation. Koh Kong and Kampot retain the most intact natural habitats in the project area; Ben Tre, Can Gio, Kien Giang and Soc Trang support the least intact habitats, due to severe levels of clearance for aquaculture and agriculture. Chanthaburi and Trat lie between these extremes, although large coastal areas of Chanthaburi have been cleared and developed. All provinces possess at least four of the eight habitat categories, ('in-shore shallow marine waters', 'mangrove forest', 'estuaries/inlets', 'inter-tidal mud flats'). 'Melaleuca forest/seasonally flooded grassland' is the most restricted habitat category in the project area and occurs in only three provinces (Koh Kong, Kampot, Kien Giang). At least 13 designated protected areas (one marine, 12 terrestrial), 13 Important Bird Areas (IBAs) and seven Key Biodiversity Areas (KBAs) have been classified in the project area, reflecting the high biodiversity conservation values of this region.

Mangrove ecosystems are vulnerable to changes in air and sea temperature, with processes such as respiration, photosynthesis and productivity likely to be affected. They are particularly vulnerable to rising sea level, and may not be able to retreat landwards if barriers exist. Consequences of climate change impacts as well as anthropogenic impacts may include a productivity loss, with a potentially disastrous knock on effect to many important commercial species of fish and shellfish in the region.

Seagrass systems are extremely vulnerable to any climate change impact which reduces light availability due to their requirement for photosynthesis. This means flooding events, increased turbidity from rainfall and the development of algal blooms due to rising sea surface temperatures and other factors may seriously inhibit seagrass development. In terms of adaptive capacity they are able to regrow after serious physical disturbances and are able to move upslope according to sea level rise.

Coral reef systems are also extremely vulnerable to any factor which reduces water quality and light availability. Bleaching (expelling their symbiotic dinoflagellate zooxanthellae) is a stress response by corals which may be caused by a multitude of factors such as high or low temperatures, high or low irradiance, reduced salinity and the presence of pollutants such as herbicides- which gives a good indication of what these organisms are most sensitive to. Corals will also very likely be severely affected by low pH due to their delicate calcium carbonate exoskeletons. It is thought that corals are able to acclimatise to environmental conditions within limits, such as small temperature variations. There has been no evidence to suggest corals are able to adapt on a genetic level to the synergistic impacts of climate and anthropogenic change. Corals can also shift latitudes, however it is thought the rate of change is too rapid for this to be a viable adaptation option.

For marine and coastal habitats other than coral reefs, the highest potential impact of climate change (without considering existing threats) was assessed to be the 'complete loss' of two categories in some parts of the project area: the inter-tidal mudflats of Ben Tre, Can Gio and Soc Trang and, the Melaleuca forests/seasonally flooded grassland of Kien Giang. For the mudflats, this could result in the loss of a high proportion of this habitat from the Mekong Delta. Most mudflats in the Delta could be permanently inundated by sea-level rise over the next century and may be exposed to increased storm events and tidal surges, with little resilience to these changes, because most coastal vegetation has been cleared and there are few nearby offshore islands which would act as a physical buffer. For Melaleuca forests, the predicted inundation of a single site, U Minh Thuong National Park (Carew-Reid, 2007) in Kien Giang would result in the loss of the largest remaining area of this habitat from the Delta.

For most habitats in most provinces in the project area, the synergistic impact of climate change when assessed in conjunction with existing threats, is considerably greater than climate change alone. Together with existing threats, climate change may cause the 'complete loss' of 'seagrass beds' in five provinces (Kampot, Koh Kong, Chanthaburi, Trat, Kien Giang), 'mangrove forest' in four provinces (Ben Tre, Can Gio, Kien Giang, Soc Trang), 'inter-tidal mudflats' in three provinces (Ben Tre, Can Gio, Soc Trang) and 'Melaleuca forest/seasonally flooded grassland' in one province (Kien Giang). These results suggest that many existing threats currently pose a greater risk than climate change. This is symptomatic of the severe current pressures on biodiversity in most of coastal Southeast Asia.

For the selected species and assemblages, the highest impact of climate change on its own may be the 'complete loss' of one species, River Terrapin. Populations in the project area are critically low and are restricted to two rivers in a single province, Koh Kong. Climate change may result in hotter nests, altered sex ratios, higher egg/hatchling mortality and loss of sandbar nesting sites. Without conservation efforts, the extirpation of this species from the project area is almost certain. Together with existing threats, climate change may cause the 'complete loss' from the project area of another three species, Dugong, Sarus Crane and Hawksbill Turtle, and 'very high' impacts to the three cetaceans, Green Turtle, and the three bird assemblages. These rankings reflect the threatened status of local populations and their dependence on marine or coastal habitats which are also threatened. One assemblage, 'migratory shorebirds', would be impacted by the loss of mudflat feeding grounds due to sea-level rise in Ben Tre, Can Gio and Soc Trang. The loss of mudflats in the Delta may weaken the integrity of the entire East Asian-Australasian Flyway for migratory shorebirds.

The fisheries and aquaculture industries within Thailand, Cambodia and Vietnam provide increasingly important roles in food security and in the economies of all three countries. Since the yield from capture fisheries is not expected to increase in the region, emphasis is being placed on the ability of the aquaculture sector to provide increasing quantities of fish to satisfy increasing demand (FAO, 2011). Brackish water aquaculture usually produces high-value products for export, whilst small-scale freshwater aquaculture is crucial in providing the rural poor with high quality protein food for home consumption (FAO, 2011). The most important species cultured are fish such as seabass and grouper, shrimps, shellfish and crustaceans

Within the marine and brackish water finfish industry, temperature and salinity are controlling factors in development of teleost larvae and juveniles. Seabass are more resistant to temperature, salinity and turbidity fluctuations than other fish such as snapper and as such may be a more suitable species for cage aquaculture in the face of climate change seabass larvae are still highly sensitive to salinity and temperature however, and the thermal limit of this species is still currently not clear.

Disease is also of great concern in the cage aquaculture industry, as historically many different diseases, fungi and other pathogens have caused mass mortality events; which are suggested in the literature to be more common as temperature increases. Teleosts in particular are vulnerable to the secondary impacts of climate change on their food supply which is comprised of trash fish and other fish products. The adaptive capacity of caged teleosts is hindered by the fact that they cannot shift their ranges to suit more favourable conditions as other fish populations can do. Farmers can potentially shift to more resilient species, such as seabass, if conditions become unfavourable for the development of their current teleost species.

Mackerel, which constitute a significant part of the wild capture fisheries for these countries, are sensitive to changes in ocean circulation particularly, as this dictates the spatial distribution of the species via their recruitment and dietary processes. Changes in ocean circulation could mean primary productivity in the region is reduced, reducing food availability for mackerel. Sea level rise and changes to ocean circulation have the potential to act synergistically to influence the larval/juvenile migration of mackerel onshore into mangrove and wetland habitats. Temperature is also extremely important in this species and influences physiological condition, developmental rate, growth rate, swimming ability, reproductive performance and behaviour. Teleosts in general may be sensitive to changes in pH, not only on their skeletal structure but also in influencing metabolic rate as the demand to osmoregulate is more intensive. The adaptive response in mackerel is thought to be shifting latitudes to more favourable conditions, which would likely be further north into the South China Sea. This obviously has important consequences for the fishing industries in Thailand, Cambodia and Vietnam who rely on this species.

Squid have extraordinary 'plasticity' in their life history stages and it has been shown that an increase in water temperature will benefit the species by increasing metabolic and reproductive rates, whilst removing their teleost competitors. There are disadvantages to this increased rate of survival however due to the fact that there is a negative relationship between hatchling size and increased temperature. Squid are highly sensitive to changes in pH, especially in early life stages, which means they will be vulnerable if there is extensive coastal run off or precipitation events as a result of climate change in the region.,. They are trophic opportunists and show much more adaptive capacity for changing environmental conditions than other marine species, and therefore it is possible that squid populations will relocate to more favourable conditions, possibly changing their diet along the way to suit conditions.

Natural resilience to climate change may differ between habitats and between selected species in the project area. Some mangrove communities in Ben Tre, Can Gio, Kien Giang and Soc Trang may shift northward along the Mekong Delta as sea levels rise, but colonization will be limited by the adaptive capacity of individual species and available space. Community composition will probably change, with some species being lost and others becoming more abundant. Seagrasses in the project area may have low resilience to climate change, because suitable conditions for growth may be naturally limited, while the coastline blocks any northward shift to higher latitudes. The remnant Melaleuca forest in Kien Giang has low resilience to climate change, because it is isolated by developed landscapes and some of its flora has little or no tolerance to saltwater.

All protected areas and other sites of conservation importance in the project area are anticipated to be at risk from climate change. Coastal and near-coastal sites in Ben Tre, Can Gio and Kien Giang may be partly or entirely inundated, which could result in the loss of over 140,000 ha of important conservation habitats, principally 'inter-tidal mudflats', 'mangrove forest' and 'Melaleuca forest/seasonally flooded grassland'. In all project provinces, sea-level rise would result in land-use conflict with terrestrial protected areas, as communities are forced to relocate to other areas. This may be most severe in Ben Tre, Can Gio, Kien Giang and Soc Trang. The single marine national park in the project area (Mu Koh Chang in Trat) and three proposed marine protected areas (Kien Giang) may be subject to loss of shallow water zones and sandy and rocky beaches (due to sea-level rise), physical damage of habitats (from increased storms), higher water turbidity, siltation of seagrasses and reefs, and altered productivity due to rising temperatures and water acidity.

Comparison of protected areas with undesignated Important Bird Areas (IBAs) indicates gaps in the current protected area network, which reduces the resilience of habitats and species to climate change. Marine protected areas are under-represented in the project area. In some provinces, there is little overlap between the locations of IBAs and designated protected areas. Undesignated sites may be more vulnerable to climate change because they may not be included in planning for adaptation efforts. Koh Kong probably has the strongest natural resilience to climate change in the project area, because it encompasses a large area of relatively intact and protected coastal habitats with a range of elevations and latitudes. This will enable some terrestrial and aquatic species to shift northward or to higher elevations, to more suitable climate spaces, as temperatures and sea level rise. Protected areas in Ben Tre, Can Gio, Kien Giang and Soc Trang probably have the least resilience to climate change, because they are small, at low elevations and isolated within developed landscapes. Chanthaburi may also have low levels of resilience due to extensive loss of coastal habitats; Trat may lie between these extremes.

Magrove plantation in Koh Kong, Cambodia

Recommendations

The potential impacts of climate change have significant implications for the management of natural resources, local livelihoods, and the coastal economy in the project area. The results of this assessment suggest that two broad approaches for the project area are warranted: firstly development of a range of adaptation responses tailored to individual provinces, contiguous coastal stretches, habitats and species; and, secondly reviews of national and provincial policies on natural resource management; protected area networks and their management effectiveness; and the fisheries and aquaculture sectors in Cambodia, Thailand and Vietnam, in the light of climate change. Recommendations are listed in two groups – those recommendations that should or could be implemented through the BCR project itself, and those that go beyond the scope of the BCR project, requiring a broader effort, although BCR may contribute in some part

Recommendations for BCR

1. Efforts for the management of habitats in the project area should focus on the following habitats of highest priority in the context of climate change: 'seagrass beds' – Kampot, Koh Kong, Chanthaburi, Trat, Kien Giang; 'mangrove forest' – Ben Tre, Can Gio, Kien Giang, Soc Trang; 'inter-tidal mudflats' – Ben Tre, Can Gio, Soc Trang; 'Melaleuca forest/seasonally flooded grassland' – Kien Giang.

2. For Koh Kong (and to a lesser extent Kampot), adaptation planning should focus on maintaining natural resilience, because the province retains large and intact areas of coastal habitats which are partly protected. For Ben Tre, Can Gio, Kien Giang, Soc Trang and Chanthaburi, actions should focus on rehabilitation of habitats, due to the severe loss of coastal habitats in these provinces and high exposure hazard for remaining habitats, species and protected areas.

3. For all provinces, actions should include enhancing resilience, including strengthening of policies and the establishment of new community-managed projects for natural resource management, and/or protected areas, which are developed in the light of climate change. Detailed recommendations for each province are provided in table 12

4. This assessment helps identify management priorities for broad categories of coastal and marine habitats in the light of climate change, but is not based on quantitative analysis. The following additional analyses could be conducted to strengthen and refine the study findings:

- Map and quantify the extent of coastal and marine habitats in the project area. This can be done through a combination of remote sensing, and use of the Shoreline Video Assessment Methodology (S-VAM)

- Estimate the extent of coastal habitats (including offshore islands) to be inundated by sea-level rise. This has already been conducted for the Mekong Delta (Carew-Reid, 2007), including four of the project provinces. A similar analysis could be conducted for the remaining provinces in the project area, Chanthaburi, Trat, Koh Kong and Kampot.

Recommendations going beyond BCR

5. Review management effectiveness and funding for protected areas in coastal provinces: In 2011-2012 through funding support from Mangroves for the Future, IUCN is working with the Department of National Parks (DNP) to conduct a Management Effectiveness Evaluation (MEE) of all 24 Marine and Coastal Protected Areas in Thailand. This includes the Koh Chang MPA in Trat province in the BCR project area. Lessons learned from this could be shared with Cambodia and Vietnam through BCR. IUCN has also conducted a zoning process for Paem Krasop Wildlife Sanctuary in Koh Kong province (An Dara et.al., 2009) with the proposed zoning system being approved by Prime Minister Hun Sen in 2011

6. A vulnerability assessment methodology for protected areas should be developed, similar to the species and habitat methodologies used in this assessment: IUCN Southeast Asia Group is developing a proposal to be submitted to the German government, to develop an assessment of climate change impacts on species and habitats in protected areas in Vietnam, Thailand, and Lao PDR.

7. Research on climate change impacts and adaptive capacity of individual species, including monitoring responses of wild populations of cultured species to provide clues for appropriate adaptation of the aquaculture industry should be promoted.: This assessment shows more clearly than anything else, the huge gaps in our knowledge and understanding of what exactly will happen

to individual species. While the knowledge gaps are too many and too large for a single project like BCR to address alone, BCR should make some contribution to increasing our understanding, by for example supporting continuous monitoring of at least one relevant species in each country. This could be for example Irrawaddy dolphins in Trat, mud crabs in Koh Kong, and migratory shorebirds in Ben Tre and Soc Trang

8. Groundwater extraction in the Mekong Delta is contributing to subsidence and therefore exacerbates the impact of sea level rise on coastal ecosystems in the BCR focal provinces in Vietnam. In addition, coastal ecosystems of Soc Trang and Ben Tre provinces in particular will be affected by upstream development on the Mekong River that changes flows of water and sediment to the coast. IUCN's Mekong Water Dialogues project has recently completed a detailed report on the groundwater situation in the Mekong Delta (Bayly-Stark, 2011), and is also actively participating in regional processes deliberating Mekong mainstream development, with the Mekong River Commission (MRC) and others. This work will be continued until December 2014

9. REDD+ and voluntary carbon markets should be explored for potential to support longer-term restoration and management of coastal ecosystems including mangroves and seagrass in the project provinces. IUCN is already starting to look at these possibilities in Vietnam through a small project supported by the Swedish government.

Children help their parents selling fish

1. Introduction

Climate change presents an ever-increasing threat for virtually all socio-ecological systems. Direct consequences of cumulative post-industrial emissions have been shown to include increasing global temperature, perturbed regional weather patterns, rising sea levels, acidifying oceans and changed nutrient loads (Brierley and Kingsford, 2009) as well as increased severity/frequency of extreme weather events (Brander, 2007). Coastal communities in Southeast Asia are already vulnerable to coastal environmental change in the form of flooding, physical damage from wind and wave action, and economic losses as a result of severe weather and coastal regions of Cambodia, Thailand and Vietnam are predicted to experience rising sea levels and warmer temperatures, altered rainfall, and increased flooding and drought, which is anticipated to cause large impacts across marine and terrestrial ecosystems. The coastal ecosystems and biodiversity of Southeast Asia are considered to be among the most vulnerable in the world to climate change, and the Mekong Delta is ranked as one of the top five 'megadeltas' in the world forecast to be severely impacted by sea-level rise and increased storm and flood events (Cruz et al., 2007). Cambodia and southern Vietnam are identified as particularly vulnerable to climate change, partly due to low current capacity to adapt to anticipated impacts (Yusuf and Francisco, 2009).

Assessment of the vulnerability of natural resources to climate change is a critical first step toward identifying management priorities and developing adaptation actions. Climate change impacts outlined by Brierley and Kingsford (2009) have the potential to threaten fisheries and aquaculture systems by altering water quality (temperature, salinity, pH and presence of diseases, pathogens and toxic events) and local oceanic conditions (flooding, alteration of tides and currents, sea level rise). Climate change can be expected to impact fish production through effects on reproductive success, recruitment processes, survival and growth of target species and/or their prey (Bell et al., 2011). These effects occur both directly, due to inherent sensitivities of marine organisms to changing environmental conditions, and/or indirectly through the influence of climate change on the habitats that support fish or the pathogens that can control their abundance (Brander, 2007; Munday et al., 2008).

Ideally, adaptation planning for biodiversity should be guided by detailed bioclimatic modeling for individual species (e.g. Pearson and Dawson, 2003), which attempts to quantify the potential impacts of climate change scenarios. In reality this is at best a long-term goal, because analysis is time-consuming and requires data on life history parameters, which is limited or absent for many species in Southeast Asia. Rapid vulnerability assessment provides a coarse short-term alternative. In Southeast Asia, the need for adaptation measures to cope with climate change is now widely recognized, yet there is currently no standardized methodology for vulnerability assessment for species or habitats and few explicit examples of assessments. This suggests that adaptation planning for biodiversity conservation is either not occurring at all, or is occurring without consistent approaches to identify management priorities.

This report describes the results of a literature review based rapid vulnerability assessment to climate change for coastal habitats and selected species, in the focal provinces of the IUCN project 'Building Resilience to Climate Change Impacts – Coastal Southeast Asia" funded by the European Commission. The project aims to implement community- and ecosystem-based approaches for adaptation to climate change in eight coastal provinces in the Gulf of Thailand and Mekong Delta: Chanthaburi and Trat (Thailand), Koh Kong and Kampot (Cambodia) and Kien Giang, Soc Trang, Ben Tre and Can Gio (Vietnam). The objectives of this rapid assessment are to:

- identify the vulnerability of coastal habitats and selected species in the IUCN project area to climate change;
- identify coastal habitats of highest priority for adaptation planning; and,
- identify some of the adaptation strategies that may be relevant in the project area.

2. Methods

2.1 Coastal habitats and species addressed in this study

For the purposes of this study the coastal habitats of the IUCN project area were grouped into nine broad categories: ‘in-shore shallow marine waters’, ‘seagrass beds’, ‘mangrove forest’, ‘Melaleuca swamp/seasonally flooded grassland’, ‘estuaries/inlets’, ‘inter-tidal mudflats’, ‘sandy beaches’ ‘rocky beaches’ and ‘coral reefs’. Categories were identified on the basis of project team experience in the project area and existing information.

Commercially important fishery and aquaculture species that support the livelihoods of local people in the project area were identified for review based on consultations with the regional heads of IUCN in the three countries concerned. These species are grouped under the industry of which they belong to for ease of reference, These are the marine and brackish shellfish and shrimp industries (mud crab, green mussel, blood cockle, oyster and shrimp/prawn), the marine and brackish finfish industry (seabass, grouper and other teleosts), and the wild capture industry (Mackerel and Squid).

Six mammal species, one bird species, three bird assemblages (comprising another 39+ species) and three reptile species were also selected for assessment (see Appendix 4 for complete list).

The spread of species was selected to encompass a range of habitat requirements and life histories, and both threatened and common species were included, reflecting the fact that climate change impacts are cross-cutting across many species. Species and justification for their selection are as follows.

- Mammals. Dugong *Dugong dugon,* Irrawaddy Dolphin *Orcaella brevirostris* (marine populations only), Indo-Pacific Humpback Dolphin *Sousa chinensis*, Finless Porpoise *Neophocaena phocaenoides*, Lyles Flying-fox *Pteropus lylei* and Large Flying-fox *P. vampyrus.* The project area supports populations of global and/or regional importance of most of these species. Dugong and the three cetaceans are inshore shallow-water specialists which contribute to ecotourism values in the Gulf of Thailand, and particularly in Cambodia, form part of cultural beliefs of coastal communities. Both bat species are frequently regarded as economic pests, but play an important role in pollination and seed dispersal, and contribute to the maintenance of plant species utilized by local communities in coastal regions of Cambodia, Thailand and Vietnam (Fujita, 1988).

- Birds. Sarus Crane *Grus antigone,* for which the project area supports globally important populations of the subspecies *G. a. sharpii*, with potential to generate income locally from bird-watching tourism, and three assemblages of other bird species:

  ‘Other large waterbirds’ (six species). At least six other large waterbird species, all storks, occur in the study area. All species are heavily hunted and most populations in the project area are in decline.

  ‘Colonial-nesting medium-sized waterbirds’ (14+ species). This assemblage comprises cormorants and darter (three species), egrets and herons (eight species), a spoonbill, and ibis (two species). These species form large nesting or roosting colonies, often in coastal habitats, and are subject to hunting and habitat loss in the study area.

  ‘Migratory shorebirds’ (19+ species). This assemblage comprises non-breeding seasonal visitors to the project area and which congregate in large numbers on inter-tidal mudflats.

- Reptiles. Green Turtle *Chelonia mydas*, Hawksbill Turtle *Eretmochelys imbricata* and River Terrapin *Batagur baska*. All are threatened in the study area and are subject to intensive hunting (historically and/or currently) by local communities, for consumption or commercial sale.

2.2 Compilation of data

The following information was compiled in order to conduct the vulnerability assessments:

- status (location, extent) of habitat categories in the project area (extent was not quantified);

- status, distribution and relevant life history parameters of selected species;

- protected areas and other sites of conservation importance in the project area; and,

- predicted climate change in the project area.

Information on the distribution and extent of coastal habitats was obtained from existing literature, Google Earth© satellite imagery and maps of the project area. Information on species, protected areas and climate change was obtained from published and unpublished reports.

2.3 Vulnerability assessment

The following definitions and ecological principles were used for the vulnerability assessments.

- 'Vulnerability' to climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as "the degree to which a system [or species] is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system [or species] is exposed, its sensitivity, and its adaptive capacity" (Gitay et al., 2002: 74). The IPCC defines three variables necessary to assess vulnerability: the climate hazard (exposure), sensitivity to the hazard, and the capacity to adapt or cope with the potential impacts (Gitay et al., 2002: 4).

- 'Exposure' is the nature and degree to which a species or system is exposed to significant climatic variations. This depends on the extent of climate change across a species range or habitat and degree to which microhabitat buffering could protect individuals (e.g. by providing thermally sheltered habitats under rocks or logs) (Williams et al., 2008 and references therein).

- 'Sensitivity' is "the degree to which a system [or species] is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea-level rise)" (Gitay et al., 2002: 71). The sensitivity of individuals or species is influenced by geographic range and/or population size (species with small ranges and/or small populations are predicted to be more sensitive to environmental change) (Williams et al., 2008).

- 'Adaptive capacity' is the extent to which individuals, populations or species can adjust to change. This includes evolutionary change and/or plastic ecological responses by individuals and populations. All organisms may be expected to have some intrinsic capacity to adapt to changing conditions (Williams et al., 2008). Adaptive capacity may be expressed through relatively 'passive' traits, such as genetic diversity (wide genetic diversity may impart greater natural resilience to change) or phylogeographic diversity (the extent to which genetically different populations of a species are dispersed across the landscape, with more diverse and widely scattered populations probably being more resilient to change). Life history traits will also be important determinants of the ability to adapt to change (species with high reproductive rates, fast life history, short life span and ability to disperse across habitats to track the preferred climate space, are predicted to be more resilient and recover faster from change). More 'active' adaptive capacity is 'plasticity': the ability of an organism to adjust to altered conditions by ecological changes (see below) or evolutionary changes (i.e. through natural selection acting on quantitative traits).

- 'Ecological' plasticity involves active changes in the short-term, by individuals or species, to cope with change, through physiological changes (e.g. acclimation, modified thermoregulation) or behavioural changes [e.g. seeking out shelter within the existing habitat, dispersing away from the site to more suitable areas, changes in diel (24-hour) or seasonal temporal activity, changes in microhabitat use within the site, changes to biotic interactions]. In the short-term, ecological plasticity is likely to be more important than evolutionary potential, because it acts within a generation, whereas evolutionary genetic changes involve multiple generations (Williams et al., 2008).

Williams et al. (2008) identify two assumptions which must be met for successful adaptation to occur: biogeographic connectivity (is there sufficient habitat which will enable individuals to shift to more suitable climate spaces?); and, that there is adequate time for ecological adaptation. Biogeographic connectivity is influenced by at least three variables:

- the extent to which organisms have the opportunity to shift northward to higher latitudes, or upward to higher elevations, to escape rising temperatures. An upward altitudinal shift of 500 m is needed to compensate for a 3.58°C temperature rise and a northward shift of 350 km is required to compensate for a 3.58°C rise (Dudgeon, 2007), or alternatively, 'Elevation is coupled to temperature such that a one degree change in temperature occurs over an elevation of 100 m (dry conditions) or 200 m (wet conditions)… The relationship between latitude and temperature…averages a change of 0.5° latitude per degree temperature change, a polar movement of 55 km per degree of warming….the next century could see 100-1400 m of elevation shifts and/or 60-400 km of poleward movements.' (Bickford et al., 2010: 1046);

- whether habitat corridors (e.g. riverine vegetation and the rivers themselves) are oriented north-south or east-west (north-south oriented corridors provide greater opportunity to move northward to higher latitudes); and,

- whether there are physical barriers along these corridors which will hinder movement (e.g. large roads, dams).

2.4 Assessment methodology

Based partly on the definitions and ecological principles outlined above, Williams et al. (2008) developed a conceptual framework to assess the vulnerability of a species to climate change. Their conceptual approach places 'adaptive capacity' as a variable within 'sensitivity', and does not consider potential synergistic impacts with existing threats.

Bezuijen (2011) applied these definitions and ecological principles, and the conceptual framework of Williams et al. (2008), to develop a trial methodology to assess the vulnerability of species to climate change. The methodology comprises a systematic assessment in a tabular format of potential exposure, sensitivity (based on geographic range, population size and life history traits) and adaptive capacity of a species to climate change. The assessment of adaptive capacity focuses on ecological plasticity and does not consider evolutionary (genetic) adaptive capacity, due to a lack of information on this subject for most species and because it is less likely to be important in the short term for identifying management actions. Exposure, sensitivity and adaptive capacity are each assigned a ranking (Low, Medium High), which are converted into an overall 'vulnerability ranking'. The final step in the process is the assessment of climate change and existing threats. Climate change is anticipated to act in synergy with existing pressures on biodiversity, which may cause net impacts greater than climate change alone (Opdam and Wascher, 2004). This is particularly relevant in much of Asia, including the project area, where existing pressures on species and habitats are severe.

Bezuijen (2011) tested the draft methodology on several species and assemblages, but emphasized it was a trial approach which required field testing and refinement. Meynell (2011) subsequently adapted the methodology of Bezuijen (2011) for the vulnerability assessment of wetland habitats. Both methodologies were developed for the Mekong River Commission by the International Centre for Environmental Management (ICEM).

This paper applies the trial methodologies of Bezuijen (2011) and Meynell (2011), with modifications, to the coastal habitats and selected mammal, bird and reptile species in the project area. This is the first study to apply these trial methodologies and represents a test of both approaches. The need for improvement and further circulation among peers is anticipated. Definitions of terms for each methodology are provided in Appendices 1 and 2. For shellfish and fish , each species was subject to a rapid literature search to determine their sensitivity to the main climate change impacts which are defined as temperature change, sea level rise, changing ocean chemistry, altered ocean circulation, increased severity/frequency of extreme events, changes in precipitation, drought/water stress and other aspects, where secondary and synergistic impacts to the species are considered. An overall summary of vulnerability as ascertained from the literature is then given, followed by a short discussion on the adaptive capacity of the species and/or the industry. Not all climate impacts are considered for all species due to an overall paucity of information on the ecological responses to climate change impacts.

Note that in the climate change literature, 'adaptive capacity' or 'adaptation' also refers to the capacity of humans to manage, adapt and minimise the impacts of climate change. In this report, 'adaptive capacity' refers to the natural capacity of organisms to adapt to change, and 'adaptation' refers to human management efforts undertaken to address climate change.

The steps undertaken in the current study, together with the steps which may occur following this study, are summarized in Figure 1.

2.5 Limitations

Flora and invertebrates were not within the scope of the study. Assessment was limited to species in marine and coastal habitats (given the coastal focus of the IUCN project) and those having some economic, cultural or social significance to local sectors. The latter criterion reflects the fact that biodiversity conservation per se is not the principle objective of the IUCN project.

For the selected species and assemblages assessed in this study, the study findings cannot be used to infer priorities for species conservation in the project area, because only a small number of species was assessed. Many other marine and coastal vertebrate species occur in the project area, including some which are critically endangered, but which were not assessed.

For the vulnerability assessments for both species and habitats, Bezuijen (2011) and Meynell (2011) emphasise that these are trial methodologies which require further testing and refinement. The current study represents the first 'test' of these methodologies. Improvement and further circulation among peers is required. For both methodologies, the ranking of individual variables is subjective and non-quantitative, and results are dependant on available knowledge of habitats and species, which is limited for most species assessed in this study. For species, the methodology is an over-simplification of the complexity of how climate change interacts with a species, and does not consider (for example) cascade effects on other species. These limitations are reiterated here for both methodologies.

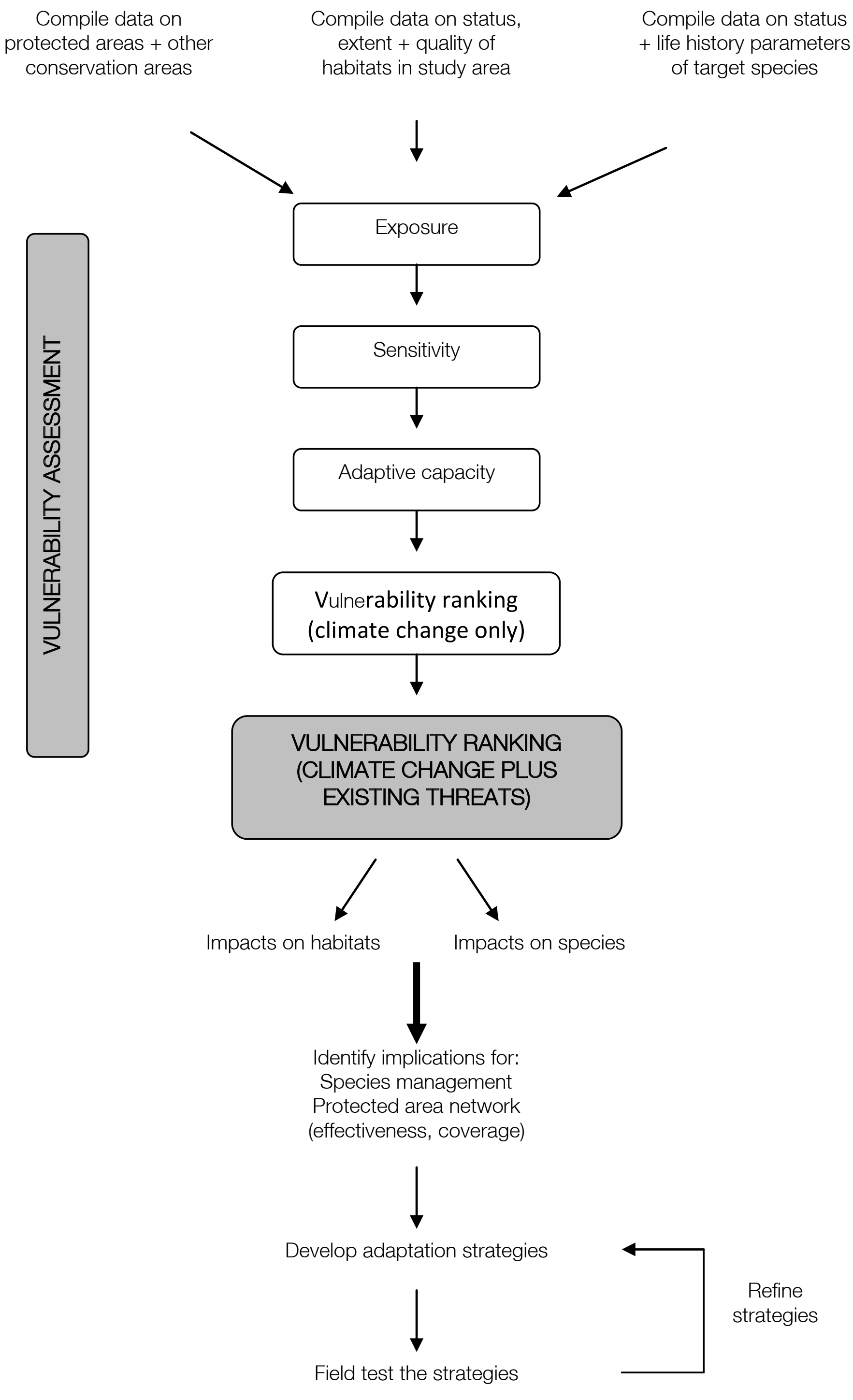

Figure 1. Steps undertaken in the current study (up to 'Identify implication.') and the subsequent steps which could be implemented.

3. The project area

3.1 Coastal habitats

The eight provinces in the project area possess a high diversity of marine and terrestrial coastal habitats. All possess at least four of nine habitat categories, 'mangrove forest', 'estuaries/ inlets', 'inter-tidal mud flats' and 'shallow in-shore marine waters', although the extent and condition of each habitat varies between provinces (Appendix 3). 'Melaleuca swamp/seasonally flooded grassland' is the most restricted habitat category within the project area and occurs in only three of the provinces (Koh Kong, Kampot, Kien Giang). This habitat category is one of the most threatened in the Lower Mekong Basin. It includes Melaleuca forest, mixed peat swamp forest, grassland and a range of largely unique, range-restricted freshwater flora communities (Le Kong Kiet, 1994; Safford et al., 1998; Tran Triet et al., 2000). The U Minh wetlands of Kien Giang and Ca Mau Provinces in the Mekong Delta contain the only mixed peat swamp forest and the most extensive Melaleuca forests in the Delta, and U Minh Thuong National Park, in Kien Giang Province, supports the largest remaining areas of these communities (Safford et al., 1998). Kien Giang encompasses nearly all of the Ha Tien Plain, which forms the western region of the Mekong Delta, and which supports the largest grasslands in the Delta (Tran Triet et al., 2000). Most grasslands have been cleared for development (Tran Triet et al., 2000).

Seagrass beds occur in at least five provinces of the project area, in the Gulf of Thailand and the south-west coast of Vietnam (Appendix 3). In the Mekong Delta, no seagrass beds appear to occur within the project provinces, but at least 100 ha of seagrass beds occur around the Con Dao island archipelago (Cox, 2002), south-east of Soc Trang Province. Mapping of seagrass beds is incomplete in the study area, but suggests that beds are located in relatively discrete patches around islands, in shallow water straits between islands and the mainland, and along short sections of the coast, rather than occurring as continuous beds over very large areas. Small, nearby offshore islands are present in most provinces and support coastal habitats (e.g. mangroves, seagrass beds, sandy beaches). These islands contribute to the natural resilience of the project coastline to climate change, by acting as a physical buffer against storm damage.

Koh Kong and Kampot Provinces retain the most intact natural habitats in the project area, due to low levels of economic development, suggesting they probably also have the highest natural resilience to climate change. In Koh Kong, the presence of large protected areas along the coast also contributes to the maintenance of coastal habitats and natural resilience to climate change (Section 3.3). In contrast, Ben Tre, Can Gio, Kien Giang and Soc Trang have been subject to severe loss of coastal habitats, particularly mangrove and Melaleuca forests, due to development for aquaculture and agriculture. Most of the coastlines and inland areas of these provinces now support shrimp and fish farms and remnant vegetation is fragmented and isolated. Due to high levels of clearance and the lack of offshore islands, these provinces are highly vulnerable to sea-level rise and physical damage from increased storms and tidal surges. Approximately 74% of the coastline in Kien Giang retains mangroves, mostly in poor condition, but which support 27 of the 39 mangrove species known from Vietnam (Duke et al., 2010; their report provides a detailed mapping inventory of this province's shoreline). Shoreline erosion is severe along parts of the Kien Giang coast, partly due to ongoing cutting of mangroves (for fuelwood or other uses) and is resulting in damage or loss of village lands, dykes and fish ponds (Duke et al., 2010). The extent of 'hard infrastructure' coastal development (seawalls, dykes) is highest in Can Gio, where numerous seawalls are present along the coastline. A large seawall is present near Sihanoukville Town in Kampot.

The coastlines of Chanthaburi and Trat lie between the extremes of Koh Kong and the Mekong Delta. Large areas of the coast have been cleared and developed, yet these provinces support the largest remaining mangrove forests in the Gulf of Thailand (around 96 sq. km. each). Between the 1970s and 1990s, approximately 50% of Thailand's mangroves were cleared, mostly for shrimp farms, and national mangrove coverage declined from 3,200 sq. km. (1975) to 1,600 sq. km. (1996) (DMCR, 2007, 2009). Mangrove loss in the Gulf was much higher than along the Andaman coast, which supports over 60% of the remaining mangrove forests in Thailand (DMCR, 2007, 2009). By 2007, mangrove cover had recovered to 2,400 sq.km., largely due to intensive replanting efforts in both provinces, meaning that half of what was lost since the 1970s has been restored since the 1990s (DMCR, 2007, 2009) (although it will take time for these new stands to regain equivalent maturity of stature and species richness) (R. Mather in litt.).

3.2 Selected species

The project area supports a large number of globally threatened marine and terrestrial vertebrate fauna and is of outstanding value for biodiversity conservation (Seng et al., 2003; Tordoff et al., 2002, 2004). In addition to globally threatened species, the project area supports populations of many species of national or regional importance, and many species important for food security and the local economy.

Of the species selected for assessment, little data is available on the status of cetaceans, flying-foxes and sea turtles in the project area. For cetaceans and sea turtles, available information suggests the project area supports breeding populations of regional importance (Appendix 4 and references therein). There is extremely little information on the presence of flying-foxes in the project provinces. Villagers in Paem Krasop Wildlife Sanctuary in Koh Kong reported the presence of a large colony (An Dara et.al., 2009) and both species selected for assessment form breeding and roosting colonies in coastal habitats and are likely to occur in other parts of the project area. The project area is critically important in contributing to the survival of Dugong in the Gulf of Thailand, due to the presence of seagrass beds in the project area. Three provinces in the project area, Koh Kong, Kampot and Kien Giang, support globally important populations of Sarus Crane (Appendix 4 and references therein).

The project provinces in Cambodia and Vietnam also support globally important populations of 'other large waterbirds' and 'migratory shorebirds'. The Mekong Delta supports at least 247 bird species, of which at least 50% (c.123 species) are dependant on wetlands (Buckton and Safford, 2004). This includes 40% of the eastern race *sharpii* of Sarus Crane, at least 35 migratory bird species, and 21 species for which the Delta holds a large proportion of regional or global populations (Buckton and Safford, 2004). The Delta is a critical feeding site for shorebirds along the East Asian-Australasian Flyway.

Despite the high levels of habitat loss in Ben Tre, Can Gio and Soc Trang, these provinces provide critical feeding sites for more than 1% of the total biogeographic (regional) population of at least nine species in the assemblage 'migratory shorebirds' (Nordmann's Greenshank, Asian Dowitcher, Spoon-billed Sandpiper, Oriental Pratincole, Far Eastern Curlew, Malaysian Plover, Black-tailed Godwit, Kentish Plover, Greater Sand-Plover; Tordoff et al., 2002; Buckton and Safford, 2004). These provinces also hold the largest populations of 'medium-sized colonial-nesting waterbirds' in the project area, including more than 1% of the total biogeographic (regional) population of at least eight species in this assemblage (Little Cormorant, Oriental Darter, Great Egret, Chinese Egret, Purple Heron, Black-faced Spoonbill, Glossy Ibis, Black-headed Ibis; Tordoff et al., 2002; Buckton and Safford, 2004).

River Terrapin occurs in a single province in the project area, Koh Kong, and is among the most threatened species in Indochina. Less than 20 mature females may remain along two coastal rivers, Sre Ambel and Stung Kaaong (Platt et al., 2003). This population, together with populations on the east coast of Peninsular Malaysia, was recently recognized as a new and critically endangered subspecies (Praschag et al., 2009).

In general, the project provinces in Cambodia and Vietnam support a higher number of the selected species than in Thailand. The coastal areas of Chanthaburi and Trat Provinces do not appear to support nationally/globally important populations of large waterbirds, colonial-nesting species or shorebirds. The shallow inshore waters of the Thai coastline, and Mu Koh Chang Marine National Park in Trat, support important regional populations of Irrawaddy Dolphin (Trat Bay may support 150-200 individuals; Monanunsap et al. 2010) and probably also Dugong and sea turtles, especially given severe hunting pressures on these species in nearby coastal provinces of Vietnam (Appendix 4 and references therein). Local awareness of cetaceans in Trat is high (Monanunsap et al., 2010), especially given the recent deaths of over 40 dolphins as fishing bycatch (Anon, 2011).

3.3 Protected areas and other sites of conservation importance

The extent to which a species or habitat is impacted by climate change may be influenced by the extent to which it is represented in protected areas, and, the effectiveness of management to reduce existing threats. Protected area networks are globally regarded as a critical factor in maintaining and enhancing the resilience of landscapes and seascapes to climate change (e.g. Dudley et al. 2010; Steffen et al. 2009). A detailed analysis of protected area coverage and management effectiveness in the project area is beyond the scope of this study, but a list of protected areas and other sites of conservation importance were compiled (Appendix 5). This data indicates the following (from Appendix 5 and references therein).

At least 12 officially designated terrestrial protected areas (five national parks, one wildlife sanctuary, one Ramsar site, one nature reserve, one Man and The Biosphere Reserve, one multiple-use area, one non-hunting area, one forest park) and one marine national park are located in the project area. A further three marine protected areas and one nature reserve are proposed. The most number of officially designated sites, and also the largest areas under protection, are in Koh Kong and Kampot Provinces; the least are in Chanthaburi and Trat (Table 1). Mu Koh Chang Marine National Park is the largest marine protected area in the project area. All project provinces have at least one protected area (marine or terrestrial).

Thirteen Important Bird Areas (IBAs) and seven Key Biodiversity Areas (KBAs) have been classified within the project area, reflecting the high biodiversity conservation values of this region. None of these IBAs are located within the Thai project provinces (the nearest are the 'Inner Gulf of Thailand IBA' west of Chanthaburi Province and 'Koh Kapik IBA' in Cambodia, south of Trat Province; Birdlife International 2004), although both the 'Trat Wetlands' and 'Mu Koh Chang' Marine National Park (both in Trat) are classified as KBAs (CEPF, 2007).

Comparison of officially designated protected areas and IBAs indicates that the degree of overlap between these categories is highest in Koh Kong and Can Gio Provinces; in other words, the most important coastal sites identified for bird conservation in these two provinces have been officially protected. There is poor overlap between coastal protected areas and IBAs in three provinces (Kampot, Ben Tre, Kien Giang), even though the total area of protected areas and IBAs in Kampot and Kien Giang is similar (Table 1). The lowest overlap is in Ben Tre, where IBAs encompass 36,000 ha but only 4,510 ha has been protected (Table 1). At least two small coastal protected areas but no IBAs or KBAs occur in Chanthaburi, and no coastal protected areas, IBAs or KBAs appear to occur in Soc Trang, reflecting a lack of conservation values meeting IBA or KBA criteria. In Thailand, the under-representation of mangroves and mudflats within the national protected area system and the need to address this, has been recognised for almost 20 years (Kasetstart University, 1987: 106; Parr, 1994) but not yet adequately addressed.

Table 1. Comparison of Important Bird Areas (IBAs) and designated and proposed protected areas in the project area. See Appendix 5 for data sources.

Country	Province	IBA (ha)	Designated (ha)	Proposed (ha)	Notes
Cambodia	Koh Kong	35,357	242,600	?	2 IBAs, both relatively well-represented
	Kampot	29,705	26,000	?	5 IBAs, poorly represented
Thailand	Chanthaburi	0	>1,520	?	No IBAs or national protected areas
	Trat	0	65,000	?	1 marine protected area
Vietnam	Kien Giang	37,523	39,475	29,100	3 IBAs, poorly represented
	Ben Tre	36,000	4,510	?	2 IBAs, poorly represented
	Can Gio	75,740	75,740	?	1 IBA, well represented
	Soc Trang	0	0	?	No IBAs or national Pas

At least eight IBAs within the project area qualify as Ramsar sites but are not yet officially designated: five in Cambodia (Koh Rong Archipelago and Sre Ambel IBA in Koh Kong; Stung Kampong Smach, Prek Taek Sap and Kampong Trach IBA in Kampot) and three in Vietnam (Ha Tien, U Minh Thuong and Kien Luong IBAs in Kien Giang). No Ramsar sites are designated or proposed in the Thai project provinces (BirdLife International, 2005).

These comparisons are limited because they do not account for the effectiveness of management within these protected areas, nor the presence of any community projects outside protected areas which benefit biodiversity conservation. In addition, sites classified as IBAs are principally based on bird conservation values and do not account for many other biodiversity values in the project area, particularly marine fish, marine habitats, cetaceans, sea turtles and mammals. Nonetheless, this brief analysis indicates the following.

- Marine protected areas are significantly under-represented within the current protected area network in the project area. Given the importance of intact marine systems for resilience against climate change, this suggests that new marine protected areas, or at least community-managed areas, should be initiated.

- In some of the project provinces, there is little overlap between the location of designated protected areas and IBAs. This may reduce resilience to climate change, because conservation efforts may only focus on officially designated sites.

- The existing terrestrial protected area network is most extensive in Koh Kong and smallest in Ben Tre (Appendix 5), suggesting these provinces have the highest and lowest resilience to climate change respectively.

3.4 Climate change

Climate change is usually expressed through the predicted changes in the main variables ofvariables, temperature andrainfall. In the coastal zone the main direct and indirect consequences of climate change that have implications for species and habitats are changes in rainfall, sea surface temperature, sea-level rise, changes in ocean chemistry, and changes in ocean circulation

3.4.1 Changes in precipitation

General global predictions for a warmer world are for an enhanced hydrological cycle with more extreme droughts and floods and enhanced evaporation (Lough, 2007). Regional rainfall patterns, including those associated with monsoons and the El Nino Southern Oscillation (ENSO) may change along with a predicted increase in extreme storm events, leading to flooding, turbidity, and coastal runoff (Solomon et al., 2007). Increased freshwater input into brackish and marine systems has important implications for both wild capture and aquaculture species as it will alter salinity levels. Some marine organisms are able to tolerate some changes in salinity (such as seabass- discussed in more detail in the 'marine and brackish aquaculture' section), however some others have at best, a limited ability to osmoregulate in the presence of freshwater, meaning flood plumes and increased storm activity may be lethal depending on the duration and resulting salinity (Hutchings et al., 2007).

3.4.2 Sea Surface Temperatures (SST)

Globally SSTs have warmed considerably as global climate has warmed over the past century (Lough, 2007). Heat content of the global ocean has increased 2.3 x 1023 joules between the mid-1950s and mid-1990s, which represents a volume mean warming of 0.06 °C, with tropical oceans being around 0.5-1.0C warmer than they were 100 years ago (Hoegh-Guldberg et al. , 2004). There is also evidence that this warming is not just occurring at the surface and that the heat content of the global oceans has increased since 1960 (Barnett et al., 2005). Temperature has been shown to be the most pervasive climate-related influence on biological function (Brierley and Kingsford, 2009), affecting physiological processes ranging from protein damage to membrane fluidity to organ function (Hochachka and Somero, 2002) in marine organisms. Because many marine organisms already live close to their thermal tolerances (Somero, 2002; Hughes et al., 2003), increases in temperature can negatively impact performance and survival (Harley et al., 2006).

In addition to affecting the timing of reproduction, there is evidence suggesting that warming temperatures may affect fecundity of tropical invertebrates such as molluscs (Przeslawski et al., 2008). Changes in temperature may have positive consequences for some tropical fish species due to an increase in primary productivity and metabolic rate (Munday et al., 2007) but in other cases reproductive capacity is reduced and wild stocks become vulnerable to levels of fishing that had previously been sustainable (Brander, 2007). As all three of the countries within the BCR projects have fisheries that are currently overfished and under pressure (FAO, 2011) this presents a situation of particular concern for the future of wild capture fisheries in this region.

3.4.3 Sea level rise

Global sea level appears to be rising by one to two 2mm per year through the thermal expansion of the oceans and the contribution of additional water through the melting of mountain glaciers and continental ice sheets (Lough, 2007). A recent reconstruction of global mean sea level from 1870 indicates that between January 1870 and December 2004, global sea level rose by 195mm (Church and White, 2006). Since the beginning of satellite measurements, sea level has risen about 80 per cent faster, at 3.4 millimetres per year, than the average IPCC model projection of 1.9 millimetres per year (Rahmstorf, 2010). Mangrove systems are particularly vulnerable to rising sea levels; this factor has the greatest long-term impact on mangrove distribution (Lovelock and Ellison, 2007). Likely consequences of sea level rise (SLR) on coastal systems in the BCR project regions include landward migration of mangroves, salt marsh and salt flats up slope, as well as changes in vegetation structure and reduced productivity which will lead to a decrease in the ecosystem services mangroves provide (Lovelock and Ellison, 2007). Where human barriers exist, mangrove systems cannot migrate and therefore a net loss can be expected in many systems in the region. Predicted mangrove losses will also reduce coastal water quality, reduce biodiversity, eliminate fish nursery habitat and adversely affect adjacent coastal habitats (Ellison and Stoddart, 1991). Fisheries are also vulnerable to SLR, especially through effects on those coastal environments which act as nursery grounds such as mangroves and seagrass systems (Munday et al., 2008). SLR will also influence connectivity among meso-scale habitat units such as estuaries, estuarine wetlands and freshwater habitats (Sheaves et al., 2006).

3.4.4 Ocean circulation

According to the review carried out by Przeslawski et al (2008), ocean circulation and upwelling patterns will change across the tropics depending on regional hydrology, although the exact nature of this change is difficult to predict. Ocean circulation has a very strong influence on the ecology of most of the marine organisms covered by this review. Global warming is also expected to increase thermal stratification of the upper ocean thereby reducing the upwelling of nutrients and decreasing productivity (Seibel and Fabry, 2003), which will undoubtedly have far-reaching implications for many marine organisms. Changes in ocean currents and circulation are occurring across the tropics in regionally specific patterns (Goreau et al., 2005) and undoubtedly affect the transport of larvae and recruitment, as shown by the spread of tropical fishes into temperate latitudes (Booth et al., 2007). Larval duration and recruitment success are regulated by physiology and environmental conditions; however ocean currents ultimately control the final destination of the marine larvae, which can mean success or failure for that organism (Becker et al., 2007). A stronger thermal stratification and a deepening of the thermocline could prevent cool, nutrient-rich waters from being upwelled (Roemmich and McGowan, 1995). Because upwelling is of fundamental importance in coastal marine systems, further elucidation of the relationship between climate and upwelling is a high research priority (Harley et al., 2006). There is a paucity of information regarding the potential impacts of altered ocean circulation on commercially important fish and shellfish species in Southeast Asia.

3.4.5 Changing ocean chemistry

Predictions from ocean models suggest that ocean pH several centuries from now will be lower than at any time during the past 300 million years (Caldeira and Wickett, 2003). Reduced pH has been shown to have disastrous consequences for calcifying organisms such as coral (Hoegh-Guldberg, 2007) crustaceans, molluscs, zooplankton, phytoplankton (Chen, 2008) and on other skeletal structures even going as far as to modify the metabolic rate of fish due to compensatory measures taken to regulate pH across their gill systems (Munday et al., 2007). Altering ocean chemistry in the tropics will have widespread implications to a plethora of species groups; marine microbes (Webster and Hill, 2007), plankton (McKinnon, 2007) and macroalgae (Diaz-Pulido et al., 2007) will all be adversely affected by changes in pH, which will have significant knock on effects to the wider ecosystems of which they are a part. The sensitivity of tropical marine fishes and commercially important species to changes in pH at large magnitudes or by large increments is unknown (Munday et al., 2007). Fish eggs are much more sensitive to pH changes than juveniles or adults, and consequently the largest effects of acidification are likely to be on reproductive performance which may flow through to population replenishment if the impacts are sufficiently large (Brown et al., 1989).

3.4.6 Climate change scenarios for the project area

Available data on climate change scenarios for the project area comprise general overviews for Cambodia, Thailand and Vietnam (MRC, 2009a,b; MRC and ICEM, 2009), 2050 scenarios downscaled for the project provinces (Chinvanno, 2011), and modeling for the Lower Mekong Basin for the period 2010-2050 (TKK and SEA START, 2009; Hoanh et al., 2010) and up to 2100 for the Mekong Delta (Carew-Reid, 2007). These studies indicate the following changes in climate may occur in the project area over the next several decades.

- In Cambodia, there may be an increase in mean annual temperature of 1.4-4.3°C by 2100 and an overall increase in mean annual rainfall, with most predicted increase in the wet season. In Thailand, mean annual temperature may increase, the length of the dry season may decrease, there may be higher rainfall in the dry season, and possibly, water shortages in some river basins. In Vietnam, mean annual temperature may increase by 2.5°C by 2070 and there may be increases in mean annual minimum and maximum temperatures. Throughout the region, there will probably be an increase in the frequency, severity and duration of extreme weather events, particularly floods and drought.

- For Koh Kong and Kampot, mean annual minimum and maximum temperatures may increase by up to 1.6 and 2.3°C respectively and there may be 17-25 more days per year with temperatures over 35°C (Suppakorn, 2011). Storms in the Gulf of Thailand, wind speed and number of days with high waves are predicted to increase. In contrast to an overall national increase in rainfall predicted for most of Cambodia (MRC and ICEM, 2009), annual precipitation is predicted to decrease (by -0.5 to -4.5%) in these provinces, with fewer days of rain per year. Sea level could rise by 40 cm by 2050 (Suppakorn, 2011).

- In the Mekong Delta (and Lower Mekong Basin generally), mean annual temperature is predicted to increase up to 0.8°C, the duration of warm periods may increase and also cover much larger areas than currently, and the number of days over 33°C is predicted to increase by 19-65 days/year. Annual precipitation in the Delta is predicted to decrease by 4 to 7% (-50 to -100 mm), in contrast with most other regions of the Lower Mekong Basin, where precipitation is predicted to increase. Despite this, the Delta could experience higher river flows due to increased precipitation and upstream flows. Increased upstream flows could cause greater water availability in the Delta in the dry season, but would also increase the risk of flooding.

- For the Mekong Delta, the highest potential impacts of climate change are predicted to be from sea-level rise. About 30 per cent of the Delta (c.12,376 sq km) is predicted to be inundated by 2100, assuming a 1 m sea level rise (Carew-Reid, 2007). Two provinces in the project area, Ben Tre and Kien Giang, are among the ten provinces of Vietnam which could be the most impacted by sea-level rise (Carew-Reid, 2007). For three project provinces in the Delta, 28-50% of the area of these provinces could be completely inundated (Carew-Reid, 2007; Table 2). Kien Giang may experience the highest flooding of any province in Vietnam, and which could comprise over 12% of the total area of land in Vietnam potentially affected by sea-level rise (Carew-Reid, 2007).

Table 2. Predicted extent of inundation under a scenario of 1-m rise in sea-level, for three provinces of the IUCN project in the Mekong Delta. Data extracted from Carew-Reid (2007: 14-15). Estimates not available for Can Gio Province.

Province	Flooded area (sq km)	% of province area	'Water bodies, wetlands' (sq km)	'Forest and other natural vegetation' (sq km)	Mangrove forest (sq km)
Ben Tre	1,131	50.1	202	39	0.6
Kien Giang	1,757	28.2	34	182	22
Soc Trang	1,425	43.7	157	49	0

- Saline intrusion is already the main factor limiting agricultural production in the Mekong Delta, with almost 2 million hectares of land subject to dry season salinity extending 50 km inland (Carew-Reid, 2007). In Ben Tre and Kien Giang Provinces, saltwater intrusion has occurred over 40 km upstream along some rivers (Carew-Reid, 2007).

- Levels of carbon dioxide are rising globally, but there is little data on specific impacts to biodiversity (Bates et al., 2008). Seawater acidification due to rising carbon dioxide levels is anticipated to cause severe impacts on marine fish, invertebrates, corals and many other fauna (Harley et al., 2006; Gambaiani et al., 2009 and references therein).

The widespread mortality of green mussels in Koh Kong Province worries farmers in 2011 as they observe the changes in season
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4. Vulnerability assessment

4.1 Coastal habitat

4.1.1 Climate change impacts on Mangrove ecosystems:

Mangrove ecosystems in Thailand, Cambodia and Vietnam will undoubtedly have a suite of climate change and other anthropogenic impacts to contend with, and adapt to, in the coming years.

Increasing air temperatures have the potential to impact mangroves as they are exposed to air (Marshall and Johnson, 2007). Many of the species in mangroves are also sensitive to changes in air temperature, particularly extremes of temperature, for example seabirds and marine turtles (Marshall and Johnson, 2007). Ecological impacts on organisms of increased air temperatures include both reduced water availability and range shifting (Hoegh-Guldberg et al., 2004), changes in length of growing season and changes in ecosystem composition (Klein, 1999).

Species groups from plankton to corals, and fish to seabirds, are all sensitive to changes in water temperature (Marshall and Johnson, 2007). Within mangrove systems, processes such as respiration, photosynthesis and productivity will be affected by changes in both water and air temperature, with reduced productivity at low latitudes and increased winter productivity at higher latitudes being the likely consequence (Cheeseman et al. , 1997; Clough and Sim, 1987).

Mangrove systems are particularly vulnerable to rising sea levels; this factor is the greatest long-term impact on mangrove distribution (Lovelock and Ellison, 2007). Likely consequences of SLR on coastal systems in the region include landward migration of mangroves, salt marsh and salt flats up slope, changes in vegetation structure and reduced productivity which will lead to a decrease in ecosystem services mangroves provide (Lovelock and Ellison, 2007). Where human barriers exist, mangrove systems cannot migrate and therefore a net loss can be expected in at least some systems in the Southeast Asian region. Predicted mangrove losses will also reduce coastal water quality, reduce biodiversity, eliminate fish nursery habitat and adversely affect adjacent coastal habitats (Ellison and Stoddart, 1991). Fisheries are also vulnerable to SLR, especially those coastal environments which act as nursery grounds such as mangroves and seagrass systems (Munday et al., 2008). SLR will also influence connectivity among meso-scale habitat units such as estuaries, estuarine wetlands and freshwater habitats (Sheaves et al., 2006). Organisms with historical spawning sites that are topographically distinct and will be altered with sea level change (Kingsford and Welch, 2007).

Flood events and coastal inundation will results in impacts to fish species, especially coastal species and those using mangrove systems as nursery grounds (Lovelock and Ellison, 2007; Munday et al., 2007). Mangroves themselves will be adversely affected by reduced rainfall (Lovelock and Ellison, 2007).

4.1.2 Climate change impacts on coral reef systems:

Perhaps the largest body of literature in the tropical climate change context belongs to the impact of increased water temperature on coral reef systems, and the associated ‘bleaching’ that takes place when corals expel their symbionts, the dinoflagellate zooxanthellae (Veron et al., 2009). Effects of temperature related effects of global warming on coral reefs are highly visible, well-defined and extensively documented (Veron et al., 2009). Small increases (1-2°C) in sea temperature above the long-term summer maxima destabilises the relationship between host corals and their symbiotic algae , on which they rely for energy and growth (Veron et al., 2009). As bleaching is a ‘stress response’ by corals, they will in fact bleach in response to a variety of different factors including high or low irradiance (Lesser et al., 1990), low temperatures (Jokiel and Coles, 1977), reduced salinity (Kerswell and Jones, 2003) and the presence of toxins such as herbicides (Negri et al., 2007) and bacterial infections (Kushmaro et al., 1996). Increased water temperature also has the potential to affect both the reproductive output of parental colonies, and the success of early coral life stages in corals (Hoegh-Guldberg et al., 2007). Experiments have shown incomplete fertilisation in corals as well as a decreased symbiont density in zooxanthellae larvae (Bassim et al., 2002; Edmunds et al., 2005). Tropical cyclones have the potential to cause widespread damage in the region, particularly to coral reef structures from high energy wind and wave action (Fabricus et al., 2007). During cyclone events, reef structure is flattened and coral skeletons are often shifted into large piles or carpets of rubble which are unsuitable as settlement substratum for new corals until consolidation, which may not be the case for decades for inshore reefs (Fabricus et al., 2007). Corals are adversely affected by changes in light regimes, and as such more intense storms and flood events will have detrimental effects (Hoegh-Guldberg et al., 2007).Corals are particularly sensitive to changes in water quality and as a result more frequent and/or intense storm events and cyclones will mean increased flood mortality events, altered coral community composition and tropic cascades resulting from increases in nutrients and sediments (Fabricus et al., 2007). Corals will likely be significantly adversely affected by changes in ocean chemistry which will severely impact their ability to accrete calcium carbonate (Hoegh-Guldberg, 2007).

While few studies have attempted to distinguish individual coral species responses to climate change, Foden et.al. (2011) assessed 799 global warm-water reef-forming coral species against 10 important biological traits that make corals particularly sensitive to climate change. They found 566 species (71%) are potentially susceptible to the impacts of climate change (having at least one sensitivity trait), with 253 of these having between two and six sensitivity traits. Staghorn corals for example have more sensitive species, while mushroom corals, brain corals and cauliflower corals have fewer sensitive species. The study also showed that while 28% of all corals are already threatened with extinction, two-thirds of these species are now additionally threatened by climate change. In addition (and perhaps more worrying) is that of the 72% of all corals that are not currently threatened with extinction, over half of these species are now threatened by climate change (Foden et.al., 2011).

Table 3: Summary of the sensitivities of coastal habitats to climate change impacts

	Coastal habitats		
	Mangrove	Seagrass	Coral reefs
Physical climate parameters	Sensitivity	Sensitivity	Sensitivity
Rainfall increasing	Yes- may affect salinity levels. Mangroves are sensitive to extreme low salinity.	Yes- seagrass are sensitive to changes in light availability and salinity which rainfall may alter	Yes- vulnerable to any impact which reduces light availability and changes in salinity
Rainfall decreasing	Yes- reduces water availability	No- Seagrass do not need freshwater supplies	No- coral reefs do not require freshwater
Air and water temperature increase	Yes- can affect water availability, length of growing season, photosynthesis and overall productivity	Yes- initially higher water temperatures may cause growth increase however seagrass have thermal tolerance beyond which mortality occurs	Yes- coral reef ecosystem highly sensitive to temperature drop or rise
Increase in severity/ frequency of storms	Yes- vulnerable to physical damage	Yes- seagrass are sensitive to physical damage and impacts to the availability of light. Extreme events may cause flooding and sedimentation.	Yes- vulnerable to any impact which reduces light availability and changes in salinity
SLR	Yes- particularly vulnerable to SLR	No- it is thought seagrass have the capacity to move upslope with sea level rise however it is not known whether rate of sea level rise will be too rapid for seagrass to move	Yes- coral reefs are sensitive to sea level rise as it affects their ability to photosynthesise

Salinity changes	Yes- sensitive to very low salinity	Yes- seagrass are vulnerable to low salinity	Yes- vulnerable to freshwater input
pH changes	Yes- sensitive to low pH levels, especially as juvenile marine organisms use mangroves as nursery habitats	Yes- seagrass are vulnerable to changes in pH	Yes- as they require calcium carbonate to build their exo-skeletons
Turbidity	Yes- may affect light availability and decrease water quality- important for many species using mangrove habitats as nurseries	Yes- vulnerable to any impact which reduces light availability	Yes- as increased turbidity affects their ability to photosynthesise
Changes in upwelling	Yes- likely to impact ecosystem dynamics due to the role of upwelling in providing nutrients and food for multitude of marine organisms	Yes- may affect nutrient availability or light availability (if plankton blooms result) which may affect the wider seagrass ecosystem	Yes- may impact the wider coral ecosystem via changes to nutrient availability etc

4.1.3 Climate change impacts on seagrasses:

Seagrass species are going to have to adapt to a wide range of conditions brought about by climate variability including increased temperature and decreased light availability, physical disturbance from cyclone/storm activity, and potentially exposure to nutrients and toxicants. Storms and floods have created highly turbid conditions which have limited light availability for seagrasses in the past and have caused declines of seagrass population in other tropical regions (Shaffelke et al., 2005; Waycott et al., 2007). Seagrasses are also particularly vulnerable to these changes and physical disturbance to seagrasses are likely from sediment movement (erosion and deposition), turbulent water motion and storm surges (Waycott et al., 2007). Flooding from severe storm events reduce salinity and increase turbidity, creating difficult and often fatal conditions for seagrasses to grow in (Waycott et al., 2007).

Sea level rise should not present as much as a threat to seagrasses as to some other ecosystems (e.g. coral reefs). Seagrasses are well adapted to growing both vertically and horizontally, and as such should be capable of growing up slope as sea level rises (Waycott et al., 2007). The potential rate of vertical growth of most seagrasses will be greater than the predicted rate of sea level rise (Waycott et al., 2007).

4.1.4 Vulnerability assessments

A total of 64 vulnerability assessments were conducted (eight habitat categories x the eight provinces in the project area) (Table 3). The assessments indicate the following.

- Without considering existing threats, the highest impact of climate change to habitats in the project area is assessed to be the 'complete loss' of two categories in some parts of the project area: the inter-tidal mudflats of Ben Tre, Can Gio and Soc Trang and, the Melaleuca forests of Kien Giang. For the mudflats, the predicted loss in the project provinces would result in the loss of most of this habitat from the Mekong Delta. Most mudflats in the Delta may be permanently inundated by a one-metre rise in sea level over the century and would be exposed to increased storm events. They are already subject to high exposure hazard with little resilience to further change, because most coastal vegetation has been cleared and there are few offshore islands to buffer against storm damage. For Melaleuca forests, the complete inundation of a single site, U Minh Thuong National Park (Carew-Reid, 2007) would result in the loss of the largest remaining area of this habitat from the Delta. The in-shore shallow waters of the Delta may be more sensitive to rising temperatures than the in-shore waters of Chanthaburi, Trat, Koh Kong, Kampot and Kien Giang, because the large, shallow sheets of water across tidal mudflats may warm more quickly, on a daily and seasonal basis, than slightly deeper areas with more heterogeneous beds and shores.

- For most habitats in most provinces, the synergistic impact of climate change combined with existing threats may be considerably greater than climate change alone. For example, the number of habitats and sites assessed to be under 'very high' impact or 'complete loss' are each three times higher when climate change and existing threats are considered together (Table 4). Results also indicate that in isolation, climate change impacts to a habitat may be considerably lower than when combined with existing threats e.g. in isolation may cause 'medium' impact but with existing threats, may cause 'complete loss'. These findings accord with experimental studies in marine ecosystems (Harley et al., 2006 and references therein).

- These findings suggest two points: first, for most habitats and in most of the project area, existing threats pose a greater threat than climate change; second, that the scale of impact between 'climate change only' and 'climate change + existing threats' is not consistent, indicating the importance of including existing threats in the assessment process.

- Together with existing threats, climate change may cause the 'complete loss' of seagrass beds (in five provinces), mangroves (four provinces), mudflats (three provinces) and Melaleuca forest (one province), and 'very high' impacts to these habitats in the other provinces where they occur (Table 3). These rankings reflect the threatened status of these habitats, due either to their restricted extent (as a result of previous clearance) or ongoing clearance, pollution or other human activities. The loss of Melaleuca forest from only one of the project provinces, Kien Giang, could result in the loss of most of this habitat from the Mekong Delta.

- High impacts to seagrass beds were identified, because impacts could be both extensive and intensive i.e. extending over the entire geographic range of seagrasses within the project area and probably impacting all patches without exception. It seems likely that without conservation actions, large-scale die-off of seagrass beds would eventually occur in the project area, due to increased water depth, greater turbidity due to increased storm events (both of which could release additional terrestrial and marine suspended sediments and pollutants into the water, and reduce light levels and rates of photosynthesis) and physical damage caused by more severe storms. Resilience to climate change may already be low, because the patchy distribution of seagrass in the project area suggests that suitable areas for growth are already naturally limited. The sensitivity of seagrass to climate change has been noted in Europe (e.g. Gambaiani et al., 2009 and references therein).

Table 4. Vulnerability assessment of climate change for coastal habitats in the study area. Method developed by Meynell (2011) and Bezuijen (2011). See Appendix 1 for definitions. CC-climate change, IBA-Important Bird Area, SFG-seasonally flooded grassland, SLR-sea-level rise.

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Cambodia: Koh Kong Province											
In-shore shallow marine waters	Med	High (long coastline)	Not appli-cable	Med (shallow waters suscep-tible to rising temps)	Med	• 40 cm SLR would reduce shallow water habitats; larger storms would cause higher turbidity/siltation • Coastline partly protected by islands	N/a	N/a	N/a	Med	Med
Sandy beaches	High	High	Not appli-cable	Low	Med-High	• Permanent inundation of lower parts of beaches on islands + mainland	N/a	N/a	N/a	Med-High	Med-High
Rocky beaches	High	High	Not appli-cable	Low	Med-High	• Permanent inundation of lower parts of beaches on islands + mainland	N/a	N/a	N/a	Med-High	Med-High
Inter-tidal mudflats	High	Med	Not appli-cable	Low	Med-High	• Permanent inundation due to 40 cm SLR; impacts may be high in IBAs	N/a	N/a	N/a	High	High
Estuaries/inlets	High	High	Not appli-cable	Med-High	Med-High	• Many estuaries intact & retain mangroves–some resilience to CC	N/a	N/a	N/a	Low-Med	High
Seagrass beds	High	Low-Med	?	Low	High	• Large-scale die-off due to increased turbidity (storms, waves)+40 cm SLR	No	No	Low-Med	High	Complete loss

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Mangroves	Med	High	?	Med	Med	• Partial inundation – 40 cm SLR • Resilient due to intact conditon	Yes	No	High	Med	High
Melaleuca/SFG	Med	Med	?	Med	Med	• Loss of community due to reduced rainfall+higher temperatures	Yes	No	High	Med	Very High
Cambodia: Kampot Province											
In-shore shallow marine waters	Med	Med (shorter coastline)	Not appli-cable	Med (see Koh Kong)	Med	• As for Koh Kong Province	N/a	N/a	N/a	Med	Med
Sandy beaches	High	High	Not appli-cable	Low	Med	• As for Koh Kong Province	N/a	N/a	N/a	Med-High	Med-High
Rocky beaches	High	High	Not appli-cable	Low	Med-High	• As for Koh Kong Province	N/a	N/a	N/a	Med-High	Med-High
Inter-tidal mudflats	High	Med	Not appli-cable	Low	Med-High	• As for Koh Kong Province	N/a	N/a	N/a	High	High
Estuaries/inlets	High	High	Not appli-cable	Med-High	Med-High	• As for Koh Kong Province	N/a	N/a	N/a	Low-Med	High

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Seagrass beds	High	High	?	Low	High	• As for Koh Kong Province	No	No	Low-Med	High	Complete loss
Mangroves	Med	High	?	Med	Med	• As for Koh Kong Province	Yes	No	High	Med	High
Melaleuca/SFG	Med	Med	?	Med	Med	• As for Koh Kong Province	Yes	No	High	Med	Very High
Thailand: Chanthaburi Province											
In-shore shallow marine waters	High	High (long coastline)	Not appli-cable	Med (see Koh Kong)	Med	• As for Koh Kong, but coastline more exposed & vulnerable (fewer islands)	N/a	N/a	N/a	Low	Low
Sandy beaches	Low	Low	Not appli-cable	Low	Low	• Vulnerability relatively low because this habitat type poorly represented in this province	N/a	N/a	N/a	Low	Low
Rocky beaches	Low	Low	Not appli-cable	Low	Low	• Low impact-few rocky beaches	N/a	N/a	N/a	Low	Low
Inter-tidal mudflats	High	Med	Not appli-cable	Low	Low-Med	• Permanent inundation due to 40 cm SLR; impacts may be high in IBAs	N/a	N/a	N/a	Med	Med

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Estuaries/inlets	High	Low-Med	Not appli-cable	Low	Med	• Damage from increased storms; lower resilience due to loss of mangroves but replanting is occurring	N/a	N/a	N/a	Med-High	Very High
Seagrass beds	High	High	?	Low	Med	• As for Koh Kong Province	Yes	No	High	Med	Complete loss
Mangroves	High	Low-Med	?	Low	Med-High	• Low resilience due to intensive clearance but replanting is occurring	Little (coast developed)	Partly	Med	Med-High	Very High
Melaleuca/SFG	N/a	None	N/a	N/a	N/a	• No large remnants in study area	N/a	N/a	N/a	N/a	N/a
Thailand: Trat Province											
In-shore shal-low marine waters	Med	High (long coastline)	Not appli-cable	Med (see Koh Kong)	Med	• Coastline has more islands than Chanthaburi & subsequently less exposure to storm damage	N/a	N/a	N/a	Low-Med	Low-Med
Sandy beaches	Med	Med	Not appli-cable	Low	Med	• As for Koh Kong Province; vulnerability higher than Chanthaburi because there is more of this habitat and therefore more extensive impacts	N/a	N/a	N/a	Med	Med

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Rocky beaches	Med	Med	Not applicable	Low	Med	• Permanent inundation of lower parts of beaches on islands + mainland	N/a	N/a	N/a	Med	Med
Inter-tidal mudflats	High	Med	Not applicable	Low	Low-Med	• Permanent inundation – 40 cm SLR	N/a	N/a	N/a	Med-High	Med-High
Estuaries/inlets	High	Low-Med	Not applicable	Low	Med	• As for Chanthaburi Province	N/a	N/a	N/a	Med-High	Very High
Seagrass beds	High	Med	?	Low	Med-High	• As for Koh Kong Province	Yes	No	High	Med-High	Complete loss
Mangroves	High	Low-Med	?	Low	Med-High	• As for Chanthaburi Province	Some (coast developed)	Partly	Med	Med-High	Very High
Melaleuca/SFG	N/a	None	N/a	N/a	N/a	• No large remnants in study area	N/a	N/a	N/a	N/a	N/a
Vietnam: Kien Giang Province											
In-shore shallow marine waters	Med	High (long coastline)	Not appli-cable	Med (see Koh Kong)	Med	• As for Koh Kong Province	N/a	N/a	N/a	Med	Low-Med

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Sandy beaches	Med	Low	Not applicable	Low	Med	• Permanent inundation – 40 cm SLR	N/a	N/a	N/a	Med	Med
Rocky beaches	High	Med-High (Phu Quoc)	Not applicable	Low	Med-High	• Permanent inundation – 40 cm SLR around islands + mainland	N/a	N/a	N/a	Med-High	Med-High
Inter-tidal mudflats	High	Med	Not applicable	Low	Low-Med	• Permanent inundation – 40 cm SLR	N/a	N/a	N/a	Med-High	Med-High
Estuaries/inlets	High	High	Not applicable	Low	High	• Bank erosion, mangrove loss, due to storm damage, altered river flows • Highly cleared – low resilience to CC	N/a	N/a	N/a	High	Very High
Seagrass beds	High	Med (Phu Quoc)	?	Low	Med-High	• As for Koh Kong Province	Yes	No	High	Med-High	Complete loss
Mangroves	High	Low	?	Low	High	• Inundation-40 cm SLR; little scope for expansion-other lands cultivated	No	Yes	Low	Very high	Complete loss
Melaleuca/SFG	High	High	High	Med-High	Med-High	• Complete inundation of U Minh Thuong NP due to 1 m SLR	No	Yes	Low	Complete loss	Complete loss

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Vietnam: Ben Tre Province											
In-shore shallow marine waters	High	Med (short coastline)	Not appli-cable	High (large very shallow tidal areas in Delta)	High	• Increased turbidity-more storms; 1 m SLR. Low resilience-most coastal vegetation already cleared • Large areas of very shallow waters may be warmed more easily than deeper areas along Thai/Cambodian coast (even those areas still termed 'in-shore shallow waters')	N/a	N/a	N/a	Med	Med
Sandy beaches	N/a	None	Not appli-cable	N/a	N/a	• Few sandy beaches occur naturally	N/a	N/a	N/a	N/a	N/a
Rocky beaches	High	Low	Not appli-cable	Low	Low-Med	• Few rocky shores occur naturally	N/a	N/a	N/a	Low	Low
Inter-tidal mudflats	High	High	Not appli-cable	Low	High	• Permanent inundation – 1 m SLR	N/a	N/a	N/a	Complete loss	Complete loss
Estuaries/inlets	High	High	Not appli-cable	Low	High	• As for Kien Giang Province	N/a	N/a	N/a	High	Very high

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Seagrass beds	?	?	?	?	?	• No data located for Ben Tre Province	?	?	?	?	?
Mangroves	High	Low	?	Low	High	• Permanent inundation – 1 m SLR	No	Yes	Low	Very high	Complete loss
Melaleuca/SFG	N/a	None	N/a	N/a	N/a	• No large remnants in study area	N/a	N/a	N/a	N/a	N/a
Vietnam: Can Gio Province											
In-shore shallow marine waters	High	Med (short coastline)	Not appli-cable	High (see Ben Tre)	High	• As for Ben Tre Province	Yes (see above)	No	High	Med	Med
Sandy beaches	Low	Low	Not appli-cable	Low	High	• Few beaches but all could be subject to permanent inundation with 1 m SLR	Low (land cultivated)	No	Med	Med	Med
Rocky beaches	High	Low	Not appli-cable	Low	Low-Med	• Relatively low loss of rocky shores due to natural paucity in province	Yes	No	High	Low	Low
Inter-tidal mudflats	High	High	Not appli-cable	Low	High	• Permanent inundation – 1 m SLR	N/a	N/a	N/a	Complete loss	Complete loss
Estuaries/inlets	High	High	Not appli-cable	Low	High	• As for Kien Giang Province	N/a	N/a	N/a	High	Very high

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Seagrass beds	?	?	?	?	?	• No data located for Can Gio Province	?	?	?	?	?
Mangroves	Med	High	?	Med	Med	• Permanent inundation-1 m SLR • Some large inland patches-may be buffered from storm damage + SLR	No	Yes	Low	Med-High	Complete loss
Melaleuca/SFG	N/a	None	N/a	N/a	N/a	• No large remnants in study area	N/a	N/a	N/a	N/a	N/a
Vietnam: Soc Trang Province											
In-shore shallow marine waters	High	Med (short coastline)	Not appli-cable	High (see Ben Tre)	High	• As for Ben Tre Province	Yes (see above)	No	High	Med	Med
Sandy beaches	None	None	Not appli-cable	N/a	N/a	• As for Ben Tre Province	N/a	N/a	N/a	N/a	N/a
Rocky beaches	High	Low	Not appli-cable	Low	Low-Med	• Relatively low loss of rocky shores due to natural paucity in province	Yes	No	High	Low	Low
Inter-tidal mudflats	High	High	Not appli-cable	Low	High	• Permanent inundation – 1 m SLR	N/a	N/a	N/a	Complete loss	Complete loss

Habitat	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity (only applicable to vegetation communities)			Vulnera-bility	Vul.+other threats
		Extent in wetland/ region	Vegetation species rich-ness	Life history traits OR other*	Over-all		Adequa te suitable space for change?	Physical barriers to movement?	Overall		
Estuaries/inlets	High	High	Not appli-cable	Low	High	• As for Kien Giang Province	N/a	N/a	N/a	High	Very high
Seagrass beds	?	?	?	?	?	• No data located on Soc Trang Province	?	?	?	?	?
Mangroves	High	Low	?	Low	High	• As for Kien Giang Province	No	Yes	Low	Very high	Complete loss
Melaleuca/SFG	N/a	None	N/a	N/a	N/a	• No large remnants in study area	N/a	N/a	N/a	N/a	N/a

*For the abiotic habitat categories, this refers to the perceived sensitivity of the habitat to climate change. For example, 'in-shore shallow waters' would be more sensitive to rising temperatures than deeper water columns.

- For mangrove forest in Ben Tre, Can Gio, Kien Giang and Soc Trang Provinces, colonization of some species northward along the Mekong Delta will probably occur, but would be unlikely to replace the full species richness and diversity of existing communities in the project area due to (a) the limited area of upstream habitat available for colonization, and (b) differing requirements of individual mangrove species to saltwater concentrations and tidal regimes. Under a scenario of a one metre rise in sea level, the composition of mangrove communities in the project area would probably change significantly, with the loss of some species and increased abundance of others.
- For Melaleuca forest and freshwater swamp communities in Kien Giang, adaptive capacity to climate change is limited because most surrounding areas are cleared for agriculture. Freshwater communities within the province will probably be lost due a lack of tolerance for saltwater, and opportunities for northward colonization are limited due to competing land uses. Purely from the perspective of biodiversity conservation, the protection of remnant grasslands in Kien Giang would be one of the highest priorities for this province, given the severely threatened status of this ecosystem

Table 5. Summary of vulnerability assessments for coastal habitats and selected species in study area. For the habitat categories, assessments add to 64 (8 categories x 8 project provinces).

Vulnerability ranking	Habitat categories		Species (10 spp., 3 assemblages)	
	Climate change only	Climate change + existing threats	Climate change only	Climate change + existing threats
Low / Low-Medium	9	8	2	0
Medium/Medium-High	30	17	5	2
High/High-Very high	8	6	2	0
Very high	3	10	3	7
Complete loss	4	13	1	4
Not applicable (habitat not in site)	7	7		
Unknown (insufficient information)	3	3		

- Small, isolated habitats may be subject to proportionately high losses. For example, sandy beaches form a small component of the coastline in Can Gio Province, but are already threatened by extensive development of sea walls and other ‘hard’ infrastructure. Increased wave damage and sea-level rise may result in the loss of small habitats in such sites.
- The natural north-south orientation of rivers in the project area provides some resilience to climate change, because it provides some organisms the opportunity to shift to new climate spaces by moving north to higher latitudes along rivers and riparian corridors. Koh Kong and Kampot probably have the highest natural resilience to climate change in the project area, because they retain the most extensive, intact and protected terrestrial habitats, including coastal rivers, and a range of elevations near the coast. This provides organisms the opportunity to shift northward (to higher latitudes) or upward (to higher elevations). In the other provinces in the project area, remnant terrestrial habitats are small and largely bounded by developed lands at low elevations, providing little opportunity for a shift northward or to higher elevations. For these reasons natural resilience to climate change is probably lowest in five provinces, Ben Tre, Can Gio, Kien Giang, Soc Trang (Mekong Delta) and Chanthaburi. These differences have implications for the nature of adaptation planning (Section 5).
- The highest conservation priorities for coastal habitats in the project area are those most at risk of ‘complete loss’: seagrass beds (for which conservation efforts should be focused on Kampot, Koh Kong, Chanthaburi, Trat and Kien Giang Provinces), inter-tidal mudflats (Ben Tre, Can Gio, Soc Trang), mangrove forest (Ben Tre, Can Gio, Kien Giang, Soc Trang) and Melaleuca forest (Kien Giang). Habitats potentially subject to ‘very high’ impacts are in Table 5.

Table 6. Habitats and selected species assessed to be most vulnerable from the combined effect of climate change and existing threats. SFG-seasonally flooded grassland. CA-Cambodia, IBA-Important Bird Area, TH-Thailand, VN-Vietnam.

	Vulnerability	Provinces in project area which will be impacted
Habitat		
Seagrass beds	Complete loss	CA – Kampot, Koh Kong; TH – Chanthaburi, Trat; VN – Kien Giang
Inter-tidal mudflats	Complete loss	VN – Ben Tre, Can Gio, Soc Trang
Mangroves	Complete loss	VN – Ben Tre, Can Gio, Kien Giang, Soc Trang
	Very high	TH – Chanthaburi, Trat
Melaleuca forest/SFG	Complete loss	VN – Kien Giang
	Very high	CA – Kampot, Koh Kong
Selected species (incomplete for study area)		
Dugong	Complete loss	CA – Kampot, Koh Kong; TH – Chanthaburi, Trat; VN – Kien Giang
Sarus Crane	Complete loss	VN – Kien Giang (Ha Tien, Kien Luong, U Minh Thuong IBAs)
Hawksbill Turtle	Complete loss	CA – Kampot, Koh Kong, VN – Kien Giang (nesting beaches)
River Terrapin	Complete loss	CA – Koh Kong

4.3 Selected species of mammals, birds and reptiles

The Intergovernmental Panel on Climate Change (IPCC) concludes that approximately 20-30% of plant and animal species are likely to be at increasingly high risk of extinction as global mean temperatures exceed warming of 2-3°C above pre-industrial levels (Fischlin et.al., 2007). More specifically for birds (an information rich group), a recent study (Foden et.al., 2011) identified that 35% of the world's 9,856 bird species possess at least one trait that makes them sensitive to climate change and 1,288 species have between two and seven of these traits. Sensitivity varies greatly between groups, with eg 70% of sandpiper species showing sensitivity traits at one extreme, and only 3% of herons and egrets showing sensitivity traits at the other extreme. In addition the study showed that while 12% of all bird species are threatened with extinction, five-sixths of these are now additionally susceptible to climate change. Conversely of the 88% of birds not currently threatened with extinction, almost one-third of these are now potentially threatened by climate change.(Foden et.al., 2011)

A total of 13 vulnerability assessments were conducted for the ten species and three assemblages selected for this study (Table 6). The assessments indicate the following:

- Without considering synergistic impacts with existing threats, the highest impact of climate change for the selected species could be the 'complete loss' of one species, River Terrapin. Populations of this species are critically low in the project area and globally, are restricted to two rivers in a single province, Koh Kong, and are threatened by over-collection of eggs. This species exhibits temperature-dependant sex determination, and rising temperatures may result in hotter nests, altered sex ratios and higher egg/hatchling mortality (Table 6; Appendix 4 and references therein). In addition, the loss of sandbar nesting beaches due to altered river flows has been documented elsewhere in South-East Asia, where upstream dam construction has reduced flood pulses which maintain sandbar formation and reduce invasion of nesting sites by woody weeds (Kalyar et al., 2007). Reduced rainfall and elevated levels of carbon dioxide may have similar impacts and inhibit the maintenance and formation of nesting sandbars. Considered with existing threats, without active conservation efforts the complete loss of River Terrapin from the project area seems certain.

- For four species (Dugong, Sarus Crane, Green Turtle, Hawksbill Turtle) and one assemblage ('migratory shorebirds'), the vulnerability to climate change on its own was ranked as 'very high'. For Dugong, this reflects the very low numbers of this species remaining in the project area and Gulf of Thailand generally, and its dependence on seagrass beds, which is ranked as one the most highly threatened habitats (Section 4.1). For sea turtles, this reflects the low numbers remaining in the project area, anticipated loss of nesting beaches due to sea-level rise, damage to critical feeding habitats (coral reefs, seagrass beds), impacts due to temperature-dependant sex determination (see above for River Terrapin) and possibly also a reduction in food sources due to climate change impacts to marine flora and invertebrates. Sea turtles have high dispersal ability and may shift to higher latitudes by moving out of the Gulf of Thailand and east along the Vietnamese coast. It is possible that populations in the Gulf of Thailand represent genetically discrete populations, in which case extirpation (due to loss nesting beaches and rising temperatures) or a permanent shift from the Gulf (by active dispersal of individuals), would both ultimately result in the regional loss of these populations. Sea turtles use oceanic currents for migration and dispersal, and the modification of currents in the Gulf due to global warming (already documented in some regions) could result in individuals being unable to locate feeding or breeding sites (Bickford et al., 2010).

- For 'migratory shorebirds' in the project area, the greatest impact of climate change would probably be the large-scale loss of inter-tidal mudflat feeding grounds in Ben Tre, Can Gio and Soc Trang, due to sea-level rise. The ability of birds to relocate to nearby sites would probably be limited, because at least one alternative feeding area, the Red River Delta (northern Vietnam) is also forecast to lose large areas to sea-level rise (Cruz et al., 2007). Mudflats at the 'Inner Gulf of Thailand' IBA may be less impacted, suggesting the importance of this site for shorebirds will increase in the future. Loss of mudflats as the sea rises would cause crowding and increased competition for food, which would place populations under stress and could also facilitate disease spread e.g. avian influenza (although the effects of climate change on this disease are unclear; Gilbert et al., 2008). Crowding would also increase the vulnerability of birds to hunting. Rising temperatures may also alter the productivity and abundance of invertebrate prey species. In general, low-latitude, heat tolerant species live within narrower thermal ranges than high-latitude species (Harley et al., 2006 and references therein), suggesting that in the remaining mudflats in the Delta which are not inundated by sea-level rise, some invertebrate populations may decline as they are subjected to rising temperatures. These anticipated impacts in the Mekong Delta would probably weaken the integrity of the entire East Asian-Australasian Flyway for migratory shorebirds.

- Similar to the coastal habitats in the project area (Section 4.1), the potential impact of climate change is considerably higher for most species when assessed in synergy with existing threats (Tables 4, 6). Together with existing threats, climate change may cause the 'complete loss' of four species from the project area, Dugong, Sarus Crane, Hawksbill Turtle and River Terrapin. For Sarus Crane, this is due to the threatened status of populations in the study area and the restricted grassland habitat it depends on (Section 4.1).

- Together with existing threats, climate change may cause 'very high' impacts to the three cetacean species assessed (Irrawaddy Dolphin, Indo-Pacific Humpback Dolphin, Finless Porpoise), Green Turtle, and the three bird assemblages ('other large waterbirds', 'medium-sized colonial-nesting waterbirds', 'migratory shorebirds'). The cetaceans are inshore shallow-water specialists and are vulnerable to changes along the coast, although Irrawaddy Dolphin and Finless Porpoise may partly adapt to climate change by exploiting new estuarine habitats created by saltwater intrusion along rivers. Potential impacts to cetaceans include reduced prey populations, resulting in more time required to catch prey and subsequently less time/energy budgets for other activities (e.g. reproduction), and sub-optimal marine habitats due to freshening of seawater and warmer temperatures (from higher rainfall and ambient temperatures respectively) (e.g. Gambaiani et al., 2009; Simmonds and Eliott, 2009 and references therein). Climate change impacts could also act in synergy with existing pressures on cetaceans from commercial fisheries (which reduce cetacean food sources and result in drowning in fishnets) (Gambaiani et al., 2009). Impacts to Green Turtle are assessed as being lower than for Hawksbill Turtle, because higher numbers persist in the project area.

- For the bird assemblages 'other large waterbirds' and 'medium-sized colonial-nesting waterbirds', sea-level rise and possibly the long-term effect of reduced rainfall, could cause the loss of established foraging and breeding sites used by large colonies. Vulnerability is assessed as 'very high' rather than 'complete loss' for 'large waterbirds' because these species have high dispersal ability and may shift to wetlands further north in the Lower Mekong Basin and other parts of Cambodia and Vietnam. Many species in the assemblage 'medium-sized colonial-nesting birds' are relatively common and widespread across mainland Southeast Asia and some may be able to adapt to altered wetland habitats or shift to other areas. For some however, such as Chinese Egret (a coastal specialist which is already globally threatened), adaptive capacity may be lower and impacts higher.

- Rising temperatures are generally anticipated to result in higher disease risks for terrestrial and marine species, due to increased rates of development, survival and transmission of pathogens, and increased host susceptibility (Harvell et al., 2002).

- Comparison of results for the habitat and species vulnerability assessments shows that landscapes which may have high ecological resilience to climate change may still possess species highly vulnerable to climate change. For example, Koh Kong probably has the highest overall ecological resilience to climate change among the provinces in the project area (Section 4.1), yet also has the species which may be most affected by climate change, River Terrapin. This indicates two points: that both habitat-based and species-based assessments are required to assess the vulnerability of biodiversity to climate change; and, that adaptation planning is required at a range of scales for landscapes and species to address climate change impacts.

- The results of the species vulnerability assessment cannot be used to identify priorities for adaptation planning for vertebrate fauna in the project area (which was not the aim of this study), because only a small subset of total species richness has been examined. To identify species conservation priorities for the project area will require vulnerability assessments to be undertaken for the remaining threatened species in the project area, and ideally, for all known marine and coastal fauna in the project area.

- The natural resilience to climate change of other marine and terrestrial fauna in the project area will vary widely. In the Mekong Delta, small mammals and birds, terrestrial invertebrates and freshwater flora communities are largely confined to small remnant habitats and would have little opportunity to shift northward or to higher elevations. U Minh Thuong National Park is one of the few known sites of the Hairy-nosed Otter *Lutra sumatrana*, a critically endangered species; the predicted inundation of the entire park by a one-metre rise in sea level (Carew-Reid, 2007) would probably result in the extirpation of this population. Saltwater intrusion would probably benefit euryhaline (wide salinity tolerance) fish and invertebrates, and their upstream range and biomass may increase; in contrast, stenohaline (narrow salinity tolerance) fish and invertebrate species would be displaced further upstream, resulting in range contraction and loss of biomass of these fish from the Delta (Halls, 2009).

Table 7. Vulnerability assessment of climate change for selected species in the study area. Method developed by Bezuijen (2011) with refinements by P-J. Meynell and M.R. Bezuijen. See Appendix 2 for definitions. *See Appendix 4. CA-Cambodia, CC-climate change, GOT-Gulf of Thailand, SFG-seasonally flooded grassland, SLR-sea-level rise, TDSD-temperature-dependant sex determination, TH-Thailand, VN-Vietnam.

Species / assemblage	Exposure	Sensitivity				Potential impacts	Adaptive capacity				Vulnerability	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeographic connectivity?	Sufficient time to adapt?	Overall		
Mammals												
Irrawaddy Dolphin *Orcaella brevirostris* (marine populations)	High	Large but probably fragmented	Unknown, possibly <several hundred individuals and in decline	Med (mobile – able to disperse to new climate spaces – but low reproductive rate)	Med	• Reduced foraging ability due to increased turbidity/siltation from increased storms • Reduced food supply-damage to reefs/seagrass-storms, SLR • CC would impact inshore shallow waters throughout local range	Med? (abundance of estuaries, bays in study area may provide suitable shelter from CC impacts)	Yes (few large hard structures along study area in GOT; abundant bays, estuaries for dispersal, foraging)	Yes (able to disperse to new climate spaces if necessary)	Med-High	Med	Very high
Indo-Pacific Humpback Dolphin *Sousa chinensis*	High	As above	As above	As above	Med	• As above	Med? (as above)	Yes (as above)	Yes (as above)	Med-High	Med	Very high

Species / assemblage	Exposure	Sensitivity				Potential impacts	Adaptive capacity				Vulnerability	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeographic connectivity?	Sufficient time to adapt?	Overall		
Finless Porpoise *Neophocaena phocaenoides*	High	As above	As above	Low-Med (may be more restricted to in-shore habitats than other species)	Med-High	• As above • CC may reduce available habitat to a smaller number of inshore sites (e.g. estuary entrances)	Low-Med? (possibly weaker dispersal ability than dolphins)	Yes (as above)	Yes (CC impacts gradual-over next several decades)	Med	Med-High	Very high
Dugong *Dugong dugon*	High	Med (GOT + Andaman Sea)	Very small (<100?)	Low (low reproductive rate + lower dispersal ability than dolphins)	Very high	• Decline / loss of critical food source – seagrass beds – due to SLR 0.4-1 m, damage from increased storms, wave action and siltation	Low (may be restricted to defined seasonal foraging routes; limited ability to shift to new climate spaces)	Yes (habitats further west in GOT)	Unknown (populations in study area may be able to shift to other parts of GOT)	Low-Med?	Very high	Complete loss (local extirpation)

Species / assemblage	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity				Vulnera-bility	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeo-graphic connectiv-ity?	Suf-ficient time to adapt?	Over-all		
Lyles Flying-fox *Pteropus lylei*	Low-Med (CC may not impact all regional habitats)	Large (but fragmented + declining)	Small(?) in study area; large in re-gion but in decline	High (good dispersal ability)	Low-Med	• Loss of breeding/roost-ing habitat-inundation of coastal forests, espe-cially mangroves • Presence of species in study area needs to be clarified	High (good dispersal abil-ity to shift to new climate spaces)	Yes	Yes	High	Low	Med
Large Flying-fox *P. vampyrus*	Low-Med (as above)	As above	As above	High (as above)	Low-Med	• As above	High (as above)	Yes	Yes	High	Low	Med

Species / assemblage	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity				Vulnera-bility	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeo-graphic connectiv-ity?	Suf-ficient time to adapt?	Over-all		
Birds												
Sarus Crane *Grus antigone sharpii*	High	Small (large proportion in study area)	Small (but globally important)	Low (good dispersal ability but restricted to specific wetland habitats)	High	• Loss of at least 3 non-breeding sites (Ha Tien, U Minh Thuong, Kien Luong) due to 1 m SLR • Decline of other sites - drying out / woody weed invasion (higher temps + carbon dioxide, lower rainfall) • Few options to disperse to other sites - severe habitat loss in Mekong Delta	Low (few other habitats/sites for species to shift to)	No (sites with suitable habitats are fragmented + isolated)	Yes	Low	Very high	Complete loss (local extirpation)

Species / assemblage	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity				Vulnera-bility	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeo-graphic connectiv-ity?	Suf-ficient time to adapt?	Over-all		
'Other large water-birds' (6 species)*	High	Large (but fragmented + declining due to habitat loss)	Med (popula-tion sizes vary among the 6 spp. but some in study area are of national+regional importance)	Med (popula-tions may increase rapidly in absence of threats; but restricted to wetland habitats)	Med	• As for Sarus Crane • Loss of at least 5 breeding+non-br. sites (U Minh Tuong, Kien Luong, Binh Dai, Ba Tri, Can Gio IBAs) due to 1 m SLR	Low-Med (less depen-dant than Sarus Crane on special-ized wetland habitats)	Yes+No (some parts of study area with continuous habitats e.g. in CA; but sites in VN fragmented + isolated)	Yes	Med	Med (prob-ably higher due to loss of breeding habitats by SLR)	Very high

Species / assemblage	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity				Vulnera-bility	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeo-graphic connectiv-ity?	Suf-ficient time to adapt?	Over-all		
'Colonial-nesting medium-sized waterbirds' (14+ spp.)*	High	Large (as above)	Large (popula-tions of 5+ spp. in study area of global impor-tance)	Med-High (most spp. are wetland general-ists with higher re-productive rates than 'other large water-birds')	Med	• Loss of at least 3 sites (U Minh Tuong, Binh Dai, Ba Tri) with large breed-ing colonies due to 1 m SLR • Inundation across Me-kong Delta due to SLR would reduce area of feeding habitats	Med (higher reproduc-tive rates than larger waterbirds but still requiring wetlands for breeding)	Yes+No (as above)	Yes	Med	Med	Very high

Species / assemblage	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity				Vulnera-bility	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeo-graphic connectiv-ity?	Suf-ficient time to adapt?	Over-all		
'Migratory shorebirds' (non-breeding seasonal visitors) (19+ spp.)*	High	Large	Large (globally important)	Low (specialist require-ments for inter-tidal sand + mud flats)	High	• Large-scale loss of mudflat feeding sites due to SLR • High impacts because many other feeding sites in Delta, GOT + Red River Delta would also be impacted by SLR • Changes in arrival/de-parture dates due to CC may no longer coincide with seasonal peak food availability	Med (strong dispersal abil-ity, able to shift to other sites if they are avail-able)	Yes (although staging sites along East Asian-Australasian Flyway are increasingly fragmented)	Yes	Med	Very high	Very high

Species / assemblage	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity				Vulnera-bility	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeo-graphic connectiv-ity?	Suf-ficient time to adapt?	Over-all		
Reptiles												
Green Turtle *Chelonia mydas*	High	Large (but possibly now fragmented)	Small (in the order of 1000s?; severe declines)	Low	High	• Altered sex ratios + hatchling survivorship due to rising temperatures (TDSD) • Mobile species, high dispersal ability; but all local pop's subject to temp. impacts • Loss of nesting beaches due to 0.4-1 m SLR • Genetic status of GOT populations unknown but may be regionally distinct – if so, loss of populations may have high conservation impacts	Med (cannot avoid TDSD related impacts but can shift to new climate spaces if nesting sites are available)	Yes	Yes	Med	High-Very high	Very High
Hawksbill Turtle *Eretmochelys imbricata*	High	Large (as above)	Small (in the order of 100s?; severe declines)	Low (as above)	High	• As above • Population already severely declined due to other threats	Med (as above)	Yes	Yes	Med	High-Very high	Complete loss (local extirpation)

Species / assemblage	Expo-sure	Sensitivity				Potential impacts	Adaptive capacity				Vulnera-bility	Vul.+other threats
		Range in CA, TH, VN	Population size in study area	Life history traits	Overall		Ecological	Biogeo-graphic connectiv-ity?	Suf-ficient time to adapt?	Over-all		
River Terrapin *Batagur baska*	High	Small	Very small (<20 mature females?)	Low	Very high	• Altered sex ratios + hatchling survivorship due to rising tempera-tures (TDSD) • Loss of riverbank nesting beaches by woody inva-sion caused by reduced flows + rainfall, and elevated carbon dioxide (documented elsewhere for this species) • Loss of estuarine forag-ing sites due to 0.4 cm SLR	Low (restricted to few rivers; cannot avoid TDSD related impacts)	No (very restricted known range)	No (cannot avoid TDSD related impacts nor dis-perse else-where)	Low	Com-plete loss	Complete loss (local extirpation)

Table 8: Summary of the sensitivities of economically important coastal species to climate change impacts

	Species						
	Green Mussel, Blood Cockle, Oyster	**Mud Crab**	**Shrimp and Prawn**	**Seabass**	**Grouper and Snapper**	**Mackerel**	**Squid**
Physical climate parameters	Sensitivity	Sensitivity	Sensitivity	Sensitivity	Sensitivity	Sensitivity	Sensitivity
Rainfall increasing	Yes- these species close their shells to exclude fresh water which is short-term adaptation	Yes- sensitive to changes in salinity	Yes- vulnerable to sudden freshwater influxes if conditioned to saline conditions	No- resilient to changes in salinity (although juveniles may still be sensitive)	Yes- but Snapper not as sensitive as grouper	Yes- probably vulnerable to large shifts in salinity- especially in coastal region where juvenile mackerel reside during early life stages	Yes- sensitive to changes in salinity
Rainfall decreasing	Yes- through decreased water quality in cultured systems	Yes- through decreased water quality in cultured systems- which may cause disease	Yes- sensitive to water stress. Systems require large influx of water to keep water quality high	Yes- sensitive to water stress	Yes- sensitive to water stress	No	No

	Species						
	Green Mussel, Blood Cockle, Oyster	**Mud Crab**	**Shrimp and Prawn**	**Seabass**	**Grouper and Snapper**	**Mackerel**	**Squid**
Air and water temperature increase	Yes- impact juveniles/larvae. Increases may cause increase in growth however must stay within thermal tolerances. May increase incidence of harmful pathogens which have human health implications- especially in Oysters as they are consumed raw	Lab studies have shown thermal tolerance to be between 23 and 32 degrees C, however in low saline conditions above 25 degrees mortalities have been recorded. Increases in temperature have shown increased growth rates however must be in thermal optimum	Yes- sensitive to the primary and secondary impacts of temperature increase. Physiologically thermal tolerances unknown but temp increases have shown increased production. Warmer conditions encourage disease, pathogens and harmful algal blooms in shrimp aquaculture	Yes- temperature is single most important factor dictating development of finfish, especially during early stages of life. Seabass vulnerable to low temperatures. Upper thermal tolerances are not known but are approximated at around 28 degrees C	Yes- all finfish sensitive to changes in temperature. Increase may cause increased output however must be within thermal tolerances which are largely unknown for grouper and snapper species.	Yes- temperature of 1-3°C in the South China Sea could shorten the incubation period of eggs for pelagic spawning. Depending on whether Mackerel are at their thermal optimum, temperature could increase or decrease growth in juveniles. Increased air and water temperatures could affect juveniles during their time in intertidal environments.	Yes- although squid have a flexible life history as a result of temperature change. It is thought that metabolic rates increase considerably for squid, until thermal tolerance is reached. Juvenile squid thought to have lower temperature tolerances.
Increase in severity/frequency of storms	Yes- at risk of physical disturbance from waves/currents etc.	Yes- at risk of physical disturbance from waves/currents etc.	Yes- in an operational sense through damage to infrastructure etc	Yes- in an operational sense through damage to infrastructure etc	Yes- in an operational sense through damage to infrastructure etc	Yes- as juvenile Mackerel spend time in coastal environments	Yes- sensitive to changes in salinity
SLR	Yes- these species are reliant on specific set of depth conditions to grow in intertidal culture systems	Yes- may affect early life stages of wild populations. May affect aquaculture operations	Yes- in an operational sense	Yes in an operational sense	Yes- in an operational sense	Yes- as juvenile Mackerel spend time in coastal environments	No

	Species						
	Green Mussel, Blood Cockle, Oyster	**Mud Crab**	**Shrimp and Prawn**	**Seabass**	**Grouper and Snapper**	**Mackerel**	**Squid**
Salinity changes	Yes- these species close their shells to exclude fresh water which is short-term adaptation	Yes- have been subject to mortality in very low salinities. Flooding events will render cultured species in particular, vulnerable	Yes- Vulnerable to extremes of both fresh and saline water	Yes- young seabass (as larvae or juvenile) are still sensitive to changes in salinity. Adults have been shown to be resilient to changes, and hence this species is popular at river mouths or in canals	Yes- Grouper are more sensitive to changes in salinity throughout their life stages than snapper however	?- probably vulnerable to salinity changes although lack of studies on South China Sea populations makes this a speculation	Yes- sensitive to changes in salinity
pH changes	Yes- to shell formation and larval/juvenile stages. Immune systems in mussels shown to be weakened by low pH	Yes- significantly more vulnerable at larval/juvenile stages	Unknown	Yes- most sensitive at young stages of life	Yes- all finfish are sensitive to changes in pH	Yes- as with other finfish- Mackerel are vulnerable to low pH on their skeletal structure	Yes- highly sensitive to changes in pH- with ability to bind oxygen to tissues being affected- having consequences for growth, reproduction and other physiological processes

	Species						
	Green Mussel, Blood Cockle, Oyster	**Mud Crab**	**Shrimp and Prawn**	**Seabass**	**Grouper and Snapper**	**Mackerel**	**Squid**
Turbidity	Yes- can block their feeding apparatus. Has knock on effects to wider ecosystem if these organisms are negatively affected, as they help regulate water quality	Unknown	Yes- vulnerable to poor water quality	No- have been shown to be resilient to changes in turbidity (although juveniles thought to have some sensitivity to overall water quality)	Yes- grouper and snapper are both sensitive to changes in water conditions	Unknown	No
Changes in upwelling	Yes- for food supply to caged species- and to food supply and larval dispersal in wild populations	Yes- for food supply to caged species- and to food supply and larval dispersal in wild populations	Yes- for food supply	Yes- for food supply	Yes- for food supply	Yes- implications for food availability as Mackerel feed on zooplankton	Yes- dictates food availability
Changes in circulation	Yes- for food supply to caged species- and to food supply and larval dispersal in wild populations	Mud crabs rely on local currents for larval transport and dispersal	Yes- for food supply	Yes- for food supply	Yes- for food supply	Yes- Mackerel rely on current for larval dispersal, transport and for provision of food	Yes- dictates food availability and transport

	Species						
	Green Mussel, Blood Cockle, Oyster	**Mud Crab**	**Shrimp and Prawn**	**Seabass**	**Grouper and Snapper**	**Mackerel**	**Squid**
Other aspects	Sensitivity to disease is high amongst cultured species. Crab has been shown to be reservoirs of disease which affect shrimp	Habitat destruction is particularly devastating for mud crabs- large synergistic relationship between environment and species with species performing important ecological function	Disease is the biggest factor causing mass mortalities in shrimp/prawn systems	Disease is also important consideration in finfish cage culture	Both grouper and snapper are sensitive to disease in culture systems which may be exacerbated by other water quality issues and climate change factors (i.e. increased temperature)		Squid occupy ecological niches that become available when their teleost competitors are adversely affected by climate change

Table 9: Summary of the adaptive capacity of economically important coastal species to climate change impacts

	Species						
	Green Mussel, Blood Cockle, Oyster	Mud Crab	Shrimp and Prawn	Seabass	Grouper and Snapper	Mackerel	Squid
Physical climate parameters	Adaptation	Adaptation	Adaptation	Adaptation	Adaptation	Adaptation	Adaptation
Rainfall increasing	Extent to which unknown	May shift to more favourable conditions. Cultured individuals cannot shift so are more vulnerable	Farmers can condition shrimp/prawn to freshwater conditions thus reducing vulnerability but increasing vulnerability to saline intrusion	Already have high adaptive capacity as adults to changes in water conditions	Unknown	Unknown	May move away from areas with unfavourable conditions
Rainfall decreasing	Unknown	Unknown	See below	Farmers may have to increase flushing mechanisms in cage culture to keep water quality within tolerable limits	Operationally may need to invest in more efficient water cycling systems	N/A	N/A
Air and water temperature increase	Thermal tolerances for these species largely unknown. Shift latitudes for wild populations. Cultured populations cannot shift so are more vulnerable	Wild populations have been shown to shift 100s of kms south (in Australia) to cooler, more favourable conditions. Cultured crab will be more vulnerable	Largely unknown. Farmers may have to increase flushing mechanisms to keep water quality high, in order to decrease the likelihood of incidences of disease etc	Adaptive mechanisms largely unknown	Adaptive mechanisms largely unknown	Very limited information on this species. Wider fisheries literature suggests populations may shift latitudes to more favourable conditions.	Large adaptive capacity to temperature change

	Species						
	Green Mussel, Blood Cockle, Oyster	**Mud Crab**	**Shrimp and Prawn**	**Seabass**	**Grouper and Snapper**	**Mackerel**	**Squid**
Increase in severity/ frequency of storms	Cultured species cannot move out of unfavourable conditions	Cultured species cannot move out of unfavourable conditions	Use of coastal protection (either hard or soft -engineering options, or use of mangrove systems as natural buffers) to protect shrimp pond infrastructure	Coastal defence mechanisms for farmers	Coastal defence mechanisms for farmers	unknown	May move away from areas with unfavourable conditions
SLR	Farmers may be able to move cages with corresponding sea level rise	Farmers may be able to move cages with corresponding sea level rise	See above	Farmers can chose to move cages with corresponding sea level rise	Farmers can chose to move cages with corresponding sea level rise	unknown	N/A
Salinity changes	Extent to which unknown	Largely unknown	Can be conditioned one way or the other, but will then be vulnerable to either saline intrusion or influx of freshwater	High adaptive capacity to salinity changes as adults	Long term adaptive mechanisms unknown. From an operational perspective farmers may chose to operate closed circuit systems which have better control of water quality parameters	unknown	May move away from areas with unfavourable conditions

	Species						
	Green Mussel, Blood Cockle, Oyster	Mud Crab	Shrimp and Prawn	Seabass	Grouper and Snapper	Mackerel	Squid
pH changes	Unknown- pH may act synergistically with temperature increase	Opinion appears to be divided about the adaptive capacity of crustaceans to lowering pH, however most agree that they will not be able to adapt to rapid changes	Unknown	Metabolic increase (and therefore increase in food requirements) as finfish increase osmoregulation across their gills	Long term adaptive mechanisms unknown	Metabolic increase (and therefore increase in food requirements) as finfish increase osmoregulation across their gills. May have feeding pattern implications for Mackerel	unknown
Turbidity	Unknown	Unknown	Unknown	N/A	Long term adaptive mechanisms unknown	Unknown	N/A
Changes in upwelling	Wild populations can move to more favourable conditions. Cultured species are limited in their adaptation responses	Wild populations can move to more favourable conditions. Cultured species are limited in their adaptation responses	Farmers may have to switch to synthetically produced food which does not rely on trash fish etc	Farmers may have to switch to synthetically produced food which does not rely on trash fish etc	Yes- Farmers may have to switch to synthetically produced food which does not rely on trash fish etc	Unknown	May move away from areas with unfavourable conditions
Changes in circulation	Wild populations can move to more favourable conditions. Cultured species are limited in their adaptation responses	Wild populations can move to more favourable conditions. Cultured species are limited in their adaptation responses	Farmers may have to switch to synthetically produced food which does not rely on trash fish etc	Farmers may have to switch to synthetically produced food which does not rely on trash fish etc	Yes- Farmers may have to switch to synthetically produced food which does not rely on trash fish etc	Unknown. May shift latitudes to more favourable conditions.	May move away from areas with unfavourable conditions

	Species						
	Green Mussel, Blood Cockle, Oyster	Mud Crab	Shrimp and Prawn	Seabass	Grouper and Snapper	Mackerel	Squid
Other aspects	Adaptation to disease largely unknown	Overall vulnerability is high if habitat destruction and climate change impacts act synergistically	Adaptive capacity very low if water quality is low and disease is acting synergistically with high temperatures and water stress. Farmers can increase flushing rates or switch to closed systems (see adaptation examples in BCR paper for more information)	Caged finfish already subject to a number of stressors linked to water quality, so their adaptive capacity to climate stressors ontop of these is largely unknown. Their natural instinct to move away from unfavourable conditions cannot be carried out in caged conditions and as such this renders them vulnerable	Long term adaptive capacity unknown. Farmers may chose to breed more resistant strains of finfish	Adaptive actions for fisheries managers and fishers themselves for the Mackerel species are discussed in the paper 'Adaptation responses in the BCR region' by same author	

4.4 Selected species of the marine and brackish shellfish

4.4.1 Green Mussel (perna viridis), Blood Cockle (anadara nodifera), and Oyster (crassostrea commercialis)

Brackish waters along the coast of Thailand, Cambodia and Vietnam are Tratitionally used for shellfish production, collected by hand from natural beds (FAO, 2011). More recently, coastal shellfish aquaculture started with the introduction of intensive culture technologies and has today become a significant source of income, along with shrimp culture (FAO, 2011). There are three main invertebrate commercial species in the BCR project regions, the green mussel *(Perna viridis)*, the blood cockle *(Anadara spp.)* and the oyster *(Crassostrea commercialis)*. The Green mussel is the most important species cultured along the coast of Thailand and further along the coast of the South China Sea, and it contributes around 44% of total production of coastal aquaculture in Thailand alone, whilst the blood cockle *(Anadara nodifera)* contributes around 12% (FAO, 2011). At present all seed used in aquaculture is naturally obtained (FAO, 2011). Green mussels are cultivated using Tratitional bamboo traps or palm fronds in muddy intertidal areas at a depth of 4-8 metres, although several new techniques for culture have recently been introduced in the form of polyethylene rafts, longlines and racks (FAO, 2011). Oysters are cultured using cement blocks and natural rocks, although hanging rafts/longlines can also be used (Lacanilao et al., 1991). *Oyster* are cultured in areas near river mouths which are protected by natural or artificial barriers against strong wind and wave action (Lacanilao et al., 1991). The blood cockle is usually reared closed to the shore in estuarine areas with fine mud at the depths of 0.5-1 m, much shallower than the green mussel. The area should not be exposed above sea level for more than 2-3 hours during low tide (FAO, 2011) which will undoubtedly mean this species is more vulnerable to those climate change impacts which will affect this equilibrium.

Sensitivity

(i) Temperature change

Molluscs are broadcast spawners, which means they release gametes into the water column where fertilisation and embryonic development take place (Marshall and Bolton, 2007). In these early life stages, organisms are more sensitive to a warming, acidifying ocean (Kurihara et al., 2004). Already studies have confirmed reduced fertilisation, size and malformed skeletogenesis in the larvae of oysters under these conditions (Kurihara et al., 2007; Parker et al., 2008). Water temperatures affect the timing of reproduction itself in invertebrates, with optimal temperatures for development corresponding to spawning times (Ramofofia et al., 2003). Rising sea surface temperatures (SST) in the BCR project areas will almost certainly lead to changes in the reproductive phenology and fecundity for those species with spawning periods that are tightly regulated by exogenous cues such as temperature (Lawrence and Soame, 2004), as tropical invertebrate species generally seem to have less tolerance to temperature variations than their temperate counterparts (Compton et al., 2007). Unfortunately, we have little precise information on lethal threshold temperatures for the vast majority of tropical benthic invertebrates, particularly across various life stages and in concert with other natural stressors. This makes predictions based on climate change models very difficult for many species (Przeslawski et al., 2008). What has been proved however; is that warming temperatures and increasing acidification conditions have acted synergistically to reduce reproductive potential in some invertebrate species, which has far-reaching implications for shellfish species in the BCR project regions; namely a reduction in yield, an increase in abnormal larvae and reduced growth rates (Parker et al., 2008).

With temperature change comes an increase in human pathogenic microorganisms, which may be a consideration for invertebrate production in Southeast Asia (Cochrane, 2009). Oysters in particular, have been shown to harbor a pathogen called *Vibrio parahaemolyticus*, which causes gastroenteritis when consuming oysters raw (Cochrane, 2009). The outbreak of gastroenteritis associated with Alaskan oysters in 2004 extended by 1 000 km the northernmost documented source of oysters that caused illness due to this organism (McLaughlin et al, 2005), suggesting that increases in SST might lead to microbial hazards in areas where they were not considered before, and especially in oyster species.

Diseases and parasites may also increase with a shift in SST, as has been evidenced by the shift of oyster parasite *Perkinsus marinus* by 500km in a single year, corresponding with above-average annual SST (Ford, 1996). Other pathogens which have caused mass mortalities in oyster populations *(Perkinsus marinus and Haplosporidium nelsoni)* have been documented moving northwards as a result of irregular sea surface temperatures (Brander, 2007). Much more research is needed to understand the linkages between temperature and tropical commercially important invertebrates, such as the mussels, cockles and oysters currently cultured in the BCR project area, in order to predict more accurately how they will be affected by increases in atmospheric and sea temperatures from climate change.

(ii) Changing ocean chemistry

An altered pH presents a significant problem for calcifying organisms such the commercially important tropical invertebrate species of importance in the BCR project regions. Increased acidification could affect the survival of valuable invertebrate species by weakening their calcium carbonate shells (Bell et al., 2011) especially if the pH falls below 7.5 (Raven et al., 2005). Fragile larval skeletons will be particularly vulnerable to ocean acidification (Kurihara & Shirayama, 2004), potentially resulting in recruitment failure of a whole suite of marine organisms but in particular commercially important invertebrates such as the cockle, mussel and oyster. Increased CO2 in surface waters may lower the metabolic rate of these invertebrates, however the extent to which this will happen is unknown, as laboratory studies investigating the effects of increased CO2 on invertebrates have used large incremental increases (Przeslawski et al., 2008) and therefore there is little knowledge of the effects of a gradual increase of CO2 and pH.

Ocean acidification may affect the immune response of mussels, specifically shown for the blue mussel *(Mytilus edulis)* where the impacts are bought through changes in the physiological condition and functionality of haemocytes which in turn are caused by calcium carbonate shell dissolution (Bibby et al., 2008). Opinion appears to be divided about how well calcifying organisms, like mussels, cockles and oysters will be able to adapt to increasing pH. Jackson et al. (2007) indicate that calcifying benthic invertebrates might have a limited capacity to adapt their skeleton-forming mechanisms in response to the rapid changes in pH that are anticipated. However, a high degree of adaptability was observed in the shell-forming secretome of some gastropods (Jackson et al., 2006) and some researchers speculate that warming SSTs might actually stimulate increased calcification through enhancement of the physiological processes involved, potentially ameliorating the effect of acidification (McNeil et al, 2004; Kleypas et al, 2005).

(iii) Sea Level Rise (SLR)

SLR can inundate intertidal shallow water species in tropical regions (Barbosa et al., 2008), and as the mussel, oyster and cockle species which are cultured in the BCR project area depend on a specific set of depth conditions in which to grow, they are vulnerable and sensitive to changes in SLR. If the rate of SLR is slow, then aquaculture operations can move landward if feasible, however this depends on many factors such as the presence of physical barriers to movement, and whether other factors (climate or anthropogenic) are also acting synergistically on the species. If operations cannot move, there is a possibility of local extinctions of certain species (Przeslawski et al., 2008). The amount of intertidal habitat lost due to SLR will be determined by geomorphology and tidal amplitude (Lovelock and Ellison, 2007).

(iv) Altered ocean circulation

Changes in ocean circulation predicted to occur as a result of climate change (Goreau et al., 2005) will affect larval dispersal and recruitment and affect the supply or quality of planktonic food (Przeslawski et al., 2008), which will have far reaching consequences for marine organisms. Food availability is an important factor controlling reproduction in benthic invertebrates (Lester et al., 2007) and in influencing larval success (Brodie et al., 2005). Changes in ocean circulation may therefore have significant impacts on growth and development, reproduction, larval survival, and species ranges by changing the duration and time of food availability; importantly, the effects of changing food availability may supersede predicted changes based on physiological tolerances of invertebrates (Lester et al., 2007). Barth et al. (2007) demonstrate the importance of ocean circulation in the ecology of intertidal invertebrates, as a one month delay in the 2005 spring transition to upwelling favourable wind stress of California resulted in a higher than average near shore surface water temperature (2 °C warmer than normal), nutrients and chlorophyll-a were respectively 50 and 30 % less than usual, resulting in an 83% reduction in the mussel recruitment density. Changes in larval dispersal by wild populations of mussel, cockle and oyster will no doubt take place if ocean currents around the tropics change, as is predicted (Goreau et al., 2005). Changes in tropical monsoon and other large-scale climatic events may also affect larval dispersal (Munday et al., 2007). The extent to which this will impact aquaculture is unknown at this stage. The local effects of sea level rise on intertidal invertebrates in the BCR project regions are currently unknown.

(v) Changes in precipitation and Increase in severity or frequency of extreme events

Responding to changes in salinity mussels, cockles and oysters close their shells to exclude freshwater, however this response is thought to be a short-term coping action, and cannot be sustained in the long term (Przeslawski et al., 2008). Turbidity and sedimentation are other consequences of increased storm activity, and are known to be physiologically stressful to intertidal invertebrates (Fabricius et al., 2007). These conditions can reduce grown rate of bivalves (oysters, mussels and cockles) by blocking their feeding apparatus (Lohrer et al., 2006). Changes in bivalve communities due to climate change may also exacerbate the effects of increased turbidity for other organisms as this group plays an important part in regulating water quality (Przeslawski et al., 2008). The exposure and sensitivity of bivalves to turbidity and sedimentation will not only depend on the biology of each organism but also on the frequency and magnitude of events such as storms, the distance from shore, local wave and current patterns and coastal stability (Wolanski et al., 2005). The intensity of storms is predicted to increase (Solomon et al., 2007), which means the risk of physical disturbance to intertidal invertebrates is high.

(vi) Other aspects

Disease has been and will continue to be of great concern in aquaculture systems in Southeast Asia (Merican, 2006; Ferguson et al., 2007). Poluinin and Mouritsen (2006) state that increased levels of parasitic infections as a result of temperature increase will have severe repercussions for intertidal communities, as evidenced by the results of a simulation model that predicts frequent local parasite induced extinctions following a modest increase in ambient temperatures. Sessile cultured invertebrates such as mussels, cockles and oysters are inherently vulnerable to disease, the risk of which is compounded in an aquaculture environment where stocking densities are high. Przeslawski et al.(2008) state that intertidal species (such as the shellfish species discussed here) may already be more vulnerable to change than their shallow subtidal counterparts, as they are already living near their physiological limits. Cultured mussels, cockles and oysters are unable to move to more favourable conditions unlike wild populations, which also place these organisms at a high vulnerability level to change (Przeslawski et al., 2008). Although research investigating multiple stressors has Tratitionally been focussed on coral reef ecosystems and rocky intertidal habitats (Przeslawski et al., 2008), it has been shown that temperature can interact with other stressors such as pollution, ocean acidification and reduced salinity to negatively affect commercially important intertidal invertebrates such as mussel, cockle and oysters, which occur naturally and are cultured along the coasts of Thailand, Cambodia and Vietnam. Much more research is needed to understand the linkages between temperature and tropical commercially important invertebrates, such as the mussels, cockles and oysters currently cultured in the BCR project areas, in order to predict more accurately how they will be affected by increases in atmospheric and sea temperatures from climate change.

4.4.2 Mud Crab (Scylla serrata)

Mud crabs of the genus Scylla are large, edible crustaceans closely associated with mangrove environments and other coastal habitats throughout the tropical Indo-West Pacific region (Overton and Macintosh, 2002). Wild female mud crabs go up to 50kms offshore to spawn, where by the eggs hatch into planktonic zoea larvae and over a period of three weeks get transported back to the coastline via coastal currents (Overton and Macintosh, 2002). Juvenile crabs then return to mangrove environments; however little is known about the settlement and recruitment processes involved for all Scylla species between the post-larval stages and their emergence as juvenile crabs in mangrove forests (Moser, 2001).

As well as wild populations being caught by fisher folk, this species is intrinsic to the aquaculture industry in the BCR project areas. Mud crabs have only been reared from stock captured from the natural environment due to the difficulty of producing larvae on a commercial scale (ACIAR, 1999), which represents a fundamental constraint to the full development of mud crab aquaculture. Mud crab aquaculture in the BCR project areas includes both the systematic rearing of the species from the fry stage onwards and fattening of wild juveniles in captivity. Fattening is a very profitable activity, employing high densities of crabs at low costs, however total production is low because of mortalities due to cannibalism (Keenan and Blackshaw, 1999). Grow-out systems for mud crab show much more variety with high production. They are usually pond-based, with or without mangroves, although intertidal pens can also be used (Keenan and Blackshaw, 1999). Collecting stock captured from the wild in South East Asian countries to provide the aquaculture industries with broodstock obviously threatens the viability of natural stocks and contributes to concerns about the sustainability of mud crab aquaculture (Keenan and Blackshaw, 1999).

Sensitivity

(i) Temperature

Larvae of the mud crab reared in laboratories have been shown to be highly sensitive to changes in temperature and salinity, with mass mortality occurring above 25 degrees C and in low saline conditions (Hill, 1974). Hamasaki (2003) showed that mud crab larvae reared under 23 degrees and over 32 degrees suffered mass mortalities or did not develop at all. The number of days from hatching to attainment of each larval stage decreased with increasing temperature (Hamasaki, 2003). These results show that the optimum temperatures for development of early-stage mud crab are between 23 and 32 degrees, which has important implications for mud crab aquaculture in the BCR project areas. If predicted regional warming of the SST in the areas where mud crab are cultured increases to over 32 degree thresholds, larval development could be severely impacted. The decreased amount of time between larval stages as temperature increased in Hamasaki's (2003) study does suggest however that increased temperature might be beneficial to the development of juvenile mud crabs in culture systems, however there appears to be a set of optimum conditions for development, which warrants further investigation if more accurate predictions for this species in the face of climate change impacts is to be ascertained.

(ii) Changing ocean chemistry

Altered water quality conditions have the potential to affect both wild and cultured mud crabs. An altered pH presents a significant problem for calcifying organisms such as crustaceans, as it interferes with shell formation (Przeslawski et al., 2008). Fragile mud crab larval skeletons may be particularly vulnerable to changes in pH, potentially resulting in recruitment failure (Przeslawski et al., 2008). As with other calcifying organisms in the project region (mussels, oysters and cockles), there is a paucity of knowledge on the specific effects of gradual decreasing pH in mud crab. Opinion appears to be divided about how well calcifying organisms, like mud crabs will be able to adapt to increasing pH Jackson et al. (2007) indicate that calcifying benthic invertebrates might have a limited capacity to adapt their skeleton-forming mechanisms in response to the rapid changes in pH that are anticipated. However, a high degree of adaptability was observed in the shell-forming secretome of some gastropods (Jackson et al., 2007) and some researchers speculate that warming SSTs might actually stimulate increased calcification through enhancement of the physiological processes involved, potentially ameliorating the effect of acidification (McNeil et al., 2004).

(iii) Altered ocean circulation

Since wild populations of mud crab rely on ocean currents to disperse their larvae, and the larvae themselves rely on currents to bring them back in-shore, it can be surmised that wild crabs will be vulnerable to any changes in current or ocean circulation, however the extent to which this will happen is unknown.

(iv) Changes in precipitation

According to FAO (2011) mud crab have lifecycles related to rainfall and temperature patterns but a quantification of the link is yet to be undertaken. Correlation of catches of mud crab with rainfall suggests changes in rainfall (and therefore salinity) will undoubtedly affect some or all of the life cycle stages of both wild populations and cultured populations (FAO, 2011). This study, carried out for Australian populations of mud crab, also highlighted the paucity of data on this species and the need to develop further studies and forecast models to provide information for managing this fishery in the face of climate change (FAO, 2011). Secondary impacts to mud crab aquaculture include the climate change impacts on crab feed which include molluscs (mussels) and other crustaceans (graspid crabs [FAO, 2011]). Further investigation of these secondary impacts is required.

(V) Other aspects

Studies on mud crab culture have shown that eggs are particularly vulnerable to fungal and ciliate infections and cause mass mortality (Quinitio et al., 2001). If conditions such as increased temperature and higher water demand (and therefore decreased flushing of aquaculture ponds) create a more hospitable environment for pathogens, then the delicate juvenile stages of the mud crab could be threatened. Mud crabs have been shown to be efficient carriers of the widespread epizootic in White spot syndrome virus (WSSV), which has been responsible for mass mortalities in the South East Asian shrimp industry. Suppamattaya et al. (1998) showed that mud crabs can carry the virus but not necessarily be killed by it, as mortality only occurred in 20% of the sample size, which suggests keeping mud crabs in shrimp ponds prone to WSSV infection increases the vulnerability of the system to mortality events.

Overall vulnerability

Significant differences amongst wild populations of *Scylla serrata* have led authors to believe that local environmental conditions have a large influence on life history traits in this species, as they exhibit strong site fidelity (Ewel, 2008). This means that wild populations are highly vulnerable to changes in optimum breeding conditions and the synergistic effects from climate impacts and other anthropogenic impacts (habitat destruction, pollutants) may have distinct negative consequences for species survival. More information is needed about the adaptive capacity of wild populations of mud crab before any accurate predictions regarding their future survival can take place. Habitat destruction, in particular, is a concern for mud crab species. A mutual benefit exists between mangrove ecosystems and mud crabs- crabs promote mangrove growth by increasing nutrient levels and facilitating nutrient recycling visa defecation and mortality, as well as oxygenating the anaerobic mud and reducing salt accumulation at root tips by burrowing, whilst Mangroves increase crab survivorship by providing protection from predators and physical parameters by reducing sunlight and heat exposure (Przeslawski et al., 2008). Mangroves also provide crucial conditions, such as detritus and surface algae, which support large amounts of invertebrates and juvenile fish species which in turn provide food for mud crabs (Przeslawski et al., 2008). Mangrove habitats are therefore vital to the survival of wild mud crab species (Badjeck et al., 2010). Sea level rise, changes in sediment flow due to altered currents and the addition of pollutants could impact on any mangrove fishery in the project regions, negatively impacting this mutually beneficial relationship.

4.4.3 Blue Swimmer Crab (Portunus pelagicus)

The Blue swimmer crab (Portunus pelagicus) also known as sand crabs, are crustaceans whose last pair of legs have been modified as swimming paddles (Kangas, 2000). They are an economically very important species which are widely caught and cultivated across the Indo-Pacific region (FAO, 2011), and are ideal aquaculture species due to their ease and frequency of spawning in captivity (Andres et al., 2010). They are found in estuaries and inshore marine waters in the wild (Kangas, 2000). Wild populations of Blue swimmer crabs feed on a variety of sessile and slow-moving invertebrates, including bivalve molluscs, crustaceans, polychaete worms and brittle stars (Kangas, 2000). They are opportunistic, bottom-feeding carnivores and scavengers (Kangas, 2000) which means they will be less sensitive to climate related impacts on their food supply than more specialist feeders.

Sensitivity

(i) Temperature change

It is predicted that extremes in water temperature will increase, which are likely to have significant effects both on survival of larvae and adults blue swimmer crabs as well as affecting growth and reproduction (Hutchings et al., 2007). It has been shown that temperature significantly affects the length of larval life of crab species, with this particular species having an increased larval duration at lower temperatures (Kangas, 2000). A sea surface temperature rise would therefore likely increase developmental rate overall, resulting in a net increase in production in culture systems. As with other marine and freshwater species however, these increases would only occur within the thermal tolerance of the individual species. For blue swimmer crabs this has been shown in laboratory settings to be around 39.5oC (Neverauskas and Butler, 1982). Specific thermal tolerances for both wild and cultured blue swimmer crab in the BCR project focal provinces are unclear at this stage, and require further investigation. Interestingly, the blue swimmer crab has been shown to be highly tolerant of large fluctuations in oxygen availability at a range of temperatures (Meagher, 1971), suggesting this species may be more suited to culture systems than other crustacean species.

(ii) SLR

As with mud crabs, wild populations of blue swimmer crabs may be sensitive to sea level rise as they depend on intertidal habitats during their life cycles. Migration of blue swimmer crabs occurs between estuaries and the open ocean during their adult, larval and juvenile stages (Kangas, 2000).

(iii) Changing Ocean chemistry

Altered water quality conditions have the potential to affect both wild and cultured blue swimmer crabs. An altered pH presents a significant problem for calcifying organisms such as crustaceans, as it interferes with shell formation (Przeslawski et al., 2008). Predicted changes in ocean pH will negatively affect shell and skeleton formation, development and strength, thereby affecting their primary function, as protection from physical damage, including predation in wild crustacean stocks (Hutchings et al., 2007).

(iv) Changes in precipitation and increase in severity/frequency of extreme events

Studies have shown that salinity significantly affects both the survival and growth of early blue swimmer crab juveniles (Romano and Zeng, 2006). Mortality in this particular study (Romano and Zeng, 2006) was significantly higher for juveniles cultured at salinities ≤15 ppt and at 45 ppt., suggesting this crab is particularly sensitive to both extremes of salinity. Currently there is little published information on the salinity tolerance and optimum salinity levels for early blue swimmer crabs (Lestang et al., 2003) although their natural distribution appears to be dependent on salinities (Kangas, 2000). In wild populations, the combined parameters of temperature and salinity have been shown to influence the distribution, activity and movement of the blue swimmer crab (Kangas, 2000), suggesting these parameters will no doubt adversely affect cultured populations, however there is a lack of empirical evidence in the southeast Asian region as to the effects of increased temperature and differential salinity levels on blue swimmer crabs.

(v) Altered ocean circulation

Wild blue swimmer crabs use ocean currents and wind patterns as dispersants of their larvae and juveniles (Kangas, 2000) and as such any changes to ocean circulation in the BCR project focal provinces is likely to affect this species. First-stage blue swimmer crab zooea have been witnessed feeding on the surface of the sea, where offshore winds have pushed them offshore, whereas later in the season they have been witnessed being transported back onshore with the onshore wind patterns (Romano and Zeng, 2007).

(vi) Other factors

Diseases and pathogens are of significant importance to aquaculture systems and the combined effect of climate impacts such as rising temperatures and anthropogenic stressors such as poor water quality may significantly adversely affect the blue swimmer crab. In particular the rhizocephalan *Sacculina granifera* infection may cause degeneration of the gonads in both male and female crabs and a modification of the secondary sexual characteristics in the male crab resulting in the acquisition of female characteristics (Kangas, 2000). Wild populations are highly vulnerable to changes in optimum breeding conditions and the synergistic effects from climate impacts and other anthropogenic impacts (habitat destruction, pollutants), which may have distinct negative consequences for species survival. More information is needed about the adaptive capacity of wild populations of blue swimmer crab before any accurate predictions regarding their future survival can take place.

Overall vulnerability

High temperatures, extremes of salinity and lowered pH, all have the potential to negatively affect the blue swimmer crab and as such this species is sensitive to climate related impacts. Changes in sea level rise, ocean circulation and localised weather such as wind patterns may cause changes in both wild and cultured blue swimmer crab; affecting reproductive and feeding processes. Habitat destruction presents a concern for blue swimmer crab due to the ecological linkages between the species and mangrove systems. Mangroves provide crucial conditions, such as detritus and surface algae, which support large amounts of invertebrates and juvenile fish species which in turn provide food for crustaceans (Przeslawski et al., 2008). Mangrove habitats are therefore vital to the survival of wild blue swimmer crabs (Badjeck et al., 2010).

4.4.4 Shrimp (Litopenaeus vannamei) and Prawn (Penaeus monodon)

Shrimp/prawn farming represents a sizable economic activity providing considerable livelihood opportunities in the BCR target regions, with Thailand being the leading global cultured shrimp producer (375,320 tonnes valued at US$1 196 billion in 2005 [FAO, 2011]). The giant tiger prawn *(Penaeus monodon)* and white-leg shrimp *(Litopenaeus vannamei)* constitute around 80% of total farmed shrimp production in the region (FAO, 2011). Disease in shrimp culture has been the major limiting factor in production in recent years, but despite this the industry has grown rapidly with a concurrent reduction in mangrove area to accommodate new aquaculture sites (Bush et al., 2010). The 'boom crop' nature of shrimp production in Southeast Asia has meant that the promise of high returns on investment has gradually been tempered by riskier returns in global markets and increasing levels of social and ecological uncertainty and vulnerability (Bush et al., 2010) which must be taken into account when considering the vulnerability of the species involved in this industry to future climate change and other impacts. There are regulations in place, at least in Thailand, to manage the environmental impacts of intensive shrimp aquaculture, for example farms larger than 8ha must by law construct wastewater oxidation ponds to minimise discharging harmful effluent (FAO, 2011).

Sensitivity

(i) Temperature

Increases in SST represent a significant threat for shrimp culture in the region. According to Handisyde et al. (2006) increases in temperature in aquaculture systems can cause multiple negative impacts to production, such as an increase in harmful algal blooms that release toxins into the water and increase fish kills; decreased dissolved oxygen (vital to the survival of shrimp species); competition and parasitism from invasive species; an increased incidence of disease and parasites and change in location or size of suitable range for a given species; as well as altered local ecosystems. There are however potential positive benefits to increased temperature, which apply to all aquaculture systems discussed in this report in the region, such as potentially enhanced growing seasons, enhanced growth rates and feed conversions and enhanced primary productivity which may benefit shrimp culture via the food chain (Handisyde et al., 2006), however thermal tolerances need to be taken into consideration which unfortunately are largely unknown for many marine and freshwater organisms in the region.

The operational impacts of increased temperature in shrimp culture may include changes in infrastructure and operation costs, increased infestation of fouling organisms, pests and/or predators, changes in production levels and expanded geographic distribution and range of aquatic species (Handisyde et al., 2006).

(ii) SLR

Operational impacts of rising sea level may include damage to pond infrastructure, changes in aquaculture zoning, increased insurance costs, reduced freshwater availability, and competition for space with ecosystems providing coastal defence or simply loss of land available for shrimp aquaculture (Handisyde et al., 2006) which may be compounded by mangrove loss as a result of anthropogenic activities. Loss of mangrove habitats as a result of climate change (for example sea level rise) means a loss of multiple ecosystem functions, one of which is supplying seed for aquaculture activities in the BCR project regions. The availability of a suitable supply of water is one of the most important environmental factors determining site variability for shrimp production (Lebel et al., 2002). To minimise costs of pumping water, many farms in the region are located as close as possible to the source of the supply; consequently many are situated adjacent to the coastline, and as such are highly vulnerable to both sea level rise and the impacts of storms (Boromthanarat, 1995; Lebel et al., 2002).

(ii) Altered ocean circulation

Changes in oceanographic function, for example wind speed or velocity, currents and wave action, may cause a decreased flushing rate of shrimp ponds that can affect food availability to stock, whilst also altering water exchanges and waste dispersal, contributing to a reduction in water quality. This may contribute to accumulation of waste products in ponds and increased operational costs (Handisyde et al., 2006).

(iii) Changes in precipitation

Salinity changes and coastal run-off due to rainfall can cause decreased growth and reproductive rates in some invertebrates, for example Banana prawns, whose growth rates strongly correspond with rainfall in tropical Australia (Staples and Vance, 1986). Early shrimp farms in the region required the use of brackish water, as it was believed that a salinity of 12-25 parts per thousand (ppt) was necessary for shrimp survival (Lebel et al., 2002). Water scarcity within this range led to the use of water both lower and higher, and some species are not grown successfully in salinities from 4-36 ppt (Lebel et al., 2002). Fresh water can be used almost exclusively in shrimp ponds, using a method whereby larvae are progressively introduced to less saline waters (Briggs and Funge-Smith, 1997). These methods of acclimating shrimp to reduced salinities suggests that they can adapt to changes in salinity in the long-term, however these changes need to be gradual, and as such shrimp are still vulnerable to rapid changes in salinity that would result from increased precipitation events in the project regions.

(iv) Increase in severity or frequency of extreme events

Storms and extreme tidal flooding cause large waves and high winds and structural damage to coastal communities, which would almost certainly impact shrimp production. Damage to infrastructure may cause higher capital costs by needing to redesign cages, moorings etc that can withstand more physical damage, which may also increase insurance costs. Flooding may cause unwanted introductions to shrimp ponds such as predators or disease (Handisyde et al., 2006), or escaping of stock, which will cause a net loss.

(v) Drought/competition for water

Over much of Asia El Nino results in dryer conditions (NOAA, 2005) and this may have negative impacts on shrimp. For example the 1991-1993 El Nino contributed to areas of drought in Thailand, Indonesia and the Philippines which in turn lead to a decrease in shrimp production through reduction in water quality and associated disease, as well as reduced availability of wild seed and broodstock (Rosenberry, 2004). From an operational perspective, drought may cause a loss of opportunity for existing or potential shrimp farmers, as it may be too hard to insure against (Handisyde et al., 2006). Altered/reduced freshwater supplies may exacerbate existing climate impacts on shrimp (i.e. increased temperature, decreased salinity, sea level rise and acidification) and will ultimately result in high costs to maintain pond levels (Lebel et al., 2002). Conflicts may arise between aquaculture operations and other water users if demand is high/supply is low. Further investigation is required into the effects of water shortages on the communities and industries within the BCR project regions if accurate predictions for aquaculture species are to be developed.

(vi) Other aspects

Agricultural activities operating in the same localities as shrimp ponds may have negative implications for the species and overall production. High levels of pesticides contaminating the water supply through agricultural runoff can be lethal to aquaculture animals and lower doses may have sub-lethal toxic effects (Barg, 1992). Concern has also been expressed regarding the impacts of insecticides on aquaculture; Flegal (1992) reported that two of the chemicals used by rice farmers to control crabs in their fields are extremely toxic to tiger prawn juveniles. Pollutants from the shrimp farming industry in the target regions has been a considerable concern due to the wide suite of impacts associated with intensive culture. These include nutrient and organic enrichment potentially leading to anoxic sediments, changes in benthic communities and eutrophication, salinisation of freshwater and pollution from illegal pond sediment disposal and the growing use of a variety of chemical products (Dierberg et al., 1996; Primavera et al. 1993). Disease has been a major limiting factor in shrimp aquaculture in recent years (FAO, 2011) and climate change impacts may provide more favourable conditions for pathogens to flourish in within shrimp ponds (Bell et al., 2011). Pathogens cause disease if shrimp are stressed (Smith et al., 1999) and as such shrimp species are particularly vulnerable to the synergistic effects of primary and secondary impacts of climate change. Since 1994, White spot syndrome virus (WSSV) has been a major cause of disease in shrimp farms in Thailand, as well as other countries in the region (Flegel, 1996). Suppamattaya et al. (1998) have shown that some other commercially important species which are kept in shrimp ponds in the BCR project areas, such as mud crab (Scylla serrata) act as reservoirs for the disease; transmitting it but not showing any symptoms of the virus themselves. Since the outbreaks of the white spot virus, the aquaculture industry has been forced to concentrate on management of intake and waste waters from shrimp ponds, in order to minimise production loss (Lebel et al., 2002). Habitat destruction of mangroves can lead to coastal erosion as well as changes in sedimentation patterns and shoreline configuration, which may affect shrimp farms close to the coast (Smith et al., 1999). Mangroves provide shrimp farms with a natural buffer against storms and pathogens and can improve water quality via nutrient uptake (Smith et al., 1999).

Overall vulnerability

Commercially important prawn and shrimp species are vulnerable to a multitude of factors. Temperature increase has been shown to cause the development of harmful algal blooms which alter optimum conditions for survival, whilst providing an ideal environment for diseases, fungi and pathogens in which to develop (Handisyde et al., 2006). Drought and reduced water availability, leading to water stress conditions inside shrimp ponds present a significant problem for shrimp and prawn species. These conditions may exacerbate existing climate impacts on shrimp (i.e. increased temperature, decreased salinity, sea level rise and acidification) and will ultimately result in high costs to maintain pond levels (Lebel et al., 2002). High stocking densities and water stress will undoubtedly exacerbate these problems and put shrimp and prawn and the people who depend on their survival for their livelihoods, at a high level of vulnerability.

4.5 Selected species in marine and brackish finfish culture

4.5.1 Seabass (Lates calcarifer), Grouper (Epinephelus spp.) and Snapper (Lutjanus spp.)

Grouper is the most popular cultured finfish in Southeast Asia, largely due to their fast growth, acceptance of dry pellet food, successful spawning in captivity, high feed efficiency and very high market value (Boonyaratpaliin, 1997). Grouper species that are cultured in the target regions include orange-spotted grouper *(Epinephelus coioides)*, Malabar grouper *(E.malabaricus)*, humpback grouper *(Cromileptes altivelis)*, giant grouper *(E. lanceolatus)*, tiger or brown-marbled grouper *(E. Fuscoguttatus* [Kongkeo et al., 2010]). Grouper can only be cultivated in cages, with seed mainly collected from the wild, although limited artificial spawning and larva rearing techniques have been developed since 1993 (FAO, 2011).

Seabass *(Lates calcarifer)*- known as Barramundi in some parts of the Asia-Pacific region- has been the most popular brackish water fish cultivated in Thailand since 1973 (FAO, 2011). This species can be cultivated in earthen ponds, cages and pens (FAO, 2011). In the Kampot and Koh Kong provinces of Cambodia, seabass grouper and snapper are grown in cages but production has declined since 1993 due to dependence on wild supply (FAO, 2011). Seabass are a fast growing fish, tolerant of many coastal conditions such as fluctuating salinity and turbidity, as well as rough handling and the crowded conditions of aquaculture cages (Boonyaratpaliin, 1997)

Snapper species *(Lutjanus spp.)* command a high price similar to both Grouper and seabass species, and as such it is a popular cultured finfish in the BCR project provinces.

Sensitivity

(i) Temperature

Temperature has been shown to be the most important factor dictating development of finfish (Munday et al., 2007). Temperature during larval rearing of seabass and grouper have a great effect on health and survival of both of these species (Boonyaratpaliin, 1997). Seabass appear to be more vulnerable to low temperatures than other cultured species, with an increased survival rate of 66.4% from 11.3% when temperatures were increased from 27-29°C to 34-35°C in experiments by Ruangpanit and Kongkumnerd (1992). According to Katersky and Carter (2005) seabass are cultured over a wide range of temperatures some of which approach the upper thermal tolerance for this species. It has been shown that cultured groupers can tolerate temperatures from 22-28 °C, whereby under 15°C they will not feed (Boonyaratpaliin, 1997). There is limited information available on exact upper thermal tolerances on either the seabass, grouper or snapper spp.

(ii) SLR

Operational impacts of rising sea level may include damage to cage infrastructure, changes in aquaculture zoning, increased insurance costs and reduced freshwater availability (Handisyde et al., 2006) which may be compounded by mangrove loss as a result of anthropogenic activities. Loss of mangrove habitats as a result of climate change (for example sea level rise) means a loss of multiple ecosystem functions, one of which is supplying seed for aquaculture activities in the BCR project regions.

(iii) Changing ocean chemistry

The sensitivity of tropical marine fishes to changes in pH at large magnitudes or by large increments is unknown (Munday et al., 2007). Fish eggs are much more sensitive to pH changes than juveniles or adults, and consequently the largest effects of acidification are likely to be on reproductive performance which may flow through to population replenishment if the impacts are sufficiently large (Brown et al., 1989). Increased levels of dissolved CO2 can decrease the pH of fish tissue, which can be compensated via the control of ions across the gills (Munday et al., 2007). This compensatory measure may have some physiological costs in caged finfish such as seabass, grouper and snapper however much more investigation is required into the effects of pH on these species.

(iv) Changes in precipitation

Seabass cages are mainly located along the river mouths or canals because this species can tolerate lower salinity or even freshwater (Tacon and Halwart, 2007). Seabass larvae are still sensitive to changes in salinity, despite more tolerance in older life stages, and salinity needs to remain between 25 and 30ppt (marine) to avoid mortality in aquaculture systems for this species (Boonyaratpaliin, 1997). Seabass fry can tolerate freshwater when they attain a size of 4.5 mm total length, but growth is reduced (Boonyaratpaliin, 1997). Therefore even an exceedingly adaptable fish such as the seabass is vulnerable to changes in salinity, which means increased rainfall events or flooding from rivers etc may place this species at risk. Groupers on the other hand are marine fish and cannot withstand freshwater immersion for more than 15 minutes (Boonyaratpaliin, 1997), suggesting much more vulnerability to changes in salinity than seabass. Some species of snapper such as the mangrove red snapper *(Lutjanus argentimaculatus)* are found in brackish estuaries and the lower reaches of freshwater streams (Emata, 2003) and as such it can be concluded that this species will be less sensitive to changes in salinity within aquaculture sites.

(v) Changes in the severity/frequency of extreme events

Cyclones, flooding and storm surges will undoubtedly have serious implications to cage culture operations within Thailand, Cambodia and Vietnam.As seabass are less sensitive to changes in turbidity than most other cultured finfish, extreme events causing disturbances the water column may not produce as much as a threat to this species in cage culture than others, for example the grouper. Flooding may not be as damaging to either the seabass or the snapper species cultured in the region due to their tolerance to varying levels of salinity, where as grouper may be more sensitive to these events. The sensitivity of seabass, snapper and grouper to extreme events needs to be investigated in more detail in order to produce a more comprehensive vulnerability analysis.

(VI) Other aspects

According to Boonyaratpaliin (1997) groupers are euryphagous, showing greater preference for crustacea and live food than for fish and dead organisms, which may make them vulnerable to any secondary effects of climate change Boonyaratpaliin (1997) also states that their nature is sluggish and in their natural habitat they are often found to be resting in rocky crevices or at the bottom of cages when cultured, which helps the species save energy for growth thereby resulting in an increased feed efficiency. This characteristic however, may make grouper species more vulnerable to any climate change impacts, or indeed anthropogenic impacts, that make conditions at the bottom of aquaculture pens unfavourable (for example temperature changes, salinity changes, build up of waste or algal blooms etc). Disease has been and will continue to be of great concern in aquaculture systems in Southeast Asia as there is an increased risk of disease occurrence within cage reared fish (Merican, 2006) and the potential risk of transfer of diseases to (and from) natural fish populations (Ferguson et al., 2007). In the 1980s in particular, seabass in culture systems in Southeast Asia were affected by the tailrot disease caused by the myxobacteria *Flexibacter*, whilst groupers were infected by a disease known as 'the sleepy grouper disease', whereby fish would turn progressively darker and die, mostly at night (Seng,1997). These types of observations in the cage culture of finfish in Southeast Asia has led Seng (1997) to come to the conclusion that mariculture practices in floating cage systems have severe problems with disease which is not easy to control, and indeed not possible to eradicate in most cases as overlapping generations of fishes in the culture system provide a pool of pathogens for any newly placed fish.

The mangrove red snapper *(Lutjanus argentimaculatus)* in particular is vulnerable to serious diseases affecting the gills and skin of cultured individuals (Hoa and Ut, 2007). Parasitic monogenean disease has caused mass mortalities in this particular snapper species in Vietnam in the past, and is particularly lethal in small size fish less than 20cm (Hoa and Ut, 2007). Outbreak of the disease in marine fish cages is higher than pond culture systems *(Hoa and Ut, 2007)* suggesting marine systems may be more vulnerable to this disease than coastal and inshore pond systems. Cultured finfish are therefore inherently vulnerable to diseases and pathogens. This threat may be compounded with some impacts of climate change, for example increased temperature, lower salinity and other anthropogenic impacts such as reduced water quality in aquaculture sites. When analysing the vulnerability of finfish in this manner, it is appropriate to consider the synergistic impacts of climate change and other impacts which have the possibility to negatively impact finfish species. Currently, there is no such holistic literature available.

Overall vulnerability

Aquaculture has been shown to have negative impacts on water quality from increased nutrient loss from uneaten feed, faecal wastes from cage fish, and chemicals manually added to either maintain water conditions or treat disease or parasites (Tacon and Halwart, 2007). Fish species will therefore already be subject to a range of water quality impacts, which may affect their ability to adapt to further changes in their environment. All marine and freshwater aquaculture species are vulnerable to negative impacts on their food supply, namely, trash fish, fishmeal and fish oil (Tacon and Halwart, 2007). Tacon and Halward (2007) note that this dependency is not unique to cage farming systems, but also applies to pond and tank reared carnivorous fish and crustacean species, indicating a high dependence across the aquaculture industry regardless of species cultured. Increasing price, shortage of supply, variable quality and poor feed conversion ratios indicate that trash fish is not a nutritionally adequate and economical diet (Boonyaratpaliin, 1997), however it still remains the main diet component of the majority of marine finfish in cultured systems (FAO, 2011). It is important when considering the adaptation of aquaculture operations in the BCR project areas to consider the system-wide development of balanced feed formations which are less dependent (and therefore vulnerable) on trash fish production. There is also a high dependency of some cage-farming systems (notably those discussed in this section- grouper, seabass and snapper) on wild-caught seed where hatchery production is new or production is not currently sufficient to meet demand (Lovatell, 2006). This needs to be taken into consideration when analysing the effects of climate change on individual aquaculture species, as if climate change adversely affects seed production then this could have far-reaching consequences for production of that species in any number of countries, not least of all within the BCR project areas.

4.6 Selected species in wild capture fisheries

4.6.1 Mackerel (Rastrelliger brachysoma)

The Indo-Pacific Mackerel is a shallow pelagic fish species that occurs in the South China Sea and is an important target species for fishing communities located in the BCR project target regions in Thailand, Cambodia and Vietnam. This species is captured mostly via drifting gillnets however also by Tratitional bamboo traps in some areas (FAO, 1983). 160,398 tonnes of Indo-Pacific Mackerel (referred to as 'mackerel' from now on) were landed in Thailand alone in 2004 (FAO, 2011) highlighting the extent and importance of this fishery.

Sensitivity

Climate change will affect wild pelagic fish populations and communities through a range of impacts on either the larval, juvenile or adult phases (Munday et al., 2007)

(i)Temperature change

Temperature is the most pervasive climate-related influence on biological function (Brierley and Kingsford, 2009) and changes of a few degrees Celsius in ambient temperature can influence physiological condition, developmental rate, growth rate, swimming ability, reproductive performance and behaviour in fish species in tropical regions (Munday et al., 2007; Wood and McDonald, 1997). Fish are particularly sensitive to temperature changes during their early life histories, meaning an increase in temperature of 1-3°C in the South China Sea could shorten the incubation period of eggs for pelagic spawning (Munday et al., 2007). Reproduction of fish is often highly sensitive to fluctuations in temperature (Munday et al., 2008) and so warming can have either a positive or negative effect on egg production, depending on whether the target fish species is close to its thermal optimum. Mackerel spawn offshore however after egg hatching juvenile mackerel travel onshore via currents to develop in mangrove/wetland environments (Venkataraman, 1970). This means the mackerel is sensitive to changes in temperature in various stages of their lives, from egg to mature reproducing adult, as they inhabit different zones of the coast from mangrove to open ocean. Pradhan and Reddy (1962) note that both temperature and salinity appear to govern the migration patterns of mackerel; they were observed to show higher susceptibility towards temperature variations than to salinity, and overall catch rates suffered adversely from a rise in both values. There is very little information about the temperature specific-impacts of climate change on this species and their adaptive capacity, however studies such as those by Pradhan and Reddy (1962) carried out nearly 50 years ago, show that this species may well be highly vulnerable to changes in temperature. In general, most fishes are strongly adapted to the range of environmental conditions that they experience throughout the year; rapid or dramatic increases in temperature above normal maximum temperatures are expected to have significant negative effects on overall viability of some fish populations (Munday et al., 2008). In the wider tropical fisheries literature it has been stated that the magnitude of any effects from an increase in temperature are difficult to predict because: i) most studies on the effects of temperature on organism function have been conducted on temperate fishes; ii) tropical marine fishes may be more sensitive to elevated temperature than temperate marine fishes, because annual variation in water temperature experienced by tropical species is generally less than that experienced by temperate species; iii) cellular and physiological responses to temperature will interact in complex ways with environmental factors, such as food availability, to determine the outcome of higher temperature on individual phenotypic and life history traits; and iv) there is considerable potential for acclimation and adaptation to changes in temperature (Munday et al., 2007).

(ii)SLR

As juvenile mackerel inhabit mangrove and intertidal wetlands (FAO, 2011) they will be particularly vulnerable to the effects of sea level rise on these habitats, particularly if these habitats are degraded (subject to synergistic anthropogenic and/or climate impacts) or cannot naturally adapt (i.e. barriers in place to prevent landward retreat in the case of mangroves). Sea level rise will influence meso-scale habitat connectivity such as between estuaries, estuarine wetlands and mangroves (Munday et al., 2007) possibly threatening the connectivity of populations of wild mackerel.

(iii)Changing ocean chemistry

The sensitivity of tropical marine fishes to changes in pH at large magnitudes or by large increments is unknown (Munday et al., 2007). Fish eggs are much more sensitive to pH changes than juveniles or adults, and consequently the largest effects of acidification are likely to be on reproductive performance which may flow through to population replenishment if the impacts are sufficiently large (Brown et al., 1989). Increased levels of dissolved CO_2 can decrease the pH of fish tissue, which can be compensated via the control of ions across the gills (Munday et al., 2007). This compensatory measure may have some physiological costs in mackerel, however much more investigation is required into the effects of pH on this species.

(iv)Altered ocean circulation

Changes to current patterns in the South China Sea as a result of climate change could impact mackerel in a number of ways. Firstly local current systems may well be important in dispersing larvae back towards the coastline, where they settle in estuaries and progress to juvenile stages. Any changes in the strength or direction of these currents could influence larval transport along the coastline, possibly sending larvae to unsuitable habitats (Munday et al., 2007). Secondly circulation patterns could influence the production and distribution of mackerel's main food source- microzooplankton with a high phytoplankton content (FAO, 2011). Changes to productivity brought about by the effect of climate change on oceanographic circulation could influence the growth and survival of pelagic species (Munday et al., 2007) such as mackerel.

(v)Changes in precipitation

Freshwater input into the coastal zone in the South China Sea region is projected to increase in line with global climate change predictions (FAO, 2011). Changes in freshwater input are likely to impact mackerel due to the connectivity of estuarine/mangrove habitats and the open ocean environment in their life cycle.

(vi)Increase in severity/frequency of extreme events

Venkataraman (1970) observes that in Indian populations of mackerel, a large scale occurrence of juvenile individuals present inshore frequently during the period immediately after the monsoon is suggestive of migration from offshore to inshore waters, suggesting their movements are dictated by seasonal changes. Extreme events such as cyclones and storm surges may disrupt this relationship, and as such may trigger coastal migration at the wrong time, or not at all. Very little is known about the relationships between extreme events, seasonality and Mackerel species in the South China Sea, and as such it is impossible to predict impacts of, and responses to, climate change in the future.

Overall vulnerability

Mackerel are vulnerable to temperature changes in the earliest life stages up to adulthood, due to the different locations of their life history events (i.e. open ocean to inshore coastal environments). Sea level rise and specific coastal impacts such as runoff and pollutants may act synergistically on mackerel larvae and juveniles, rendering them vulnerable. Climate induced changes to oceanographic conditions could have far-reaching consequences for the growth, survival, and dispersal patterns of larval fishes, with important implications for the dynamics of adult populations (Cheal et al., 2007), however the extent to which mackerel will be impacted by these changes in unknown. This species could also be highly vulnerable to changes in ocean chemistry, as low pH has been shown to be detrimental to fish eggs and their skeletons (Munday et al., 2003). Mackerel could be highly vulnerable to changes in ocean productivity as this is the mainstay of their diet, and as such the secondary impacts of climate change on mackerel (via the food chain) must be considered in a holistic review of vulnerability for this species.

4.6.2 Squid (Loligo spp)

Thirty species of cephalopods from ten families and 17 genera are found in the waters off the coast of Thailand, Cambodia and Vietnam, with the most important species within the fishery being *Loligo chinensis, L. duvauceli, L. singhalensis, L. edulis, Loliolus sumatrensis and Sepioteuthis lessoniana*; the cuttlefishes *Sepia pharaonis, S. aculeata, S. recurvirostra, S. lycides, S. brevimana and Sepiella inermis* and the octopus *Octopus membranaceous, O. dollfusi and Cistopus indicus*. (FAO, 2011). These resources are also fully exploited (FAO, 2011). Due to the diversity of species exploited in the target regions, this review will concentrate on the overall sensitivities of squid species to climate change.

Sensitivity

(i)Temperature

Squid have a flexible life history which is a result of the highly responsive nature of their growth to temperature changes (Pecl and Jackson, 2008). For example, Loligo forbesi hatchlings reared at two temperatures with only 1^0C difference resulted in squid that were three times larger in the warmer group after 90 days than the cooler reared siblings (Forsythe and Hanlon, 1989). Tropical squid that grew through periods of warming water temperatures grew 9% faster than squid that grew through periods of cool water temperatures (Jackson and Moltschaniwskyj, 2002). It has been suggested that squid will thrive in the face of a global warming of the seas, with increased growth rates, accelerated life histories and rapid turnover in populations, which could potentially lead to population expansion at the expense of slower growing teleost competitors (Jackson, 2004). However, under continued temperature elevation there will likely come a point where growth rates start to decrease as metabolic costs continue to escalate and growth potential is subsequently reduced (Pecl and Jackson, 2008). As with many marine organisms however, squid are vulnerable to changes in environmental conditions such as temperature and salinity, during different life stages. During embryonic development of squid, temperature and salinity heavily influence the survival of both embryos and later, juvenile squid, which will ultimately dictate population success (Cinti et al., 2004). Pecl and Jackson (2009) note that as temperatures increase, development times of cephalopod eggs decrease, provided that temperatures do not fall outside of thermal tolerance boundaries, however although hatchlings emerge quicker under elevated temperatures, there is a negative relationship between incubation temperature and hatchling size so that under higher temperatures, hatchlings emerge smaller (Boletzky, 1994; Gowland et al., 2002; Vidal et al., 2002). Smaller squid hatchlings may mean smaller adults, or at least no net increase in size-at-age, even if growth rate is substantially elevated by temperature Pecl et al. 2004).

(ii)Changes in precipitation

As has been discussed, salinity is an important factor influencing embryonic development and survival in squid (Cinti et al., 2004). Squid larvae are intolerant to freshwater, and as such are extremely vulnerable to reduced salinity events; this vulnerability is compounded as adults die after spawning, and as such an entire season's recruitment may be lost (Przeslawski et al., 2008). Populations may be negatively affected if heavy rainfall and associated freshwater runoff occur during reproductive periods but they may not be affected at other times (Przeslawski et al., 2008), therefore it is difficult to assess the amount of exposure squid will have to this particular climate change impact, although they are highly sensitive to it.

(iii)Changing ocean chemistry

The associated drop of pH with rising CO2 concentrations will likely negatively affect squid, as they are highly sensitive to pH change with large decreases in oxygen affinity as pH decreases (Pecl and Jackson, 2008). This will result in a decreased ability to bind oxygen for transport to the tissues (Seibel and Fabry, 2003) which may have implications for growth, reproduction and other physiological processes at different life stages (Pecl and Jackson, 2008).

(iv)Changing ocean circulation

Alteration of global, regional or local currents and oceanic circulation may have important implications for squid and other cephalopods. Changes in primary production associated with changes in nutrient flows/upwelling are of particular significance as this constitutes the basis of the food chain for these organisms. For example Jackson and Domeier (2003) demonstrated that in Loligo opalescens population off California, although temperatures were much higher during the El Nino event, squid had slower growth rates and were strikingly smaller from lack of food due to drastically reduced productivity associated with a cessation of upwelling.

Overall vulnerability

Ecologically squid and other cephalopods are crucial components of many inshore ecosystems and demonstrate extraordinary flexibility in their life history characteristics, which may make them less vulnerable to environmental change than their fish competitors (Pecl and Jackson, 2008). They are certainly still vulnerable to the effects of climate change though, as having a very high metabolism comes with a cost. Failure to feed for even short periods is disastrous for squid, and under a regime of elevated temperatures smaller squid hatchlings would need more food but have less time to find it before facing mortality (Pecl and Jackson, 2008). Squid have been shown to be highly vulnerable to changes in salinity in their life stages (Przeslawski et al., 2008) and as such changes in precipitation, extreme events causing flood plumes from coastal areas and the like may threaten the survival of squid in the BCR project regions, having potentially disastrous consequences to squid fisheries and the individuals they support.

Squid species are highly vulnerable to changes in pH, with metabolic and physiological processes negatively affected with the consequential drop in the ability to bind oxygen for transport to bodily tissues (Pecl and Jackson, 2008). As with other marine organisms, squid are vulnerable to the secondary changes that may occur to their food supply as a result of climate change impacts, for example changing ocean circulation and therefore possibly reduced primary production from differential nutrient upwelling. Currently there is very little information about how the synergistic effects of climate and other environmental change and anthropogenic stressors such as overfishing and habitat destruction act on squid species (Root et al., 2003).

4.7 Protected areas and other sites of conservation importance

Preliminary analyses of protected areas and other sites of conservation importance in the project area indicate the following points relevant to the current study (based on data in Appendix 5 and references therein).

- Terrestrial protected areas and IBAs in the project area which are at highest potential risk from climate change are in the Mekong Delta. These comprise three designated protected areas, one proposed nature reserve and five IBAs: U Ming Thuong National Park and Kien Luong Proposed Nature Reserve, and Ha Tien, Kien Luong and U Minh Thuong IBAs (Kien Giang Province), Thanh Phu Nature Reserve and Binh Dai and Ba Tri IBAs (Ben Tre Province) and the 'Can Gio Man and The Biosphere Reserve' (which encompasses the Can Gio IBA) (Can Gio Province). At least two of the IBAs which may be impacted by sea-level rise, Binh Dai and Ba Tri, are not designated protected areas. Maps of inundation extent in the Delta with a one-metre rise in sea level (Carew-Reid, 2007) indicate all of these sites could be partly or entirely inundated, and remaining areas would be vulnerable to saltwater intrusion. U Minh Thuong National Park could be completely inundated (Carew-Reid, 2007). The inundation of these sites may result in the loss of over 140,000 ha of important habitats for conservation, principally inter-tidal mudflats, mangrove forest, Melaleuca forest/seasonally flooded grassland and sandy or rocky beaches.

- The single Marine National Park (Mu Koh Chang) and three Proposed Marine Protected Areas (Phu Quoc, Nam Du, Tho Chu) in the project area (Appendix 5) could all be impacted by climate change to some extent. Sea-level rise of 0.4-1 m in the project area may result in the complete or partial loss of sandy and rocky beaches, greater storm damage of coral reefs and seagrass beds, increased water turbidity and subsequent siltation of reefs and seagrasses, and reduced extent of shallow-water zones. Warmer temperatures may impact the survival and productivity of coral reefs and seagrasses.

- Other long-term impacts to marine and terrestrial habitats may result from reduced annual rainfall and rising levels of carbon dioxide. These may cause gradual changes in the composition of terrestrial and aquatic vegetation communities, and subsequent changes in the availability of food, shelter or breeding sites for fauna. Rising levels of carbon dioxide may mitigate some of the impacts of climate change by reducing water stress on plants, and may also assist the colonization of mangroves into freshwater if they are not limited by salinity (Hughes, 2003 and references therein; Bates et al., 2008), but may also facilitate invasion of woody shrubs which could displace existing plant communities. In marine sites, elevated levels of carbon dioxide would increase the acidity of waters, which might impact fish, invertebrates and coral reef formation (Harley et al., 2006).

- In the project area, the coastal protected area network in Koh Kong probably has the strongest natural resilience to climate change, because it encompasses a large area of relatively intact habitats and a range of elevations and latitudes ('ridge to reef' coverage). Due to its large size and non-linear shape this network also has a small boundary : area ratio, implying that edge effects to core habitats are limited. The protected areas in Ben Tre, Can Gio, Kien Giang and Soc Trang probably have the lowest resilience to climate change, because they are isolated sites within developed landscapes, at low elevations (few options for organisms to disperse northward or to higher elevations), and are small with large boundary : area ratios i.e. are subject to greater edge effects. The mangrove forests in

Chanthaburi and Trat are largely narrow, linear and fragmented, and for these reasons will also be subject to high edge effects, with potentially low resilience to climate change.

- Sea-level rise in the project area would probably result in land-use conflict with protected areas in all provinces, as communities are forced to relocate to other areas. This is likely to be most severe in Ben Tre, Can Gio, Kien Giang and Soc Trang Provinces.

- Four proposed protected areas (three marine, one terrestrial) are present in the project area, all within Kien Giang. Designation of these reserves, as well as unprotected IBAs, should be supported in order to enhance the resilience of the protected area network in the project area to climate change.

- The potential impact of climate change on the protected area networks in the project area has major implications for biodiversity conservation and the maintenance of natural habitats. It will also have important consequences for the national protected area networks of Cambodia, Thailand and Vietnam, because it suggests that the overall effectiveness of these networks will be compromised. In the Mekong Delta, some sites may disappear, while elsewhere in the project area, the condition of all coastal and marine sites may decline. As species and habitats shift northward or to higher elevations, existing protected areas may no longer encompass key populations of threatened species. These impacts have been documented for some tree species and protected areas in northern Thailand (Trisurat et al., 2009). For the project area, at least two approaches will be required to address these impacts: site-specific adaptation measures to maintain and enhance the resilience of protected areas in the project area; and, and assessment of the terrestrial and marine protected area networks of Cambodia, Thailand and Vietnam in the light of climate change.

4.8 Vulnerability assessments summarised by province

This section summarises the results of the vulnerability assessments (Sections 4.1-4.2) for each province (Table 7). For the eight habitat categories, the assessments were conducted for each province (i.e. 8 categories x 8 provinces = 64 assessments; Section 4.1), but for the selected species, assessments were only conducted for the entire project area (i.e. a total of 13 assessments; Section 4.2), because the total number of assessments would otherwise have been too great within the time of this review (13 species/assemblages x 8 provinces = 104 assessments). Here, each overall assessment ranking is extrapolated to each of the eight individual provinces (Table 7), based on consideration of the status of each species/assemblage in each province (Appendix 4), their habitats (Appendix 3) and representation within protected areas or other sites of conservation importance (Section 4.3; Appendix 5). This is a coarse extrapolation only and should not replace assessment for each species for each province.

Table 10. Summary of vulnerability assessment rankings for "Climate change+existing threats" (see Tables 3-4 in Sections 4.1-4.2 for details). 'Loss' refers to 'Complete loss'. ? – no assessment made due to lack of data. N/a-not applicable (the habitat, species or assemblage does not occur in the province or to such a small extent that impacts are considered negligible relative to other provinces).

Variable	Koh Kong	Kampot	Chanthaburi	Trat	Ben Tre	Can Gio	Kien Giang	Soc Trang
Habitat								
In-shore shallow waters	Med	Med	Low	Low-Med	Med	Med	Low-Med	Med
Sandy beaches	Med-High	Med-High	Low	Med	N/a	Med	Med	N/a
Rocky beaches	Med-High	Med-High	Low	Med	Low	Low	Med-High	Low
Inter-tidal mudflats	High	High	Med	Med-High	Loss	Loss	Med-High	Loss
Estuaries/inlets	High	High	Very High	Very High	Very High	Very High	Very High	Very High
Seagrass beds	Loss	Loss	Loss	Loss	?	?	Loss	?
Mangroves	High	High	Very High	Very High	Loss	Loss	Loss	Loss
Melaleuca/SFG	Very High	Very High	N/a	N/a	N/a	N/a	Loss	N/a
Selected species								
Cetaceans (3 species)	Very High	Very High	Very High	Very High	?	?	Very High	?
Dugong	Loss	Loss	Loss	Loss	N/a	N/a	Loss	N/a(?)
Flying-foxes (2 species)	Med(?)	Med(?)	Med(?)	Med(?)	Med(?)	Med(?)	Med(?)	Med(?)

Variable	Koh Kong	Kampot	Chanthaburi	Trat	Ben Tre	Can Gio	Kien Giang	Soc Trang
Sarus Crane	Loss	Loss	N/a	N/a	N/a	N/a	Loss	N/a
Other large waterbirds	Very High	Very High	N/a	N/a	Very High	Very High	Very High	?
Colonial-nesting medium-sized waterbirds	Low(?)	Low(?)	Low(?)	Low(?)	Very High	Very High	Very High	?
Migratory shorebirds	Very High	Very High	Low	Low	Very High	Very High	?	?
Green Turtle	Very High	Very High	?	?	?	?	Very High	?
Hawksbill Turtle	Loss	Loss	Loss	Loss	Loss	Loss	Loss	Loss
River Terrapin	Loss	N/a	N/a	N/a	N/a	N/a	N/a	N/a

Potential adaptation strategies to address climate change threats to habitats and the selected species are described in Section 5.

A fisherman comapres the size of crabs he caught
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5. Adaptive capacity and adaptation

The adaptive capacity of the majority of marine and coastal organisms to the majority of climate change impacts is largely unknown (Munday et al. 2007) and the situation is made more complicated when considering the system in question (i.e. an ecosystem or an agro-ecosystem such as a closed aquaculture system). Climate change may favour some species of tropical marine organism over others, thereby changing the biogeography of fish stocks and their relative abundance (Badjeck et al., 2010). Adaptation within the fishing industries themselves will therefore require changes to harvest strategies and processing techniques, and may affect fishing costs through changes in travel time and associated fuel and ice consumption (Mahon, 2002).

While an ecosystem may be able to recover from a single event, some authors such as Przeslawski et al. (2008) believe that recovery from multiple stressors or recurrent events expected from climate change will be significantly compromised as currently evidenced by systems such as coral communities that do not recover following repetitive bleaching events (Hoeugh-Guldberg et al., 2004). The responses of different ecosystems relative to the pace, frequency and magnitude of change will largely determine the extent of the impact from climate factors.

Mangrove response to severe storm/cyclone damage is largely unknown, however there has been some data to suggest trees can recover as long as patches of reproductive individuals remain and the hydrology and sediments are not altered to an extent where reestablishment is prevented (Ellison, 1998; Gilman et al., 2008; Sherman et al., 2001; Smith et al., 1994). According to Baldwin et al. (2001), species from the Rhisophoraceae family are the most vulnerable to damage by cyclones as they cannot re-sprout

The response of mangrove systems in the BCR project target areas to sea level rise will depend on a number of factors including, but not limited to: sediment input; changes in elevation of the mangrove substrate; regional oceanographic properties; geomorphology and topography of the coastal zone; and of course the rate of the sea level rise (Soares, 2009). This last point is paramount; these ecosystems may be able to adapt to rising sea levels and remain stable if the rate of vertical accretion of the soil surface of the wetland equals or exceeds the rate of sea level rise (Cahoon et al., 1999; Morris et al., 2002). The consequence of sea level rising relative to the elevation of the mangrove sediment surface is a landward migration as the mangrove species maintain their preferred hydroperiod (Gilman et al., 2008).

Groundwater extraction is particularly important in the context of mangrove ecosystems in the Mekong delta, as land subsistence from extraction and sediment losses from upstream dams are already causing the region's deltas to sink (Ryvitski et al., 2009) making the region particularly vulnerable to sea level rise. The presence of barriers to prevent mangroves from successfully retreating landward can be viewed as a serious limitation to their adaptation. Identifying these barriers and how they will lead to unacceptable changes in mangrove, salt flat or salt marsh communities (Lovelock and Ellison, 2007) followed by the removal of non-vital barriers (Sheaves et al., 2007) wherever possible, will be important first steps in adaptation planning and action. Human use of coastal systems will need to be carefully monitored, for example land clearing, coastal development and groundwater extraction, so that the delivery of sediments and their associated nutrients is facilitated, and the delivery of pollutants is avoided (Sheaves et al., 2007).

Corals could have two potential responses to the impacts of climate change(Hoegh-Guldberg et al., 2007) acclimatisation (a phenotypic change within the individual) and adaptation (a genetic response at the population level). Acclimatisation to climate change may be possible in corals, as they can acclimatise to changes in their environment including seasonal temperature fluctuations (Brown, 1997; Coles and Brown, 2003, Gates and Edmunds, 1999). As with any physiological trait however, there are limits to the extent to which organisms can acclimatise to environmental change (Hoegh-Guldberg et al., 2007). Adaptation has been harder to prove as a response to climate change; at a genetic level there is very little, if any evidence to suggest corals and their zooxanthellae have been able to adapt to changes in sea temperature over the past 20 years (Hoegh-Guldberg et al., 2004). Evidence suggests that rates of change are faster than reef-building corals can adapt to (Hoegh-Guldberg et al., 2004), however the speed and extent to which zooxanthellae can produce heat-adapted coral populations is currently unknown (Wooldridge, 2005).There is also a third adaptation where by corals may shift their geographic distribution by settling away from the equator (Walther et al., 2002). It is a common view that corals are too long-lived to evolve quickly and that geographic differences in temperature tolerances have evolved over much longer time frames than the decadal scale of current changes in climate (Hughes, 2003), and thus there is much uncertainty about how coral reefs will adapt to rapid changes in climate.

In all documented cases of seagrass loss from cyclone and storm damage in other tropical regions such as Queensland in Australia, recovery has been documented (Birch and Birch, 1984; Campbell and McKenzie, 2004; Waycott et al., 2007). It has been shown that seagrasses usually recover from transient impacts, with recovery of subtidal and intertidal meadows after flood-related loss observed within two years in Australian examples (Preen et al., 1995; McKenzie et al., 2000; Campbell and McKenzie, 2004). Species growing in ephemeral and dynamic communities are better adapted to live in disturbed environments therefore these species are likely to recover faster (Waycott et al., 2007). All seagrasses can adapt their physiology and morphology (Waycott et al., 2007). For shallower seagrasses response to reduced light availability will include reduced growth and biomass but may also include some physiological responses such as changing carbohydrate utilisation and pigment concentration, or even a change in morphology (Longstaff and Dennison, 1999; Waycott et al., 2005). Changes in water quality represent a serious challenge for seagrass species. Enhanced nutrients and pollutants from land run-off can cause a shift in seagrass distribution and depth penetration (Abal and Dennison, 1996). Generally, seagrasses are nutrient-limited (Duarte, 1999) and thus increases in nutrient availability promote seagrass growth (Shaffelke et al., 2005). Herbicides however, present a significant threat to seagrass communities. Herbicide exposure was implicated in the slow recovery of seagrass meadows in Hervey Bay lost due to the impact of flood plumes (Macinnis-Ng and Ralph, 2003). Studies by Macinnis-Ng and Ralph, (2003) suggested that seagrasses respond and recover at different rates when exposed to herbicides both in laboratory and natural settings.

Table11: Summary of the adaptive capacity of coastal habitats to climate change impact

	Coastal habitats		
	Mangrove	Seagrass	Coral reefs
Physical climate parameters	Adaptation	Adaptation	Adaptation
Rainfall increasing	Unknown for the long term	Thought to cope in the short term, long term adaptation not known	Unknown in the long term
Rainfall decreasing	Unknown for the long term	N/A	N/A
Air and water temperature increase	Possibly an increase in ecosystem productivity but within thermal tolerances	Largely unknown given high water temperatures will act in synergy with other climate change impacts	Unknown in the long term Possible local level acclimatisation
Increase in severity/frequency of storms	Unknown for the long term although there is evidence to suggest recovery is possible as long as sediments and hydrology are in tact	Unknown for the long term	Unknown in the long term
SLR	Likely adaptive action will be landward retreat if there are no physical barriers	<-	Unknown in the long term Possible local level acclimatisation
Salinity changes	Unknown for the long term	Unknown for the long term	Unknown in the long term
pH changes	Unknown for the long term	Unknown for the long term	Unknown in the long term

	Coastal habitats		
	Mangrove	Seagrass	Coral reefs
Turbidity	Unknown for the long term	Unknown for the long term	Unknown in the long term
Changes in upwelling	Unknown for the long term	Unknown for the long term	Unknown in the long term
Changes in circulation	Unknown for the long term	Unknown for the long term	Unknown in the long term
Other aspects	Attempts to move landwards may be hampered by a sinking coastline due to groundwater extraction	Adaptation	Adaptation

Shellfish:

Increasing sea surface temperatures may result in various effects based on different thermal tolerances, as populations based in the middle of their tolerance range my flourish due to faster development and increased growth rates, whilst those located at the edge of their thermal tolerance may become extinct (Precht & Aronson, 2004; Greenstein & Pandolfi, 2008). Much more research is needed to understand the linkages between temperature and tropical commercially important invertebrates, such as the mussels, cockles and oysters currently cultured in the BCR project regions, in order to predict more accurately how they will be affected by increases in atmospheric and sea temperatures from climate change.

Siting new aquaculture locations in Thailand, Cambodia and Vietnam for shellfish culture may be much harder in the future. Zoning of 'safe' aquaculture locations, away from run-off, coastal developments, pollutants and threatening phenomena such as red tides, will have to form part of regional/national/trans-boundary sustainability and food security plans. Increasing costs of land, threats from climate change impacts such as sea level rise and increased cyclone activity and placing regular water quality monitoring facilities within the capacity of regulatory bodies will all have to be taken into account. It is also possible that farmers may be able to choose more resilient species to culture, as suggested by de Silva and Soto (2009).

Mud crab and blue swimming crab:

Natural populations of mud crab have been shown to extend their ranges south into the lower latitudes of Australia, and have been found nearly 1000kms outside of their normal range (Gopurenko et al, 2003). Previous range expansions of this species have occurred both in the Hawaiian Islands and New Zealand, consistently into colder conditions (Brock 1960; Dell, 1964), however the reasons for these movements are unknown. Studies have also shown that blue swimming crab migrate en masse in Australia due to influxes of freshwater flood plumes (Potter et al., 1983), suggesting their natural adaptive action to unfavourable conditions is migration. While it is clear that wild populations of both mud crab and blue swimming crab have the capacity to shift their natural ranges in search of more favourable conditions, the question is will they shift northwards if conditions in the South China Sea become unfavourable?

Cultured crab species are limited in their ability to adapt as they cannot migrate, making them more vulnerable to climate change impacts than wild populations. One possible mechanism for adaptation within the mud crab fisheries in the BCR project regions is by using mangroves as natural, sustainable fisheries for mud crab production, as opposed to raising crabs in ponds away from mangrove environments. Stocking densities of crabs within mangrove culture environments must be conservative, as raising crab densities above sustainable limits will disrupt the natural food chain (Przeslawski et al., 2008).

Shrimp and prawn:

Reducing the risk of disease has become a central goal of the shrimp aquaculture industry, at least in Thailand, and as such it has been ascertained that reducing saltwater exchange can help reduce incidence of disease (Lebel et al., 2002). Shrimp and prawn are sensitive to high and very low salinity levels (Lebel et al., 2002) however shrimp can be acclimatised to total freshwater immersion using a gradual introduction technique as outlined by Briggs and Funge-Smith (1997). Moving inland has been seen to be a way in which coastal pollutants and risks associated with storms and flooding can be mitigated in the shrimp industry and as such low salinity rearing has removed a key constraint to the expansion of the industry into inland, delta and riparian areas (Flaherty et al., 1999).

Seabass, grouper and snapper:

The extent to which finfish or the finfish aquaculture industry in the BCR project areas is able to adapt to changing climatic conditions is unknown. One adaptation measure of the wild species if temperature and other conditions are unfavourable is to shift ranges (see section on Mackerel). Range shifting in wild populations is dependent on a multitude of factors such as food and habitat availability and currents (Munday et al., 2007). Sea level rise presents more of a risk to aquaculture operations than to the cultivated species per se. For the species themselves, temperature fluctuations will be more important. Seabass have shown to be tolerant to changes in temperature and salinity (Boonyaratpaliin, 1997) and therefore are much less sensitive to these climate change impacts that may manifest themselves at farm level in the future. They are however, still vulnerable to changes in salinity as larvae in early development (Ruangpanit and Kongkumnerd, 1992) which must be taken into consideration when looking at the vulnerability of this species as a whole to climate change impacts. Some authors such as Katersky and Carter (2005) suggest seabass is already being cultivated in environments close to its thermal tolerance in the tropics.

Adaptation in the aquaculture industry in Thailand specifically, has shown that farmers are capable of shifting between cultivated species which inhabit similar conditions, such as shrimp, grouper, seabass and similar species, according to price and market demand (Kongkeo et al., 2010). This kind of adaptation has not been fully explored in the literature; however it is a positive indication at the possible adaptive capacity small-scale aquaculturists in the target regions. Pilot studies in Vietnam have shown that culturing seabass and grouper species in brackish inlets previously not used for this purpose, has been successful. The experiment was carried out in areas with highly variable temporal conditions such rainfall (and therefore salinity) and turbidity. This pilot has important implications for both the species and the industry. Firstly, the study showed that both of these fish species could tolerate abrupt changes in salinity and turbidity, indicating they will not be as vulnerable to these changes if they occur as a result of climate change, as other finfish which require much more stable conditions. Secondly, it has important implications for the industry itself, as the study showed that these finfish can be successfully cultured in such an environment (i.e. one in a constant state of flux, as inlets are). This has obvious implications for the expansion of the industry, but also the adaptation of the industry in situ to future climate change impacts.

Mackerel:

As mackerel only occur in habitats where surface temperatures range between 20 and 30° C (FAO, 2011) one possible adaptive mechanism for the species may be to shift their ranges. Range shifting will depend on the availability of suitable habitat, food and conditions for breeding (Przeslawski et al., 2008). Biogeographic range shifts are one of the clearest signatures of climate change impacts in animal communities- and whilst acclimation or adaptation to increased temperature via range shifting seems possible, there is little prospect of adaptation to habitat degradation (Munday et al., 2007) which in the case of the mackerel, would severely impact a vital stage of their life history. Since mackerel have been found in low salinity environments (FAO, 2011) it can be ascertained that this species already has a greater tolerance than other teleosts (for example reef species, which do not use coastal environments as nursery grounds), however the extent to which mackerel in any life stage can tolerate extreme fluctuations in salinity is unknown.

The fisheries implications of climate change impacts on mackerel species are as yet, unknown. It should be apparent that climate change has the potential to affect all trophic levels of marine ecosystems in this region, eventually resulting in changes in the productivity and distribution of fish stocks (Rijnsdorp et al., 2009). Extensive fishing may cause fish populations to become more vulnerable to short-term natural climate variability (Rijnsdorp et al., 2009) however the extent to which this may be the case in the context of mackerel, is unknown. Fisheries managers in the BCR project areas and indeed, elsewhere have a trying time ahead. Ecosystem and resilience-based fisheries management approaches, such as those being employed on the Great Barrier Reef include the development of cross-jurisdictional regional management plans and research priorities appropriate for the changing distribution and abundance of the species being harvested or farmed and the development of monitoring, assessment and management strategies which are robust in the face of increased uncertainty due to climate change (Howden et al., 2007). Such tools would be invaluable in the fisheries of the BCR project areas, due to the potential for synergistic impacts (climate and anthropogenic) to negatively affect wild capture fisheries.

Squid:

As short-lived species with plastic growth and reproduction and high mobility, squid are better poised than many species or groups to respond to environmental change (Boyle and Boletzky, 1996). They have an extremely fast growth rate and rapid rate of turnover at population level, which means they can respond quickly to ecosystem change (Pecl and Jackson, 2008). There are of course limits to thermal tolerance, and there has been some evidence to suggest at least one of the squid species in the BCR region is already at its thermal limit. *S. Lessoniana (*the Indo-Pacific squid) has been shown to be operating near its physiological limits with respect to temperature resulting in reduced growth rates (Jackson and Moltschaniwskyj, 2002).

Squid are trophic opportunists that can occupy broad trophic niches and exploit the temporal and spatial variability in prey populations, which despite their requirement for large quantities of prey, means they have a fairly high adaptive capacity potential to prosper during periods of reduced productivity (Pecl and Jackson, 2008). In terms of shifting latitudes as a response to thermal limits, squid may already avoid warmer waters simply because food supplies are insufficient to maintain such high metabolic rates, as has been suggested for other organisms such as salmon (Welch et al., 1998). Examples of squid shifting their latitudes have already been recorded, with the sudden appearance of subtropical and tropical species in temperate Galician waters, an effect attributed to an increase in sea surface temperatures of the north-eastern Atlantic Ocean (Guerra et al., 2002). The potential of tropical squid in the South China Sea regions to shift latitudes, and indeed other potential adaptive responses to climate change, has not been explored and due to the important fishery implications of their responses to climate change, should be treated as a research priority.

A range of adaptation approaches will be required to address the potential impacts of climate change in the project area, due to the differing levels of vulnerability and resilience of the coastal habitats and selected species (Sections 4.1-4.3). A preliminary list of adaptation strategies for the project area is in Table 8, and comprises actions at five scales: policy (provincial and/or national), landscape, site, habitat and species. Further work will be required to refine these approaches for implementation. These strategies aim to maintain and/or enhance resilience to climate change. In some provinces (e.g. Koh Kong), strategies should focusing on maintaining the relatively extensive protected area network, while in other provinces, particularly those in the Mekong Delta, adaptation strategies should focus on restoring habitats within highly degraded landscapes.

Table 12. Preliminary identification of adaptation strategies for biodiversity conservation and natural resource management in the project area, in the context of climate change. IBA-Important Bird Area, PA-protected area. Note there is some overlap between actions for 'Landscape', 'Site' and 'Habitat'.

Province	Level of approach	Actions
Cambodia		
Koh Kong	Policy	• Assess the effectiveness of current policies and development plans for natural resource management and economic development in the context of climate change, and recommend changes as necessary • Review the extent to which current national/provincial policies support implementation of 'integrated coastal management' (ICM), and recommend changes necessary to strengthen this approach for climate change management in the province
	Landscape	• Maintain the existing coastal PA network and latitudinal and elevational gradients ('ridge to reef'), which impart resilience to climate change • Assess the need to expand and/or augment the PA network in the context of climate change, to maximize connectivity of habitats across elevations and latitudes. Apart from PAs this could include buffer zones, multiple-use areas, Ramsar sites and community-managed areas • Avoid disruption of protected/managed landscapes by minimizing habitat fragmentation and coastal development, especially along habitat corridors (e.g. dams on Sre Ambel River) • Conduct a detailed study of landcover/use changes in the project area, to address the issues above
	Site	• Review management effectiveness within individual PAs, multiple-use areas and other sites designated for natural resource management (training needs, funding gaps, etc); identify actions which will strengthen effectiveness in the context of climate change • Review existing conservation projects in the project area, identify key gaps and weaknesses in the context of climate change; establish new projects to address these

Province	Level of approach	Actions
	Habitat	• Mangroves: maintain intactness/quality of forests (which are the most intact in Cambodia) • Seagrass beds: map existing beds; develop/implement recovery plan • Melaleuca forests and grasslands: map extent; develop/implement recovery plan • Coral reefs: conduct vulnerability assessment and develop recovery plan
	Species	• Cetaceans, Dugong: develop programs which leverage upon coastal community beliefs (which already impart some protection to these species) • River Terrapin: protect nests and nest sites; develop recovery plan • Sarus Crane and other waterbirds: assess conservation needs; develop recovery plans • Identify all other threatened coastal / marine species; prepare recovery plans
Kampot	Policy	• As for Koh Kong
	Landscape	• Strengthen PA network by officially designating all of the coastal IBAs in this province (see Appendix 5), most of which are not yet protected and with low / no overlap with existing PAs • Expand and augment the coastal and marine PA networks in the context of climate change • Avoid disruption of protected/managed landscapes by minimizing habitat fragmentation and coastal development, especially along habitat corridors • Conduct a detailed study of landcover/use changes in the project area, to address the issues above
	Site	• As for Koh Kong
	Habitat	• Assess need to restore and/or augment existing stands of mangrove, Melaleuca • Assess need to protect inter-tidal mudflats • Seagrass beds: map existing beds; develop/implement recovery plan • Coral reefs: conduct vulnerability assessment and develop recovery plan
	Species	• As for Koh Kong (except for River Terrapin, which is not known from Kampot)
Thailand		
Chanthaburi	Policy	• As for Koh Kong
	Landscape	• The lack of a large existing protected area network in this province provides an opportunity to design and establish a network of community-managed areas in the context of climate change • Establishment of community-managed areas may be the most appropriate given the paucity of officially designated protected areas • Restore coastal wetlands throughout the developed lands along the coast e.g. reconnect streams to mainstreams, remove small dams/ sluice gates which impede flow • Conduct a detailed study of landcover/use changes in the project area, to address the issues above
	Site	• As for Koh Kong
	Habitat	• Mangroves: support and enhance current mangrove restoration programmes. As well as strengthening soil stability /coastal buffers against sea-level rise and storm damage, mangrove replanting programmes should aim to restore original species composition • Seagrass beds: map existing beds; develop/implement recovery plan • Coral reefs: conduct vulnerability assessment and develop recovery plan
	Species	• Identify all other threatened coastal / marine species; prepare recovery plans
Trat	Policy	• As for Koh Kong

Province	Level of approach	Actions
	Landscape	• Assess management effectiveness at Mu Ko Chang Marine National Park; strengthen management/expand/augment this site as necessary in the context of climate change • Assess need/benefit for Ramsar designation for the 'Trat wetlands KBA' • Assess options to expand the coastal and marine protected area network • Conduct a detailed study of landcover/use changes in the project area, to address the issues above
	Site	• As for Koh Kong
	Habitat	• As for Chanthaburi
	Species	• Cetaceans: develop conservation plans which build upon local awareness of dolphin mortalities • Identify all other threatened coastal / marine species; prepare recovery plans
Vietnam		
Ben Tre	Policy	• As for Koh Kong; and, • Assess the need to establish new policies/strengthen existing policies which promote restoration of coastal habitats e.g. mangrove planting, given the severe extent of habitat loss
	Landscape	• Strengthen coastal PA network by officially designating Binh Dai and Ba Tri IBAs • Expand/augment coastal PA network in the context of climate change: given the predicted impacts of sea-level rise and low-lying aspect of the Mekong Delta, this may require the establishment of long riparian protected corridors along rivers, extending upstream, combined with restoration of habitat buffers, to protect latitudinal and elevational gradients • Restore habitat connectivity between remnant habitats/sites • Emphasise 'soft' approaches against saltwater intrusion for the most flood-prone areas (data already available for Mekong Delta; Carew-Reid 2007): establish plans for 'managed retreat' in areas to be flooded - phase out development, create set-back zones for development, focus mangrove planting in key areas, remove large dams/barrages along main rivers • Conduct a detailed study of landcover/use changes in the project area, to address the issues above
	Site	• As for Koh Kong; and, • Particular attention should be focused on Binh Dai IBA, among the most important sites for migratory shorebirds in the Mekong Delta
	Habitat	• Mangroves: identify existing re-planting programmes and other efforts (e.g. WWF project in this province); collaborate with existing projects and/or initiate programmes in new areas; identify the potential for REDD+ as a viable strategy to assist mangrove rehabilitation • As well as strengthening soil stability /coastal buffers against sea-level rise and storm damage, mangrove re-planting should aim to restore original species composition • Inter-tidal mudflats: integrate conservation planning for this habitat with mangrove programmes; identify mudflats which may not be inundated and identify best approaches to maintain these
	Species	• Develop / implement recovery plans in the context of climate change for migratory shorebirds, especially in Binh Dai and Ba Tri IBAs • Identify all other threatened coastal / marine species; prepare recovery plans
Can Gio	Policy	• As for Ben Tre
	Landscape	• Assess need to expand/augment the PA network, including designation of Ramsar or community-managed areas (see points for Ben Tre)
	Site	• As for Koh Kong; and, • Maintain and/or strengthen the intactness of 'Can Gio Man and The Biosphere Reserve' (good existing level of overlap between the IBA and the protected area)
	Habitat	• As for Ben Tre

Province	Level of approach	Actions
	Species	• As for Ben Tre
Kien Giang	Policy	• As for Koh Kong; and, • Assess the need to establish new policies/strengthen existing policies which promote restoration of coastal habitats e.g. mangrove planting, given the severe extent of habitat loss
	Landscape	• Lobby for official designation of the Proposed (but not yet protected) Phu Quoc, Nam Du and Tho Chu Marine Protected Areas • Strengthen PA network by officially designating all of the coastal IBAs in this province (see Appendix 5) (extent of overlap varies between PAs and IBAs) • Integrate land use planning with, and learn from, the current GIZ mangrove restoration project in this province (Duke et al., 2010), and which has detailed data on shoreline condition • See also points for Ben Tre
	Site	• As for Ben Tre. Efforts should focus on U Minh Thuong National Park, e.g. the possible establishment of habitat corridors extending northward from the park
	Habitat	• Melaleuca forest, grasslands in U Minh Thuong NP: develop/implement recovery plan - protection of remnant grasslands a high priority given severely threatened status • Seagrass: map existing beds, develop/implement recovery plan • Mangroves and inter-tidal mudflats: as for Ben Tre. Integrate activities with the current GIZ mangrove restoration project in this province. A recent GIZ study proposes 5 approaches for shoreline management in the province, education/awareness for coastal protection, shoreline monitoring, mangrove protection, provision of alternative sources of firewood/building materials, and trial of shoreline restoration strategies, and concludes that a REDD scheme is feasible for mangroves in this province (Duke et al., 2010) • Coral reefs: conduct vulnerability assessment and develop recovery plan
	Species	• As for Ben Tre; and, • Large waterbirds: initiate nest protection programs (in Cambodia such programs achieve rapid population recovery when hunting pressures are removed) • Cetaceans, Dugong: develop/implement recovery plans in context of climate change
Soc Trang	Policy	• As for Koh Kong; and, • Assess the need to establish new policies/strengthen existing policies which promote restoration of coastal habitats e.g. mangrove planting, given the severe extent of habitat loss
	Landscape	• As for Chanthaburi
	Site	• As for Ben Tre
	Habitat	• As for Ben Tre
	Species	• As for Ben Tre

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Central to the effectiveness of these strategies will be integration with approaches which focus on human livelihoods and resources. Poverty is recognized as the largest barrier to developing the capacity to cope and adapt with climate change (Cruz et al., 2007 and references therein), and this is particularly relevant for the project provinces in Cambodia and Vietnam as well as specific communities in some parts of the project provinces in Thailand. For the coastal regions of Asia, the Intergovernmental Panel on Climate Change advocates ‘integrated coastal zone management’ as the key approach for adaptation planning (Cruz et al, 2007: 491).

There are large uncertainties associated with predictions of change in climate, and also the response of ecosystems and species to these changes. While filling the sizeable knowledge gaps in our understanding will be immensely important (Lovelock and Ellison, 2007), the size of our ignorance in these matters and the time it will take to reduce this, also underscores the immediate need for 'adaptive management' approaches (Cruz et al., 2007; Steffen et al., 2009), For the project area, the development of policy frameworks at all management levels which strive to accommodate flexibility, trialing new approaches, and refining policies and actions based on lessons learnt, will be critical to addressing climate change. Monitoring the effectiveness of adaptation strategies should also be included within project planning and costs.

References

Adulyanukosol, K. 1999. Dugong, dolphin and whale in Thai waters. Pages 5-15 in: Proceedings of the 1st Korea-Thailand Joint Workshop on Comparison of Coastal Environment: Korea-Thailand. Seoul National University, Seoul, South Korea.

Adulyanukosol, K. and S. Poovachiranon. 2006. Dugong *(Dugong dugon)* and seagrass in Thailand: present status and future challenges. Proceedings of the 3rd International Symposium on SEASTAR2000 and Asian Bio-logging Science (The 7th SEASTAR2000 workshop). Downloaded from: http://hdl.handle.net/2433/49742

An Dara, Kong Kimsreng, Hout Piseth and R.J. Mather (2009). An Integrated Assessment for Preliminary Zoning of Paem Krasop Wildlife Sanctuary, Southwestern Cambodia. Gland Switzerland: IUCN 52pp.

Andersen, M. and C. C. Kinze. 1999. Annotated checklist and identification key to the whales, dolphins, and porpoises (Order Cetacea) of Thailand and adjacent waters. Natural History Bulletin of the Siam Society 47: 27-62.

Anon. 2011. 100+ dolphins die on Thailand's coastline. Bangkok Post, 26 March. Downloaded from: http://beforeitsnews.com/story/511/628/100_Dolphins_Die_on_Thailands_Coastline_PICS.html

Austin, J., Butchart, N. and Shine, K.P. 1992. Possibility of an Arctic ozone hole in a doubled-CO2 climate. Nature, 360, 221–225.

Baldwin, A. et al., 2001. Regeneration in fringe mangrove forests damaged by Hurricane Andrew. *Plant Ecology*, **157**(2), 151–164.

Barber PH, Palumbi SR, Erdmann MV, Moosa MK 2000. A marine Wallace's line? Nature, 406, 692–693.

Barbosa S, Byrne M, Kelaher BP 2008. Bioerosion caused by the tropical chiton Anthopleura gemmata at One Tree Reef, southern Great Barrier Reef. Coral Reefs, 27, 635–639.

Barg, U.C. 1992. Guidelines for the promotion of environmental management of coastal aquaculture development (based on review of selected experiences and concepts). Food and Agriculture Organization of the United Nations (FAO) Fisheries Technical Paper No. 328. Rome, FAO, 122p.

Barnett, T. Pierce, D. Achutarao, K. Gleckler, P. Santer, B. Greogory, J. Washington, W. 2005. Penetration of human-induced warming into the world's oceans. *Science*, **309**(5732), 284

Bates, B. C., Z. W. Kundzewicz, S. Wu and J. P. Palutikof, eds. 2008. Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change. IPCC Secretariat, Geneva, Switzerland.

Bates, P., C. Francis, M. Gumal, S. Bumrungsri, J. Walston, L. Heaney and T. Mildenstein. 2008. *Pteropus vampyrus. In*: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <www.iucnredlist.org>. Downloaded 15 May 2011.

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

Beaumont, L. J., I. A. W. McCallan and L. Hughes. 2006. A matter of timing: changes in the first date of arrival and last date of departure of Australian migratory birds. Global Change Biology 12: 1339-1354.

Bell, J. et al., 2010. Preliminary assessment of the effects of climate change on fisheries and aquaculture in the Pacific. *The contribution of fisheries to the economies of Pacific Island Countries and Territories, Pacific Studies Series. http://www. spc. int/sppu/images/stories/preliminary% 20assessment*

Bassim, K., Sammarco, P. Snell, T. 2002. Effects of temperature on success of (self and non-self) fertilization and embryogenesis in Diploria strigosa (Cnidaria, Scleractinia). *Marine Biology,* **140**(3), 479–488

Bezuijen, M. R. 2011. Wetland biodiversity & climate change briefing paper: Rapid assessment of the impacts of climate change to wetland biodiversity in the Lower Mekong Basin. Prepared for MRC. ICEM, Hanoi, Vietnam.

Bibby, R., Widdicombe, S., Parry, H., Spicer, J. and Pipe, R. 2008. Effect of ocean acidification on the immune response of the blue mussel, Mytilus edulis. *Aquatic Biology,* 2: 67–74

Bickford, D., S. D. Howard, D. J. J. Ng and J. A. Sheridan. 2010. Impacts of climate change on the amphibians and reptiles of Southeast Asia. Biodiversity and Conservation 19: 1043–1062.

Birch, W.R. and Birch, M., 1984. Succession and pattern of tropical intertidal seagrasses in Cockle Bay, Queensland, Australia: a decade of observations. *Aquatic Botany,* **19**(3-4), 343–367.

BirdLife International and IUCN-WCPA South-East Asia. 2007. Gap analysis of protected areas coverage in the ASEAN countries. BirdLife International, Cambridge, U.K.

BirdLife International. 2004. Important Bird Areas in Asia: key sites for conservation. BirdLife International, Cambridge, U.K.

BirdLife International. 2005. Important Bird Areas and potential Ramsar Sites in Asia. BirdLife International, Cambridge, U.K.

Bischof, K., Hanelt, D. and Wiencke, C. 1998. UV-radiation can affect depth-zonation of Antarctic macroalgae. Mar. Biol., 131, 597–605.

Boletzky S . 1994. Embryonic development of cephalopods at low temperatures. Antarc Sci 6(2):139–142

Booth DJ, Figueira WF, Gregson MA, Brown L, Beretta G 2007. Occurrence of tropical fishes in temperate southeastern Australia: role of the East Australian Current. Estuarine, Coastal and Shelf Science, 72, 102–114.

Boromthanarat, S. 1995. Development of the coastal resources institute (corin). *Educating coastal managers 93.*

Boyle PR, Boletzky SV 1996 Cephalopod populations: definition and dynamics. Phil Trans R Soc Lond B 351:985–1002

Brander, K. 2007. Global fish production and climate change. *Proceedings of the National Academy of Sciences* 104, no. 50 (2007): 19709.

Brierley, A. Kingsford, M. 2009. Impacts of Climate Change on Marine Organisms and Ecosystems. *Current Biology,* **19**(14), R602-R614.

Briggs, M.R.P. and Funge-Smith, S.J., 1994. Unsustainable shrimp culture—causes and potential solutions from experience in Thailand. Appendix 2. *Development of strategies for sustainable shrimp farming. Final report to the Overseas Development Administration. Stirling, Scotland, Institute of Aquaculture, University of Stirling, 31p.*

Briggs, M.R.P. and Funge-Smith, S.J. 1995. A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquacult. Fish. Mgmt 25*, 789–811.

Brock, V. 1960. The introduction of aquatic animals into Hawaiian waters. *Internat. Rev. Ges. Hydrobiol* 45, no. 4 (1960): 463–480.

Brodie J, Fabricius K, De'ath G, Okaji K 2005. Are increased nutrient inputs responsible for more outbreaks of crown-of thorns starfish? Marine Pollution Bulletin, 51, 266–278.

Brown D, and Sadler K. 1989. Fish survival in acid waters. In: R Morris, EW Taylor, DJA Brown and JA Brown (eds) Acid Toxicity and Aquatic Animals. Cambridge University Press, Cambridge, pp. 31–44

Brown, B.E., 1997. Adaptations of reef corals to physical environmental stress. *Advances in Marine Biology,* **31**, 221–299.

Buckton, S. T. and R. J. Safford. 2004. The avifauna of the Vietnamese Mekong Delta. Bird Conservation International 14: 279-322.

Bumrungsri, S., A. Suyanto and C. Francis. 2008. *Pteropus lylei.* In: IUCN 2010. IUCN Red List of Threatened Species. Version 2010.4. <www.iucnredlist.org>. Downloaded 15 May 2011.

Bush, S.R. et al., 2010. Scenarios for resilient shrimp aquaculture in tropical coastal areas. *Ecology and society*, 15(2), p.15

Cacot, P. 1999. Description of the sexual cycle related to the environment and set up of the artificial propagation in *Pangasius bocourti* (Sauvage 1880) and *Pangasius hypophthalmus* (Sauvage 1878) reared in floating cages and in ponds in the Mekong Delta. In M. Legendre and A. Pariselle (eds.). *The biological diversity and aquaculture of Clariid and Pangasiid catfishes in South East Asia* , Proceedings of the mid-term workshop of the "Catfish Asia Project" Can Tho, Viet Nam, 11–15 May 1998, pp. 71–89. Toulouse, France: Paragraphic

Cahoon, D.R., Day Jr, J.W. and Reed, D.J., 1999. The influence of surface and shallow subsurface soil processes on wetland elevation: A synthesis. *Current Topics in Wetland Biogeochemistry*, **3**, 72–88

Caldeira K, Wickett ME. 2003. Anthropogenic carbon and ocean pH: The coming centuries may see more ocean acidification than the past 300 million years. *Nature* 2003; **425**: 365.

Campbell, S.J. and McKenzie, L.J., 2004. Flood related loss and recovery of intertidal seagrass meadows in southern Queensland, Australia. *Estuarine, Coastal and Shelf Science*, **60**(3), 477–490.

Carew-Reid, J. 2007. Rapid Assessment of the Extent and Impact of Sea Level Rise in Viet Nam. Climate Change Discussion Paper 1. ICEM – International Centre for Environmental Management, Brisbane, Australia.

Chan, E.-H. and H.-C. Liew. 1999. Hawksbill Turtles, *Eretmochelys imbricata,* Nesting on Redang Island, Terengganu, Malaysia, from 1993 to 1997. Chelonian Conservation and Biology 3: 326-329.

Chansang, H. and S. Poovachiranon. 1994. The distribution and composition of seagrass beds along the Andaman sea coast of Thailand. Phuket Marine Biology Research Centre Bulletin 59: 43-52.

Cheal AJ, Delean S, Sweatman H and Thompson AA 2007. Spatial synchrony in coral reef fish populations and the influence of climate. *Ecology* 88, 158–169.

Cheeseman, J.M. et al., 1997. Photosynthesis and photoprotection in mangroves under field conditions. *Plant, Cell & Environment,* **20**(5), 579–588.

Chinvanno, S. (2011) Climate Change Scenarios Downscaled for BCR Project Provinces. *Unpublished Report to IUCN BCR Project.*

Church, J. White, N. 2006. A 20th century acceleration in global sea-level rise. *Geophysical Research Letters,* **33**(1), L01602.

Cinti A, Baro´n PJ, Rivas AL. 2004. The effects of environmental factors on the embryonic survival of the Patagonian squid Loligo gahi.

J Exp Mar Biol Ecol 313:225–240

Clough, B. Sim, R. 1989. Changes in gas exchange characteristics and water use efficiency of mangroves in response to salinity and vapour pressure deficit. *Oecologia*, **79**(1), 38–44.

Cochrane, K. et al., 2009. Climate change implications for fisheries and aquaculture. Overview of current scientific knowledge. *FAO Fisheries and Aquaculture Technical Paper.*

Coles, S.L. and Brown, B.E., 2003. Coral bleaching–capacity for acclimatization and adaptation. *Advances in marine biology,* **46**, 183–223.

Compton TJ, Rijkenberg MJA, Drent J, Persma T 2007. Thermal tolerance ranges and climate variability: a comparison between bivalves from differing climates. Journal of Experimental

Cox, N. 2002. Observations of the Dugong *Dugong dugon* in Con Dao National Park, Vietnam, and recommendations for further research. Unpublished report. Downloaded from:http://www.sirenian.org/coxfinalreport.pdf

Crear, D., 1980. Observations of the reproductive state of milkfish populations *Chanos chanos* from hypersaline ponds on Christmas Island (Pacific Ocean). In: J.W. Avault Jr. (Editor), Proceedings of World Mariculture Society, Vol. 21. Louisiana State University, Baton Rouge, 548 pp.

Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li and N. Huu Ninh. 2007. Asia. Pages 496-506 in M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.

De Silva, S.S., Soto, D., 2009. Climate change and aquaculture: potential impacts, adaptation and mitigation. FAO Fisheries Technical Paper 537, 137–215.

Dell, R. 1964. The large Indo pacific swimming crab Scylla serrata (Forskal) in northern New Zealand, *Rec. Dom. Mus* 58 (1964): 59–62.

Diaz-Pulido, G. et al., 2007. Vulnerability of macroalgae of the Great Barrier Reef to climate change. Climate change and the Great Barrier Reef. Townsville: Great Barrier Reef Marine Park Authority & Australian Greenhouse Office, 153–192.

Dierberg, F. and Kiattisimkul, W. 1996. Issues, impacts, and implications of shrimp aquaculture in Thailand. *Environ. Mgmt* ***20***, 649–666.

DMCR. 2007. Master Plan for Mangrove Research in Thailand. Department of Marine and Coastal Resources, Bangkok, Thailand. [In Thai.]

DMCR. 2009. Master Plan for Mangrove Management in Thailand. Department of Marine and Coastal Resources, Bangkok, Thailand. [In Thai.]

Dudgeon, D. 2007. Going with the flow: global warming and the challenge of sustaining river ecosystems in monsoonal Asia. Water Science & Technology: Water Supply 7: 69-80.

Dudley, N., S. Stolton, A. Belokurov, L. Krueger, N. Lopoukhine, K. MacKinnon, T. Sandwith and N. Sekhran, editors. 2010. Natural Solutions: Protected areas helping people cope with climate change. IUCN-WCPA/TNC/UNDP/WCS/The World Bank/ WWF, Gland, Switzerland, Washington, D.C. and New York, USA.

Duke, N., N. Wilson, J. Mackenzie, Hai Hoa Nguyen and D. Puller. 2010. Assessment of Mangrove Forests, Shoreline Condition and Feasibility for REDD in Kien Giang Province, Vietnam. A Technical Report. Development of the Kien Giang Biosphere Reserve Project. Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Kien Giang, Vietnam.

Edmunds, P. 2005. The effect of temperature on the size and population density of dinoflagellates in larvae of the reef coral Porites astreoides. *Invertebrate Biology*, **124**(3), 185–193

Ellison, J. Stoddart, D. 1991. Mangrove ecosystem collapse during predicted sea-level rise: Holocene analogues and implications. *Journal of Coastal Research,* **7** (1) 151–165.

Emata, A. Borlongan. I. 2003. A practical broodstock diet for the mangrove red snapper, *Lutjanus argentimaculatus.* Aquaculture 225, 83–88

Ettinger-Epstein P, Whalan SW, Battershill CN, de Nys R 2007. Temperature cues gametogenesis and larval release in a tropical sponge. Marine Biology, 153, 171–178.

Ewel, K.C. et al., 2009. Characteristics of Scylla spp.(Decapoda: Portunidae) and Their Mangrove Forest Habitat in Ngaremeduu Bay, Republic of Palau 1. *Pacific Science,* 63(1), pp.15–26.

Fabricius KE, Alderslade P 2001 .Soft Corals and Sea Fans. A Comprehensive Guide to the Topical Shallow-Water Genera of the Central-West Pacific, the Indian Ocean and the Red Sea. Australian Institute of Marine Science, Townsville.

Fabricius KE, De'ath G, Puotinen ML, Done T, Cooper TF, Burgess SC 2008. Disturbance gradients on inshore and offshore coral reefs caused by a severe tropical cyclone. Limnology and Oceanography, 53, 690–704.

Fabricius KE, Golbuo Y, Victor S 2007. Selective mortality in coastal reef organisms from an acute sedimentation event. Coral Reefs, 26, 69.

FAO © 2011. Fishery and Aquaculture Country profiles. Thailand. Fishery and Aquaculture Country Profiles. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 12 April 2011. http://www.fao.org/fishery/legalframework/nalo_thailand/en

FAO © 2011. Fishery and Aquaculture Country profiles. Vietnam. Fishery and Aquaculture Country Profiles. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 12 April 2011. http://www.fao.org/fishery/legalframework/nalo_vietnam/en

FAO Species Catalogue.1983. Vol. 2. Scombrids of the world. An annotated and illustrated catalogue of Tunas, Mackerels, Bonitos and related species known to date.Collette, B.B. and C.E. Nauen 1983.. FAO Fish. Synop., (125)Vol.2:137 p.

FAO. © 2011. Fishery and Aquaculture Country profiles. Cambodia. Fishery and Aquaculture Country Profiles. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 12 April 2011. http://www.fao.org/fishery/legalframework/nalo_cambodia/en

Ferguson, A., Fleming, I.A., Hindar, K., Skaala, Ø., McGinnity, P., Cross, T. and Prodöhl, P. 2007. Farm escapes. In E. Verspoor, L. STratmeyer and J. Nielsen (eds), Atlantic *Salmon: Genetics, conservation and management,* pp. 367–409. Oxford, Blackwell Publishing Ltd.

Fields PA, Graham JB, Rosenblatt RH, Somero GN 1993. Effects of expected global climate change on marine faunas. Trends in Ecology and Evolution, 8, 361–367

Fischlin, A., Midgely, G.F., Price, J.T., Leemans, R., Gopal, B., Turley, C., Rounsevell, M.D.A., Dube, O.P., Tarazona, J., and Velichko, A.A. (2007). Ecosystems, their properties, goods and services. In: M.L. Parry, O.F. Canziana, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (Eds.) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, pp211-271.

Flaherty, M., Vandergeest, M. and Miller, P. 1999. Rice paddy or shrimp pond: tough decisions in rural Thailand. *World Devel. 27*, 2045–2060

Flegal, T. 1992. Insecticide danger to shrimp. Letter cited in Aquaculture News from Around the World. Infofish, 6, 36

Foden, W., Mace, G., Vié, J-C., Angulo, A., Butchart, S., Devantier, L., et al. (2008). Species susceptibility to climate change impacts. In J.-C. Vié, C. Hilton-Taylor, and S. N. Stuart (Eds.), Wildlife in a changing world (pp. 77-88). Barcelona, Spain: Lynx.

Ford SE 1996. Range extension by the oyster parasite Perkinsus marinus into the northeastern United States: response to climate change? J Shellfish Res 15:45–56

Forsythe JW, Hanlon RT 1989. Growth of the Eastern Atlantic squid, Loligo forbesi Streenstrup (Mollusca: Cephalopoda). Aquac Fish Manage 20:1–14

Fujita, M. 1988. Flying Foxes and Economics. BATS Magazine 6. Downloaded from:http://www.batcon.org/index.php/media-and-info/bats-archives.html?task=viewArticle&magArticleID=318

Gambaiani, D. D., P. Mayol, S. J. Isaac and M. P. Simmonds. 2009. Potential impacts of climate change and greenhouse gas emissions on Mediterranean marine ecosystems and cetaceans. Journal of the Marine Biological Association of the United Kingdom 89: 179-201.

Gates, R.D. and Edmunds, P.J., 1999. The physiological mechanisms of acclimatization in tropical reef corals. *Integrative and Comparative Biology,* **39**(1), 30.

Gilbert, M., J. Slingenbergh and X. Xiao. 2008. Climate change and avian influenza. Rev. Sci. Tech. 27: 459-466.

Gillett, R. 2004. The marine fisheries of Cambodia. FAO/FishCode Review. No. 4. Rome, FAO. 2004. 57p.

Gilman, E.L. et al., 2008. Threats to mangroves from climate change and adaptation options: A review. *Aquatic Botany,* **89**(2), 237–250.

Gopurenko D, Hughes JM, Bellchambers L. 2003. Colonisation of the south-west Australian coastline by mud crabs: evidence for a recent range expansion or human-induced translocation.Marine and Freshwater Research, 54, 833–840

Goreau TJ, Hayes RL, McAllister D. 2005. Regional patterns of sea surface temperature rise: implications for global ocean circulation change and the future of coral reefs and fisheries World Resource Review, 17, 350–374.

Goswami, B.N., Venugopal, V., Sengupta, D., Madhusoodanan, M.S. and Xavier, P.K. 2006. Increasing trend of extreme rain events in a warming environment. *Science*, 314: 1442–1445.

Gowland FC, Boyle P, Noble LR 2002. Morphological variation provides a method of estimating thermal niche in hatchlings of the squid Loligo forbesi (Mollusca: Cephalopoda) J Zool 258:505–513

Greenstein BJ, Pandolfi JM. 2008. Escaping the heat: range shift of reef coral taxa in coastal Western Australia. Global Change Biology, 14, 513–528.

Guerra A, Gonzalez AF, Rocha F 2002. Appearance of the common paper nautilus Argonauta argo related to the increase of the sea surface temperature in the north-eastern Atlantic. J Mar Biol Assoc UK 82:855–858

Halls, A. 2009. Climate change and Mekong fisheries. Catch and Culture 15: 12-16.

Hamann, M., Chu The Cuong, Nguyen Duy Hong, Pham Thuoc and Bui Thi Thuhien. 2005. Distribution and abundance of marine turtles in the Socialist Republic of Viet Nam. Biodiversity and Conservation 15: 3703-3720.

Hamasaki, K., 2003. Effects of temperature on the egg incubation period, survival and developmental period of larvae of the mud crab Scylla serrata reared in the laboratory. *Aquaculture,* 219(1-4), pp.561–572.

Handisyde, N.T., Ross, L.G., Badjeck, M.-C. and Allison, E.H. 2006. The Effects of Climate Change on World Aquaculture: A Global Perspective. Aquaculture and Fish Genetics Research Programme, Stirling Institute of Aquaculture. Final Technical Report, DFID, Stirling. 151pp.

Harley, C. D. G., A. R. Hughes, K. M. Hultgren, B. G. Miner, C. J. B. Sorte, C. S. Thornber, L. F. Rodriguez, L. Tomanek and S. L. Williams. 2006. The impacts of climate change in coastal marine systems. *Ecology Letters* 9: 228-241.

Harley, C.D.G. et al., 2006. The impacts of climate change in coastal marine systems. *Ecology letters,* 9(2), pp.228–241.

Harvell, C. D., C. E. Mitchell, J. R. Ward, S. Altizer, A. P. Dobson, R. S. Ostfeld and M. D. Samuel. 2002. Climate Warming and Disease Risks for Terrestrial and Marine Biota. Science 296: 2158-2162.

Hill, B.1974. Salinity and temperature tolerance of zoeae of the portunid crab Scylla serrata. *Marine Biology* 25, no. 1 (1974): 21–24.

Hines, E., K. Adulyanukosol, P. Somany, L. S. Ath, N. Cox, P. Boonyanate and Nguyen Xuan Hoa. 2008. Conservation needs of the dugong *Dugong dugon* in Cambodia and Phu Quoc Island, Vietnam. Oryx 42: 113-121.

Ho, T.L., 2008. Adapting to global warming. Outlook 8–12 (March 2008).

Hoa, DT, Ut, PV. 2007. Monogenean disease in cultured grouper (*Epinephelus* spp.) and snapper (*Lutjanus argentimaculatus*) in Khanh Hoa province, Vietnam. In: Asia-Pacific Marine Finfish Aquaculture Network Magazine, Volume XII No. 4 Pp40-42

Hoanh, C. T., K. Jirayoot, G. Lacombe and V. Srinetr. 2010. Impacts of climate change and development on Mekong flow regime. First assessment – 2009. MRC Technical Paper No. 29. Mekong River Commission, Vientiane, Laos.

Hochachka, P.W. and Somero, G.N., 2002. *Biochemical adaptation: mechanism and process in physiological evolution*, Oxford University Press, USA.

Hoegh-Guldberg, H. Hoegh-Guldberg, O.2004. The Implications of Climate Change for Australia's Great Barrier Reef: People and Industries at Risk. World Wildlife Fund and Queensland Tourism Industry Council, Brisbane.

Hoegh-Guldberg, O., Mumby, P. Hooten, A. Steneck, R. Greenfield, P. Gomez, E. Harvell, C. Sale, P. Edwards, A. Caldeira, K. Knowlton, N. et al., 2007. Coral Reefs under Rapid Climate Change and Ocean Acidification. *Science*, **318**(5857), 1737-1742.

Hoffman, J.R., Hansen, L.J. and Klinger, T. 2003. Interactions between UV radiation and temperature limit inferences from single-factor experiments. J. Phycol., 39, 268–272

Hughes, L. 2003. Climate change and Australia: Trends, projections and impacts. Austral Ecology 28: 423-443.

Hughes, L., 2003. Climate change and Australia: Trends, projections and impacts. *Austral Ecology,* **28**(4), 423-443

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J.B.C., Kleypas, J., Lough, J.M., Marshall, P., Nyström, M., Palumbi, S.R., Pandolfi, J.M., Rosen, B. and Roughgarden, J. 2003. Climate change, human impacts and the resilience of coral reefs. *Science*, 301: 929–934.

Hutchings, P. et al., 2007. Vulnerability of benthic invertebrates of the Great Barrier Reef to climate change. Climate Change and the Great Barrier Reef: A Vulnerability Assessment, 309–356

Jackson et al., 2007 D.J. Jackson, L. Macis, J. Reitner, B.M. Degnan and G. Worheide. 2007. Sponge paleogenomics reveals an ancient role for carbonic anhydrase in skeletogenesis, *Science* **316** (2007), pp. 1893–1895

Jackson GD 2004. Advances in defining the life histories of my opsid squid. Mar Freshw Res 55:357–365

Jackson GD, Domeier M 2003. The effects of an extraordinary El Nin˜o/La Nin˜a event on the size and growth of the squid Loligo opalescens off Southern California. Mar Biol 142:925–935

Jackson GD, Moltschaniwskyj NA 2002. Spatial and temporal variation in growth rates and maturity in the Indo-Pacific squid Sepioteuthis lessoniana (Cephalopoda: Loliginidae). Mar Biol 140:747–754

Jackson GD, Moltschaniwskyj NA. 2001. The influence of ration level on growth and statolith increment width of the tropical squid

Sepioteuthis lessoniana (Cephalopoda: Loliginidae): an experimental approach. Mar Biol 138:89–825

Kalyar, J. B. Thorbjarnarson and K. Thirakhupt. 2007. An Overview of the Current Population and Conservation Status of the Critically Endangered River Terrapin, *Batagur baska* (Gray, 1831) in Myanmar, Thailand and Malaysia. The Natural History Journal of Chulalongkorn University 7: 51-65.

Kasetstart University. 1987. Assessment of national parks, wildlife sanctuaries and other preserves development in Thailand. Unpublished report. Kasetstart University/Royal Forestry Department/Office of the National Environment Board/U.S. Agency for International Development, Bangkok, Thailand.

Katersky, R. and Carter, C. 2005. Growth efficiency of juvenile barramundi, Lates calcarifer, at high temperatures. *Aquaculture* 250, no. 3-4 (2005): 775–780.

Keenan, C.P. and Blackshaw, A. 1999. Mud Crab Aquaculture and Biology. Proceedings of an international scientific forum held in Darwin, Australia, 21–24 April 1997. ACIAR Proceedings No. 78, 216 p.

Khongkheo, H. Wayne. C. Murdjani. M. Bunliptanon, P. Chien, T. 2010. Current practices of marine finfish cage culture in China, Indonesia, Thailand and Viet Nam. Marine Finfish Aquaculture Network. Aquaculture Asia Magazine Volume XV No. 2, April-June P32-40.

Kingsford, M. Welch, D. 2007. Vulnerability of pelagic systems of the Great Barrier Reef to climate change. Climate Change and the Great Barrier Reef pp 556–592.

Klein, R. Nicholls, R. Mimura, N. 1999. Coastal adaptation to climate change: can the IPCC Technical Guidelines be applied? *Mitigation and Adaptation Strategies for Global Change*, **4**(3), 239–252.

Kongkeo,H. Wayne, C, Murdjani, M. Bunliptanon, P. Chien, T. 2010. Current practices of marine finfish cage culture in China, Indonesia, Thailand and Viet Nam. Aquaculture Asia Magazine Volume XV No. 2, April-June 2010 p32-40.

Kroon FJ 2005. Behavioural avoidance of acidified water by juveniles of four commercial fish and prawn species with migratory life stages. *Marine Ecology Progress Series* 285, 193–204.

Kurihara H, Kato S, Ishimatsu A 2007. Effects of increased seawater pCO2 on early development of the oyster Crassostrea gigas. Aqautic Biology, 1, 91–98.

Kurihara H, Shimode S, Shirayama Y 2004. Sub-lethal effects of elevated concentration of CO2 on planktonic copepods and sea urchins. Journal of Oceanography, 60, 743–750.

Lacanilao, F. Coloso, R. Quinitio, G. 1991. Proceedings of the Seminar-Workshop on Aquaculture Development in Southeast Asia and Prospects for Seafarming and Searanching; 19-23 August 1991;Iloilo City, Philippines. SEAFDEC Aquaculture Department, Iloilo, Philippines. 1994. p159

Lawrence AJ, Soame JM 2004. The effects of climate change on the reproduction of coastal invertebrates. Ibis, 146, 29–39.

Le Cong Kiet. 1994. Native Freshwater Vegetation Communities in the Mekong Delta. International Journal of Ecology and Environmental Sciences 20: 55-71.

Lebel, L. et al., 2002. Industrial transformation and shrimp aquaculture in Thailand and Vietnam: pathways to ecological, social, and economic sustainability? *AMBIO: A Journal of the Human Environment*, 31(4), pp.311–323.

Lekagul, B. and J. A. McNeely. 1977. Mammals of Thailand. Darnsutha Press, Bangkok, Thailand.

Lestang, S., Hall, N.G., Potter, I.C., 2003a. Do the age compositions and growth of the Portunus pelagicus in marine embayments and estuaries differ? J. Mar. Biol. Assoc. U. K. 83, 971–978.

Lester SE, Gaines SD, Kinlan BP 2007. Reproduction on the edge: large-scale patterns of individual performance in marine invertebrate. Ecology, 88, 2229–2239.

Lohrer AM, Hewitt JE, Thrush SF 2006. Assessing far-field effects of terrigenous sediment loading in the coastal marine environment. Marine Ecology Progress Series, 315, 13–18.

Lough JM 2008. 10th anniversary review: a changing climate for coral reefs. Journal of Environmental Monitoring, 10, 21–29.

Lough, J., 2007. Climate and climate change on the Great Barrier Reef. *Climate Change and the Great Barrier Reef,* 15–50

Lovatelli JR, A.P. and Yamamoto, K., 2006. The future of mariculture: a regional approach for responsible development in the Asia-Pacific region. *FAO Fisheries Proceedings. 11. 338 p*

Lovelock, C. Ellison, J. 2007. Vulnerability of mangroves and tidal wetlands of the Great Barrier Reef to climate change. Climate change and the Great Barrier Reef. Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office, Australia 238-269.

Lymer, D. Funge-Smith, S. Khemakorn, P. Naruepon, S. Ubolratana, S. 2008. A review and synthesis of capture fisheries data in Thailand: large versus small scale fisheries. Asia Pacific Fishery Commission P51 accessed at http://www.fao.org/docrep/011/i0573e/i0573e00.html

Macinnis-Ng, C.M. and Ralph, P.J., 2003. Short-term response and recovery of Zostera capricorni photosynthesis after herbicide exposure. *Aquatic Botany*, **76**(1), 1–15

Mahon R. 2002. Adaptation of fisheries and fishing communities to the impacts of climate change in the CARICOM region: issue paper-draft. Mainstreaming adaptation to climate change (MACC) of the Caribbean Center for Climate Change (CCCC), Organization of American States, Washington, DC

Marshall DJ, Bolton TF 2007. Sperm release strategies in marine broadcast spawners: the cost of quick releasing. The Journal of Experimental Biology, 210, 3720–3727.

Marshall, P.A. and Johnson, J., 2007. The Great Barrier Reef and climate change: vulnerability and management implications. Climate change and the Great Barrier Reef. Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office, Australia, pp 774–80

McKinnon, A. et al., 2007. Vulnerability of Great Barrier Reef plankton to climate change. Climate Change and the Great Barrier Reef, Great Barrier Reef Marine Park Authority and the Australian Greenhouse Office, Australia pp121–152.

McLaughlin et al., 2005 J.B. McLaughlin, A. DePaola, C.A. Bopp, K.A. Martinek, N.P. Napolilli, C.G. Allison, S.L. Murray, E.C. Thompson, M.M. Bird and J.P. Middaugh, Outbreak of *Vibrio parahaemolyticus* gastroenteritis associated with Alaskan oysters, *The New England Journal of Medicine* **353** (2005), pp. 1463–1470.

McNeil BI, Matear RJ, Barnes D 2004. Coral reef calcification and climate change: the effect of ocean warming. Geophysical Research Letters, 31, L22309, doi: 22310.21029/22004GL021541.

Meagher, T.D. 1971. Ecology of the crab *Portunus pelagicus* (Crustacea Portunidae) in southwestern Australia. University of Western Australia. Unpublished PhD thesis, 232 pp.

Merican, Z. 2006. Marine finfish cage culture: some of the strengths, weaknesses, opportunities and threats facing this expanding yet fragmented industry in China and Southeast Asia. *AQUA Culture Asia Pacific Magazine,* 2(2): 22–24.

Meynell, P-J., compiler. 2011. Case study guidance. Basin-Wide Climate Change Impact and Vulnerability Assessment for Wetlands of the Lower Mekong Basin for Adaptation Planning. Prepared for MRC. ICEM, Hanoi, Vietnam.

Moll, O. 1980. Natural history of the river terrapin, *Batagur baska* (Gray) in Malaysia (Testudines: Emydidae). Malaysian Journal of Science 6(A): 23-62.

Monanunsap, S., C. Penpian, N. Silapasan, C. Janchompoo, T. Knocome and L. Mankietkit. 2010. Photo identification of dolphin populations along the coast of Trat Province. Paper presented at SEASTAR 2000 Symposium, Phuket, 23-25 Feb 2010. (In Thai).

Moncada, F., E. Carrillo, A. Saenz and G. Nodarse. 1999. Reproduction and Nesting of the Hawksbill Turtle, *Eretmochelys imbricata*, in the Cuban Archipelago. Chelonian Conservation and Biology 3: 257-263.

Morris, J.T. et al., 2002. Responses of coastal wetlands to rising sea level. *Ecology,* **83**(10), 2869–2877.

Moser, S. 2001. Recruitment of juvenile edible mud crab Scylla olivacea into mangrove ecosystems in SE Asia. Ph.D. Thesis, University of Aarhus, Aarhus, Denmark. 133 pp.

Moverley JH, Saenger P, Curtis MA 1986. Patterns of polychaete recolonization in Queensland subtropical estuaries following severe flooding. Hydrobiologia, 134, 227–235.

MRC and ICEM. 2009. Climate Change Adaptation in the Lower Mekong Basin Countries. Regional Synthesis Report. CCAI – Climate Change and Adaptation Initiative. Unpublished report. ICEM – International Centre for Environmental Management, Hanoi, Vietnam.

MRC. 2009a. Adaptation to climate change in the countries of the Lower Mekong Basin. MRC Management Information Booklet Series No.1. Mekong River Commission Secretariat, Vientiane, Laos.

MRC. 2009b. Adaptation to climate change in the countries of the Lower Mekong Basin: regional synthesis report. MRC Technical Paper No. 24. Mekong River Commission Secretariat, Vientiane, Laos.

Munday, P.L. et al., 2007. Vulnerability of fishes of the Great Barrier Reef to climate change. Climate Change and the Great Barrier Reef, pp357–391.

Munday, P.L. et al., 2008. Climate change and the future for coral reef fishes. *Fish and Fisheries*, **9**(3), 261–285.

Nabhitabhata, J. and T. Chan-ard. 2005. Thailand Red Data: Mammals, Reptiles and Amphibians. Office of Natural Resources and Environmental Policy and Planning, Bangkok, Thailand.

Neverauskas, V.P. and Butler, A.J. (1982). Tolerance of blue crab, *Portunus pelagicus* (L.), to high temperatures. *Transactions of the*

Royal Society of South Australia, **106**: 215-216.

NOAA, 2005. The ENSO Cycle. Available online at: www.cpc.noaa.gov/products/analysis_monitoring/ensocyle/enso_cycle.shtml

Opdam, P. and D. Wascher. 2004. Climate change meets habitat fragmentation: linking landscape and biogeographical scale levels in research and conservation. Biological Conservation 117: 285-297.

Overton, J.L. and Macintosh, D.J., 2002. Estimated size at sexual maturity for female mud crabs (genus Scylla) from two sympatric species within Ban Don Bay, Thailand. *Journal of Crustacean Biology,* 22(4), pp.790–797.

Parr, J.W.K. 1994. Coverage of Mangroves in the Protected Areas Network of Thailand. Tigerpaper 21: 11-15.

Peachey, R.B.J. 2005. The synergism between hydrocarbon pollutants and UV radiation: a potential link between coastal pollution and larval mortality. J. Exp. Mar. Biol. Ecol., 315, 103–114.

Pearson, R. G. and T. P. Dawson. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology & Biogeography 12: 361-371.

Pecl GT 2004. The in situ relationships between season of hatching, growth and condition in the southern calamari squid, Sepioteuthis australis. Mar Freshw Res 55: 429–438necology and fisheries. *Reviews in Fish Biology and Fisheries,* 18(4), pp.373–385.

Pecl, G.T. and Jackson, G.D., 2008. The potential impacts of climate change on inshore squid: biology,

Phuong, N.T. and Oanh, D.T.H., 2010. Striped Catfish Aquaculture in Vietnam: A decade of unprecedented development. *Success Stories in Asian Aquaculture*, pp.131–147.

Phuong, N.T., L.X. Sinh, N.Q. Thinh, H.H. Chau, C.T. Anh, and N.M. Hau. 2007. Economics of aquaculture feeding practices: Viet Nam. *FAO Fisheries Technical Paper* 505:183–205.

Pillay KK, Nair NB 1971. The annual reproductive cycles of Ucaannulipes, Portunus pelagicus and Metapenaeus affinis (Decapoda: Crustacea) from the south-west coast of India. Marine Biology, 11, 152–166.

Platt, S. G., B. L. Stuart, H. Sovannara, L. Kheng, Kalyar and H. Kimcchay. 2003. Rediscovery of the Critically Endangered River Terrapin, *Batagur baska,* in Cambodia, with Notes on Occurrence, Reproduction and Conservation Status. Chelonian Conservation and Biology 4: 691-695.

Potter, I.C., Chrystal, P.J., Loneragan, N.R., 1983. The biology of the blue manna crab Portunus pelagicus in an Australian estuary. Mar. Biol. 78, 75–85.

Poulsen AF, Hortle KG, Valbo-Jorgensen J, Chan S, Chhuon CK, Viravong S, Bouakhamvongsa U, Yoorong N, Nguyen TT, Tran BQ 2004. Distribution and ecology of some important riverine fish species of the Mekong river basin. Technical paper no. 10. Mekong River Commission, Phnom Penh

Pradhan, L. and C Reddy. 1962. Mackerel landings at Calicut in relation tOi hydrological factors. Indian J. Fish., 9(1)A: 100-109

Praschag, P., R. H. P. Holloway, A. Georges, M. Päckert, A. K. Hunsdörfer and U. Fritz. 2009. A new subspecies of *Batagur affinis* (Cantor, 1847), one of the world's most critically endangered chelonians (Testudines: Geoemydidae). Zootaxa 2233: 57-68.

PrechtWF, Aronson RB 2004. Climate flickers and range shifts of reef corals. Frontiers in Ecology and the Environment, 2, 307–314.

Primavera, J.H. 1997. Socio-Economic Impacts of Shrimp Culture. *Aquaculture Research.* 815-827.

Primavera, J.H., Lavilla-Pitogo, C.R., Ladja, J.M. and Pena, M.R. 1993. A survey of chemical and biological

Przeslawski R., Ahyong S., Byrne M., Wörheide G., Hutchings P. Beyond corals and fish: the effects of climate change on non-coral benthic invertebrates of tropical reefs. Glob. Chang. Biol. 2008;14:2773–2795.

Puotinen MP 2007. Modelling the risk of cyclone wave damage to coral reefs using GIS: a case study of the Great Barrier Reef, 1969–2003. International Journal of Geographical Information Science, 21, 97–120.

Quinitio et al., 2001 E.T. Quinitio, F.D. Parado-Estepa, O.M. Millamena, E. Rodriguez and E. Borlongan, Seed production of mud crab *Scylla serrata* juveniles, *Asian Fisheries Science* **14** (2001), pp. 161–174.

Rahmstorf, S., 2010. A new view on sea level rise. *Nature Reports Climate Change*, (**1004**), 44-45

Ramofofia C, Byrne M, Batteglene S. 2003. Reproduction of the commercial sea cucumber Holothuria scabra in Solomon Islands. Marine Biology, 142, 281–288.

Ratcliffe, F. N. 1931. The Flying Fox (*Pteropus*) in Australia. Council for Scientific and Industrial Research Bulletin 53: 1-82.

Raven J, Caldeira K, Elderfield H et al. 2005. Ocean acidification due to increasing atmospheric carbon dioxide. Report from the Royal Society, London, 68 pp.

Rijnsdorp, A et al. 2009. Resolving the effect of climate change on fish populations. *ICES Journal of Marine Science: Journal du Conseil* 66, no. 7 (2009): 1570.

Robson, C. R. 2008. A Field Guide to the Birds of South-East Asia. Second edition. New Holland Publishers, London, U.K.

Roemmich, D. and McGowan, J.A. 1995. Climatic warming and the decline of zooplankton in the California current. Science, 267, 1324–1326.

Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Pounds A 2003. Fingerprints of global warming on wild plants and animals. Nature 421:57–60

Rosenberry, B. 2004. World Shrimp Farming. *San Diego, CA, USA: Shrimp News International.*

Ruangpanit, N. and Kongkumnerd, J. 1992. Study on some potentially suitable factors to prevent and reduce the mass mortality of seabass (Lutes *calcarifer).* Technical Paper No. 8. National Institute of Coastal Aquaculture, Songkla, Thailand, 12 pp.

Ryvitski, J.P.M, A.J. Kettner, I. Overeem, E.W.H. Hutton, M.T.Hannon, G.R. Brakenridge, J. Day, C. Vörösmarty, Y. Saito, L. Giosan, and R.J. Nicholls. 2009. Sinking deltas due to human activities. Nature Geosciences. Published online: 20 September 2009

Safford, R. J., T. Triet, E. Maltby and D. V. Ni. 1998. Status, biodiversity and management of the U Minh wetlands, Vietnam. Tropical Biodiversity 5: 217-244.

Sanguansombat, W. 2005. Thailand Red Data: Birds. Office of Natural Resources and Environmental Policy and Planning, Bangkok, Thailand.

Schaffelke, B., Mellors, J. and Duke, N.C., 2005. Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities. *Marine Pollution Bulletin*, 51(1-4), 279–296

Seibel BA, Fabry VJ. 2003. Marine biotic response to elevated carbon dioxide. Adv Appl Biodivers Sci 4:59–67

Seng, K. H., P. Bunnat, C. M. Poole, A. W. Tordoff, P. Davidson and E. Delattre (2003). Directory of Important Bird Areas in Cambodia: key sites for conservation. Department of Forestry and Wildlife, Department of Nature Conservation and Protection, BirdLife International in Indochina, and Wildlife Conservation Society Cambodia Program, Phnom Penh, Cambodia.

Seng, L.T., 1997. Control of parasites in cultured marine finfishes in Southeast Asia–an Overview. *International Journal for Parasitology,* 27(10), pp.1177–1184.

Shanks AL, Grantham BA, Carr MH. 2003. Propagule dispersal distance and the size and spacing of marine reserves. Ecological Applications, 13 (Suppl.), S159–S169.

Sheaves, M. et al., 2006. Contribution of floodplain wetland pools to the ecological functioning of the Fitzroy River Estuary.

Sheaves, M. et al., 2007. Vulnerability of coastal and estuarine habitats in the Great Barrier Reef to climate change. Climate Change and the Great Barrier Reef Marine Park: a Vulnerability Assessment. Townsville, Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, 593–620.

Sherman, R.E., Fahey, T.J. and Martinez, P., 2001. Hurricane impacts on a mangrove forest in the Dominican Republic: damage patterns and early recovery. *Biotropica,* **33**(3), 393–408.

Shirihai, H. and B. Jarrett. 2009. Whales, Dolphins and Seals. A Field Guide to the Marine Mammals of the World. A & C Black, London, U.K.

Simmonds, M. P. and W. J. Eliott. 2009. Climate change and cetaceans: concerns and recent developments. Journal of the Marine Biological Association of the United Kingdom 89: 203-210.

Slembrouck J, Baras E, Subagja J, Hung LT, Legendre M. 2009. Survival, growth and food conversion of cultured larvae of Pangasianodon hypophthalmus, depending on feeding level, prey density and fish density. Aquaculture 294:52–59

Smith SV, Buddemeier RW 1992. Global change and coral reef ecosystems. Annual Review of Ecology and Systematics, 23, 89–118.

Smith, B. D., T. A. Jefferson, S. Leatherwood, D. T. Ho, C. V. Thouc and L. H. Quang. 1997. Investigations of marine mammals in Vietnam. Asian Marine Biology 14: 111-143.

Smith, P.T., ed. 1999. Coastal shrimp aquaculture in Thailand: key issues for research. ACIAR Technical Reports No. 47, 131p.

Smith, T.J. et al., 1994. Mangroves, hurricanes, and lightning strikes. *Bioscience*, **44**(4), 256–262.

Soares, M.L.G., 2009. A Conceptual Model for the Responses of Mangrove Forests to Sea Level Rise. *Journal of coastal research*, **Vol 20**, Number 2, pp586-598

Solomon, S. et al. 2007. Climate change 2007: the physical science basis, University Press.

Somero, G.N. 2002. Thermal physiology and vertical zonation of intertidal animals: optima, limits, and costs of living. Integ. And Comp. Biol., 42, 780–789

Somero, G.N., 2002. Thermal physiology and vertical zonation of intertidal animals: optima, limits, and costs of living. *Integrative and Comparative Biology,* 42(4), p.780.

Staples DJ, Vance DJ .1986. Emigration of juvenile banana prawns, Penaeus merguiensis, from a mangrove estuary and recruitment to offshore areas in the wet-dry tropics of the Gulf of Carpentaria, Australia. Marine Ecology Progress Series, 27, 239–252.

Steffen, W., A. A. Burbidge, L. Hughes, R. Kitching, D. Lindenmayer, W. Musgrave, S. M. Smith and P. A. Werner. 2009. Australia's biodiversity and climate change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change. A report to the Natural Resource Management Ministerial Council commissioned by the Australian Government. CSIRO Publishing, Canberra, Australia.

Sundar, K. S. G. 2003. Notes on the breeding biology of the Black-necked Stork *Ephippiorhynchus asiaticus* in Etawah and Mainpuri districts, Uttar Pradesh, India. Forktail 19: 15-20.

Supamattaya, K. 1998. Experimental transmission of white spot syndrome virus (WSSV) from black tiger shrimp Penaeus monodon to the sand crab Portunus pelagicus, mud crab Scylla serrata and krill Acetes sp. *Diseases of Aquatic Organisms* 32 (1998): 79–85

Suppakorn. 2011. Report: Climate change projection for risk assessment in Koh Kong and Kampot provinces. Draft. SEA START RC, Bangkok, Thailand.

Tacon, A.G.J. and Halwart, M. 2007. Cage aquaculture: a global overview. ***In*** M. Halwart, D. Soto and J.R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, pp. 1–16. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.

Thanh Phuong, N. Hoang Oanh, T. 2009. Chapter 7. Striped catfish aquaculture in Viet Nam: A decade of unprecedented development in: De. Silva and Davy, B. 2009. Success stories in Asian Aquaculture. Springer. Pp 214.

Thinh, N.Q., T.D. Dung, and H.W. Ferguson. 2004. Histopathology of white spot in internal organs of Pangasius hypophthalmus. *Scientific Journal of Can Tho University* (Special Issue on Aquaculture and Fisheries) 120–125 (in Vietnamese).

TKK and SEA START RC. 2009. Water and Climate Change in the Lower Mekong Basin: Diagnosis & recommendations for adaptation, Water and Development Research Group. Helsinki University of Technology (TKK) / Southeast Asia START Regional Center (SEA START RC) / Chulalongkorn University. Water & Development Publications, Helsinki University of Technology, Espoo, Finland.

Tordoff, A. W., ed. 2002. Directory of Important Bird Areas in Vietnam: key sites for conservation. BirdLife International in Indochina/ Institute of Ecology and Biological Resources, Ha Noi, Vietnam.

Tordoff, A. W., Tran Quoc Bao, Nguyen Duc Tu and E. Le Manh Hung. 2004. Sourcebook of existing and proposed protected areas in Vietnam. Second edition. BirdLife International in Indochina/Ministry of Agriculture and Rural Development, Hanoi, Vietnam.

Tran Triet, R. J. Safford, Tran Duy Phat, Duong Van Ni and E. Maltby. 2000. Wetland biodiversity overlooked and threatened in the Mekong Delta, Vietnam: grassland ecosystems in the Ha Tien Plain. Tropical Biodiversity 7: 1-24.

Trisurat, Y., R. Alkemade and E. Arets. 2008. Projecting forest tree distributions and adaptation to climate change in northern Thailand. Journal of Ecology and Natural Environment 1: 55-63.

Van Zalinge, Nicolaas; Lieng Sopha, Ngor Peng Bun, Heng Kong, and John Valbo Jørgensen. 2002. Status of the Mekong *Pangasianodon hypophthalmus* resources, with special reference to the stock shared between Cambodia and Viet Nam. MRC Technical Paper No. 1, Mekong River Commission, Phnom Penh. 29 pp. ISSN: 1683-1489

Venkataraman, G 1970. *The Indian Mackerel: IV. Bionomics and life history*. **In**: CMFRI Bulletin No.24, The Indian Mackerel. Nair, R V,**(ed.)** CMFRI, Mandapam Camp, pp. 17-40.

Veron, J. et al., 2009. The coral reef crisis: The critical importance of <350 ppm CO2. *Marine Pollution Bulletin*, **58**(10), 1428-1436.

Vidal EAG, DiMarco FP, Wormorth JH, Lee PG. 2002. Influence of temperature and food availability on survival, growth and yolk utilization in hatchling squid. Bull Mar Sci 71(2):915–931

Walker SJ, Degnan BM, Hooper JNA, Skilleter GA 2008. Will increased storm disturbance affect the biodiversity of intertidal nonscleractinian sessile fauna on coral reefs? Global Change Biology, in press. Marine Biology and Ecology, 352, 200–211

Walker, B., C. S. Holling, S. R. Carpenter and A. Kinzig. 2004. Resilience, adaptability and transformability in social–ecological systems. Ecology and Society 9: 1-9.

Walther, G. Post, E. Convey, P. Menzel, A. Parmesan, C. Beebee, T. Fromentin, J. Hoegh-Guldberg, O. Bairlein, F. 2002. Ecological responses to recent climate change. *Nature,* Vol 416, Pp/389-395

Waycott, M. et al., 2007. Vulnerability of seagrasses in the Great Barrier Reef to climate change. Climate Change and the Great Barrier Reef: A Vulnerability Assessment. Great Barrier Reef Marine Park Authority, Townsville, Australia, pp193–235

Webster, N. Hill, R. 2007. Vulnerability of marine microbes on the Great Barrier Reef to climate change. Climate Change and the Great Barrier Reef Marine Park: a Vulnerability Assessment J. E. Johnson and PA Marshall. Townsville, Great Barrier Reef Marine Park Authority and Australian Greenhouse Office, 97–115.

Welch DW, Ishida Y, Nagasawa K 1998. Thermal limits and ocean migrations of sockeye salmon (Oncorhynchus nerka): long-term consequences of global warming. Can J Fish Aquat Sci 55:937–948

White, I.,Melville, M., Sammut, J., 1996. Possible impacts of saline water intrusion floodgates in Vietnam's Lower Mekong Delta. http://coombs.anu.edu.au/~vern/env_dev/papers/ papa07.html.

Wolanski E, Fabricius K, Spagnol S, Brinkman R 2005. Fine sediment budget on an inner-shelf coral-fringed island, Great Barrier Reef of Australia. Estuarine, Coastal and Shelf Science, 65, 153–158.

Wood, C. and McDonald, D. 1997. Global warming: implications for freshwater and marine fish, Cambridge Univ Pr.

Wooldridge, S. et al., 2005. Precursors for resilience in coral communities in a warming climate: a belief network approach. *Marine Ecology Progress Series*-**295**, 157-169

Yusuf, A. A. and H. Francisco. 2009. Climate Change Vulnerability Mapping for Southeast Asia. Economy and Environment Program for Southeast Asia/Swedish International Development Cooperation Agency/Canadian International Development Agency/, Singapore.

Appendices

Appendix 1. Definitions for habitat vulnerability assessment

The methodology for habitat vulnerability assessment used in this report was developed by ICEM (Meynell 2011, adapted from a species assessment methodology by Bezuijen 2011) and is used here with ICEM permission. For the current project, two modifications were made to the methodology of Meynell (2011):

- Adapative capacity of species. (1) The need for a timeframe in which to assess adaptive capacity to climate change was identified. For this project, the timeframe was broadly defined as the next several decades i.e. until ~2050, which is the timeframe for most climate change models currently available for the study area. (2) Adaptive capacity was not assessed for physical habitats e.g. sandy/rocky beaches, because it seemed unlikely that such habitats would recover from climate-induced changes within the defined timeframe. This point requires discussion as some habitats (e.g. estuaries) are highly dynamic and clearly more 'adaptable' than others.

- Sensitivity 'Variable 3'. Originally 'Vegetation habitat diversity' (Meynell 2011); changed to 'Vegetation species richness'.

Variable	Definitions
1. Exposure. Exposure for habitats will generally result from: • changing hydrology / hydraulics (i.e. flows) • changes in extent / depth / duration of inundation from rainfall and run-off • changes in sediment loads washed down from the watershed due to changes in soil erosion • sea level rise and changes in the tidal range • storm events and storm surge	High level of exposure – climate change will impact most of the habitat in the wetland with little room for expansion of the habitat Medium – climate change will impact most of the habitat in the wetland but the terrain and soils are available for expansion Low – climate change will impact a small portion of the habitat in the wetland and there is access to land/water for expansion.
2. Sensitivity	
Variable 1. Extent of habitat in the wetland	Large – habitat covers large proportion of the wetland area Medium – intermediate between Large and Small Small – habitat covers small proprotion of the wetland area None – habitat does not occur in the wetland
Variable 2. Total geographic representation of the habitat within the region	Large – Habitat common/widespread throughout region Medium – intermediate between Large and Small Small – Habitat restricted to only this and/or few other wetlands
Variable 3. Vegetation species richness (Note: not applicable to habitats which are not a vegetation community e.g. sandy beaches, rocky shores etc)	Large – large number of plant species in the habitat Medium – intermediate between Large and Small Small – few species in the habitat
Variable 4. Life history traits (Note: not applicable to habitats which are not a vegetation community)	High – species with rapid generation times Medium – intermediate between High and Low Low – long-lived trees and shrubs with slow germination and slow generation time

Variable	Definitions
3. Adaptive capacity This will largely depend upon a) the suitability of adjacent terrain and soils to allow expansion or "movement"of the habitat and b) the absence of physical barriers (natural or man-made) that might prevent expansion or "movement" of the habitat Adaptive capacity was assessed within the timeframe of predicted climate change i.e. the next several decades	High – presence of large areas of suitable land adjacent to the wetland for expansion or movement of the habitat and absence of physcial barriers Medium – intermediate between High and Low Low – small or no areas of land suitable adjacent to the wetland for expansion or movement of the habitat
Assumptions for successful adaptation by a species	
Variable 1. Adequate space for change	Is there sufficient land or water areas with suitable terrain, soils and hydrology for expansion or movement? (Yes / No)
Variable 2. Absence of physical barriers	Are there any natural or man-made physical barriers that might prevent expansion or movement of the habitat? (Yes / No)
Vulnerability	Final ranking (High, Medium, Low) based on the rankings for Exposure + Sensitivity + Adaptive capacity. If the habitat will be completely loss then state 'Complete loss'
Vulnerability+other threats	As above but including possible synergistic impacts with existing threats. [Given the existing pressures on wetlands, it is important that potential synergy between climate change and other threats is considered. For example, climate change may have small impacts by itself but high impacts when considered with another threat]

Appendix 2. Definiations for species vulnerability assessment

The methodology for species vulnerability assessment used in this report was developed by ICEM (Bezuijen 2011) and is used here with ICEM permission. No modifications were made to the methodology of Bezuijen (2011) but the need for a clear definition of geographic range (Sensitivity-Variable 1) in the context of individual assessments, and clarification of the criterion 'biogeographic connectivity' (Adaptation-Variable) 1 is given here.

Variable	Draft definitions
1. Exposure	High level of exposure – climate change will impact most of the geographic range and/or habitats of a species and there is little option for the species to seek shelter in refugia Medium – climate change will impact most of the species range but refugia are available to buffer impacts (e.g. deep pools, rocks, burrows) Low – climate change will impact a small portion of a species range or habitats and there is access to refugia.
2. Sensitivity	
Variable 1. Geographic range [scale needs to be defined in the context the project]	Large – species widespread in Cambodia, Thailand and Vietnam Medium – intermediate between Large and Small Small – species with small/restricted range Cambodia, Thailand and Vietnam
Variable 2. Population size in study area [scale needs to be defined in the context of the project]	Large – within the study area the species is common Medium – intermediate between Large and Small Small – within the study area the species is rare (either 'naturally' or due to human-caused declines)
Variable 3. Life history traits	High – species has short generation time (rapid life cycle) and/or short time to sexual maturity and/or high fecundity and/or 'generalist' requirements for food, nesting sites and/or good dispersal capability to track preferred climate space Medium – intermediate between High and Low Low – species has long generation time (slow life cycle) and/or long time to sexual maturity and/or low fecundity and/or specialised requirements for food, nesting sites and/or poor dispersal capability to track preferred climate space
3. Adaptive capacity (denoted 'Ecological' in Table 4)	High' – species has tolerance to a broad thermal range and/or can acclimatise to the new climate by sheltering in microhabitats and/or by changing its daily/seasonal patterns Medium – intermediate between High and Low Low – species has narrow thermal range and/or has little ability or opportunity to acclimatise to the new climate because there are limited microhabitats to shelter in and/or it has highly specialised daily/seasonal patterns
Assumptions for successful adaptation by a species	
Variable 1. Biogeographic connectivity	Is there sufficient habitat connectivity to allow organisms to reach suitable habitat/climate space/refugia? In particular: (a) is there scope to move to higher elevation? (Organisms on flat plains or in deltas will have little scope); (b) is there scope to move to higher latitudes? (Organisms in north-south oriented rivers will have more scope to move to new climate spaces than in east-west oriented rivers); (c) are there barriers (e.g. physical, chemical) to movement (eg dams, large roads etc)?
Variable 2. Adequate time for change	Is there adequate time to allow an individual to develop adaptive changes? (Yes / No)
Vulnerability	Final ranking (High, Medium, Low) based on the rankings for Exposure + Sensitivity + Adaptive capacity
Vulnerability+other threats	As above but including possible synergistic impacts with existing threats. [Given the existing pressures to biodiversity in mainland South-east Asia, it is important that potential synergy between climate change and other threats is considered.]

Appendix 3. Coastal habitats in the project area

Country: province	In-shore marine waters	Mangrove forest	Melaleuca forest / SFG	Estuaries / inlets	Mud-flats	Sandy beaches	Rocky beach-es	Seagrass beds	Nearby offshore islands	Existing threats	Notes
Cambodia: Koh Kong	x	Extensive (Koh Kong Bay, Peam Krasaop WS, Kompong Som Bay, Ream NP)	Koh Kapik, Sre Ambel IBAs	Numerous	x	Extensive	Few	Limited (south of Koh Kong; Koh Rong; Kompong Som Bay)	Koh Kong, Koh Rong, and smaller islands	• As above for seagrasses • Increasing coastal development	Less coastal development, more mangrove forests, than Chanthaburi/Trat
Cambodia: Kampot	x	Extensive (between Kampot and Kep)	Stung Kampoch Smach, Kampong Trach	Numerous	x	Extensive	Few	Extensive	Koh Thmei and smaller islands	• As above for seagrasses • Increasing coastal development	Coast at Sihanoukville town developed; large sea wall near town
Thailand: Chanthaburi	x	Fragmented remnants (~9,600 ha^)	None	Few	x	Few	Few	~2,700 ha; 'good' condition*	Few; small	• Most mangroves cleared • Damage to seagrasses: dredging, siltation, fishing (fishnets scour seabed)	Inner Gulf of Thailand. Intensively developed for aquaculture
Thailand: Trat	x	Some large remnants (~9,600 ha^)	None	x	x	Few	Few	~644 ha, 'fair' condition*	Ko Chang, Ko Mak, Ko Kut	• As above for seagrasses	Less developed than Chanthaburi Province
Vietnam: Kien Giang	x	Small remnants, fragmented (~3,500 ha; 74% of coastline)^	U Minh Thuong NP	Few	x	Few	Some (Phu Quoc)	Phu Quoc	Phu Quoc	• Most lands outside U Minh Thuong NP cleared • Ongoing clearance for aquaculture	Intensively developed for aquaculture
Vietnam: Soc Trang	x	Small remnants, fragmented	None	Large, extensive	Large	None	None	None, but present on Con Dao Island	None	• As above	Intensively developed for aquaculture. West bank of Mekong Delta
Vietnam: Ben Tre	x	Small remnants, fragmented	None	Large, extensive	Large	None	None	?	None	• As above	Mekong Delta. Intensively developed for aquaculture
Vietnam: Can Gio	x	Extensive inland remnants	None	x	Large	Few	Few	?	None	• As above • Beaches fragmented by sea walls	West of Mekong Delta. Intensively developed; many sea walls

Key. NP-National Park, PA-protected area, SFG-seasonally flooded grassland, WS-Wildlife Sanctuary. ^R. Mather in litt. May 2011. *From Adulyanukosol and Poovachiranon (2006). ^From Duke et al. (2010).

Appendix 4. Status of selected species in the project area

Species	IUCN status	Species status and key sites within project provinces: Cambodia	Thailand	Vietnam	Habitat requirements	Some life history parameters	Existing threats	Source
Mammals Irrawaddy Dolphin Orcaella brevirostris	VU	• Regionally important population • Koh Kong: Koh Kong island+bay north to Thai border, Kompong Som Bay. Kampot: Ream National Park, Koh Thmei island	• Regionally important population. Records from Chanthaburi: Laem Sing District. Trat: 150-200 individuals (Trat Bay)	• Status unclear; may occur in Kien Giang • Mekong Delta: few/no records	• Inshore shallow-water specialist • Food resources depend on healthy reefs, sea grasses	• Slow reproductive rate. ASM unknown; adult size at 4-6 y. Long gestation (14 months) • Long-lived (30 y)	• Bycatch in nets • Capture for aquaria • Habitat loss: damage to reefs, seabed (scouring - trawlers)	1-5, 31
Indo-Pacific Humpback Dolphin Sousa chinensis	NT	• As above	• As above. • 40+ dead dolphins (spp.?) in Trat, 2010-11 – bycatch in nets	• Status unclear; may occur in Kien Giang • Recorded in Mekong Delta (Vung Tau)	• As above	• Slow reproductive rate. SM at 10 y; gestation 10-12 mths • Long-lived (40+ y)	• As above	1,4,5
Finless Porpoise Neophocaena phocaenoides	VU	• Status unclear; little data • Koh Kong: records from Kompong Som Bay	• Chanthaburi: records from Laem Sing District. Trat: records from Klong Yai, Trat, Laem Ngop Districts	• Status unclear • Recorded from Mekong Delta (Vung Tau)	• As above	• Slow reproductive rate. Females breed once / 2 y; gestation 11 months • Long-lived (33+ y)	• As above	1,4,5
Dugong Dugong dugon	VU	• Resident, very low numbers • Kampot: records near Kien Giang (Vietnam)	• Resident (50 in GOT) • Trat: records from Ko Chang to Cambodia	• Resident, threatened • Kien Giang: records coast + Phu Quoc island	• Inshore shallow-water specialist • Diet - seagrasses	• Slow reproductive rate. SM 9-10 y. Gestation 12-14 mths • Long-lived (70+ y)	• As above • Boat strike • Hunted (Cambodia, Vietnam)	4,5,6,7
Lyles Flying-fox Pteropus lylei	VU	• Status unknown; may have been widespread • No known populations in protected areas in Cambodia	• Status unknown; few/no records • Occurs in mangroves further west in GOT	• Status unknown; may have been widespread • No known populations in protected areas in Vietnam	• Roosts in Melaleuca, mangroves • Ranges widely for foraging	• Little data. Usually 1 young only; gestation + weaning may take several months	• Hunting of adults • Loss of breeding + roosting habitat	21,22, 24

Species	IUCN status	Species status and key sites within project provinces: Cambodia	Thailand	Vietnam	Habitat requirements	Some life history parameters	Existing threats	Source
Large Flying-fox P. vampyrus	NT	• Status unknown; may have been widespread	• Status unknown; formerly widespread in GOT	• Status unknown; may have been widespread	• As above	• As above	• As above	22,23, 24
Birds								
Sarus Crane Grus antigone sharpii	VU	• Non-breeding populations • Global importance • Koh Kong: Sre Ambel IBA • Kampot: Kampong Trach IBA	• Considered extinct in the wild in Thailand	• Non-breeding populations • Global importance • Kien Giang: Ha Tien, U Ming Thuong, Kien Luong IBAs	• Seasonally flooded grasslands, forested lakes	• Slow reproductive rate. Small clutches (2-3 eggs) with extended parental care (3 mths)	• Loss of flooded grasslands • Hunting of adults • Egg/chick collection	8,9,16,17
'Other large waterbirds' (6 species)[1]	EN (1.), VU (2), NT (2), LC (1)*	• Resident+seasonal populations • National/global importance • Koh Kong: Sre Ambel River IBA • Kampot: Stung Kampong Smach + Prek Taek Sap IBAs	• No recent records	• Resident+visitors: national+ importance • Kien Giang: U Minh Tuong + Kien Luong IBAs. Ben Tre: Binh Dai + Ba Tri IBAs. Can Gio: Can Gio IBA	• Melaleuca swamp, mangroves, lakes, estuaries, rivers	• Small clutches (1-5 eggs), extended parental care (12+ months); in Cambodia nest protection shows populations rebound quickly when threats are removed	• Over-collection of eggs, chicks • Hunting of adults • Loss of nesting habitat due to agriculture and aquaculture	8-11,16
'Colonial-nesting waterbirds' (14+ spp.)[2]	EN (1), VU (1), NT (2), LC (10)	• No large populations of most of these species	• Few records for most species; no large populations	• Residents and non-breeding visitors • ≥1% biogeographic population for 5+ spp. • Kien Giang: U Minh Thuong IBA. Ben Tre: Binh Dai + Ba Tri IBAs	• Melaleuca swamp, mangroves, lakes, estuaries, rivers	• Large breeding colonies • Medium/high reproductive rate. Clutch 3-6 eggs	• As above	9,16-19

Species	IUCN status	Species status and key sites within project provinces: Cambodia	Thailand	Vietnam	Habitat requirements	Some life history parameters	Existing threats	Source
'Migratory shorebirds' (non-breeding seasonal visitors) (19+ spp.)[3]	CE (1), EN (1), VU (1), NT (3), LC (13)	• Few records of most species • Koh Kong: Asian Dowitcher and/or Nordmann's Greenshank in Stung Kampong Smach + Koh Kapik IBAs (latter with ≥1% biogeographic population of Nordmann's Greenshank)	• Few records of globally threatened species • Most populations are west of study area in 'Inner Gulf of Thailand IBA'	• Large populations in Can Gio (Can Gio IBA), Ben Tre (Ba Tri+Binh Dai IBAs; latter with ≥1% biogeographic population of 3+ spp.) • Spoon-billed Sandpiper at Can Gio + Ba Tri IBAs	• Tidal mud- and sandflats, mangroves, high-tide roosts	• Reproductive rate not applicable for most species – non-breeding visitors to study area • Seasonal availability of invertebrate prey critical for all species • Arrival / departure dates to Mekong Delta may be changing	• Hunting • Habitat loss for agriculture and aquaculture • Most of Delta already cleared	9,11,16-18, 20,25, 30
Reptiles								
Green Turtle *Chelonia mydas*	EN	• Nesting status unknown but any populations probably small and threatened • Kampot: recorded in Koh Tang Archipelago IBA	• Few sandy beaches – little nesting habitat • Elsewhere in GOT, possibly only 10 nesting females/year	• Persist in Tho Chu, An Thoi (Kien Giang); also Con Dao island • Possibly only 10 nesting females/year	• Sandy nest beaches • Invertebrate prey availability depends on intact reefs, seagrass beds, clean water	• Variable reproductive rate. ASM varies among regions; ~ 20+ y. Lay 1-9 clutches /season, but high egg/hatchling mortality	• Fishing bycatch • Opportunistic catch by shellfish divers (est. 100s turtles/yr) • Egg collection • Hunting of adults	9,14, 16, 26
Hawksbill Turtle *Eretmochelys imbricata*	CE	• Nesting status unknown but any populations probably very small and threatened • Nesting may persist on islands west of Koh Kong, Kampot	• Few sandy beaches – little nesting habitat • Nest sites documented further west in GOT	• Severe national decline; possibly <10 clutches/yr • Possibly still nests on islands of Kien Giang • Formerly nested in Con Dao island group	• As above	• Variable reproductive rate. ASM varies among regions; ~20+ y. Lay 1-6 clutches / season, but high egg/hatchling mortality	• As above; and, 1970s-80s: rearing facilities were in Kien Giang. Eggs were sourced from islands in GOT incl. Phu Quoc	26-28
River Terrapin *Batagur baska*	CE	• Resident populations rediscovered in Koh Kong: Sre Ambel, Stung Kaaong Rivers • Possibly <20 mature females	• No records	• Historically occurred in southern Vietnam • Any populations probably on verge of extirpation	• Coastal rivers, saline + freshwater habitat; • Nests on sandbars	• Variable reproductive rates. Females lay 1-3 clutches per season	• Over-collection of eggs; nest damage-humans, trampling by cattle	12-15, 29

Key. IUCN status: LC-Least Concern, NT-Near Threatened, VU-Vulnerable, EN-Endangered, CE-Critically Endangered. ASM-age of sexual maturity, GOT-Gulf of Thailand, IBA-Important Bird Area, SM-sexual maturity.

[1]'Other large waterbirds': Milky Stork *Mycteria cinerea* (VU), Painted Stork *M. leucocephala* (NT), Black-necked Stork *Ephippiorhynchus asiaticus* (NT), Lesser Adjutant L. javanicus (VU), Greater Adjutatnt *L. dubius* (EN), Asian Openbill *Anastomus oscitans* (LC).

[2]'Colonial-nesting medium-sized waterbirds': Indian Cormorant *Phalacrocorax fuscicollis* (LC), Little Cormorant *P. niger* (LC), Oriental Darter *Anhinga melanogaster* (NT), Cattle Egret Bubulcus ibis (LC), Great Egret *Ardea alba* (LC), Little Egret *Egretta garzetta* (LC), Chinese Egret *Egretta eulophotes* (VU), Purple Heron *Ardea purpurea* (LC), Grey Heron *Ardea cinerea* (LC), Javan Pond Heron *Ardeola speciosa* (LC), Black-crowned Night Heron *Nycticorax nycticorax* (LC), Black-faced Spoonbill *Platalea minor* (EN), Glossy Ibis *Plegadis falcinellus* (LC), Black-headed Ibis *Threskiornis melanocephalus* (NT).

[3]'Migratory shorebirds': Nordmann's Greenshank *Tringa guttifer* (EN), Asian Dowitcher *Limnodromus semipalmatus* (NT), Spoon-billed Sandpiper *Eurynorhynchus pygmeus* (CE), Oriental Pratincole *Glareola maldivarum* (LC), Far Eastern Curlew *Numenius madagascariensis* (VU), Malaysian Plover *Charadrius peronii* (NT), Black-tailed Godwit *Limosa limosa* (NT), Kentish Plover *Charadrius alexandrinus* (LC), Greater Sand-Plover *Charadrius leschenaultii* (LC), Common Redshank *Tringa totanus* (LC), Marsh Sandpiper *Tringa stagnatilis* (LC), Common Greenshank *Tringa nebularia* (LC), Wood Sandpiper *Tringa glareola* (LC), Common Sandpiper *Actitis hypoleucos* (LC), Grey-tailed Tattler *Heteroscelus brevipes* (LC), Curlew Sandpiper *Calidris ferruginea* (LC), Pacific Golden Plover *Pluvialis fulva* (LC), Lesser Sand Plover *Charadrius mongolus* (LC), Little Ringed Plover *Charadrius dubius* (LC).

Information sources: 1-Smith et al. (1997), 2-Adulyanukosol (1999), 3-Andersen and Kinze (1999), 4-Beasley and Davidson (2007), 5-Shirihai and Jarrett (2009), 6-Adulyanukosol and Poovachiranon (2006), 7- Hines et al. (2008), 8-Safford et al. (1998), 9-Tordoff (2002), 10-Sundar (2003), 11-Tordoff et al. (2004), 12-Moll (1980), 13-Platt et al. (2003), 14-Nabhitabhata and Chan-ard (2005), 15-Praschag et al. (2009), 16-Seng et al. (2003), 17-Sanguansombat (2005), 18-Buckton and Safford (2004), 19-Robson (2008), 20-BirdLife International (2004), 21- Bumrungsri et al. (2008), 22-Lekagul and McNeely (1977), 23-Bates et al. (2008), 24-Ratcliffe (1931), 25-Nguyen Duc Tu (IUCN Vietnam) in litt. 28 April 2011, 26-Hamann et al. (2005), 27-Chan and Liew (1999), 28-Moncada et al. (1999), 29-Kalyar et al. (2007), 30-Beaumont et al. (2006), 31- Monanunsap et al. (2010).

Appendix 5. Protected areas and other sites of conservation importance

Site	Name	Location	Area (ha)	Habitats	Key biodiversity values	Existing threats
Cambodia: Koh Kong Province						
IBA–KH028	Koh Kapik	South of Koh Kong town	27,289	Mangroves, mudflats, sandy beaches, Melaleuca forests	Most intact mangroves in Cambodia, AD, NG, LTM	Habitat loss, hunting
IBA–KH029	Sre Ambel	Estuary Sre Ambel River	8,068	Mudflats, mangroves, Melaleuca swamp	Sarus Crane, other large waterbirds, LTM, RT	As above
National Park	Botum Sakor	West of Sre Ambel town	176,900	Mangroves, beaches, hills, forests	Marine and terrestrial fauna, flora	As above
Wildlife Sanctuary	Peam Krasop	Includes most of Koh Kapik IBA	26,000	See Koh Kapik IBA	Partly encompasses Koh Kapik IBA	As above
Ramsar site	Koh Kapik and Inlets	Southern part of Koh Kapik IBA	12,000	See Koh Kapik IBA	Encompasses the Koh Kapik IBA	As above
Multiple Use Area	Dong Peng	Includes some of Sre Ambel IBA	27,700	Mudflats, mangroves	Encompasses 7,200 ha of Sre Ambel IBA	As above
Cambodia: Kampot Province						
IBA–KH032	Stung Kampong Smach	Estuary Kampong Smach River	13,790	Mudflats, mangroves, Melaleuca, Nypah	Large waterbirds, migratory shorebirds	As above
IBA–KH033	Prek Taek Sap	Estuary of Taek Sap River	3,579	As above; Koh Thmei island	Milky Stork-most important non-breeding site in Cambodia	As above
IBA–KH034	Koh Rong Archipelago	Koh Rong+nearby islands	10,561	Sandy beaches, reefs, mangroves, seagrasses	Malaysian Plover, possibly Green Turtle	As above
IBA–KH035	Koh Tang Archipelago	Koh Tang+nearby island	667	Sandy/rocky beaches, coral reefs	Nicobar Pigeon, Christmas Island Frigatebird	As above
IBA–KH040	Kampong Trach	Western edge of Mekong Delta	1,108	SFG, Melaleuca scrub	Sarus Crane	As above
National Park	Ream	Adjacent to Prek Taek Sap IBA	21,000	Mangrove, mudflats, beaches, seagrass	Adjacent to Prek Taek Sap IBA	As above
National Park	Kep	Near Kep town	5,000	Islands, sandy/rocky beaches	Marine+terrestrial fauna/flora	As above
Thailand: Chanthaburi Province. No IBAs, Ramsar sites or coastal protected areas						
Non-hunting Area	Khung Krabaen	Coast (Royal Study Centre)	?	Mudflats, mangroves	Mangrove communities	?
Forest Park	Khao Laem Singh	Chanthaburi River entrance	1,520	Evergreen forest, Casuarinas, sandy beach	No globally/nationally threatened species(?)	Small size
Thailand: Trat Province. No IBAs, Ramsar sites or coastal terrestrial protected areas						
Marine NP	Mu Koh Chang	Ko Chang island+waters	65,000	Coral reefs, seagrasses, sandy/rocky beaches	Dugong, cetaceans, sea turtles. KBA #210	?

Site	Name	Location	Area (ha)	Habitats	Key biodiversity values	Existing threats
Not protected	Trat wetlands	? No data located	?	? No data located	KBA #257; Potential Ramsar site	?
Vietnam: Kien Giang Province						
IBA–VN003	Ha Tien	North-west Mekong Delta	6,981	SFG, Melaleuca scrub	Bengal Florican, Sarus Crane. KBA#301	Habitat loss
IBA–VN004	U Ming Thuong	North-west Mekong Delta	22,918	Peat swamp forest, SFG, Melaleuca forest	Peat swamp forest, large waterbirds, migratory shorebirds, HNO, freshwater turtles	Burning, hunting
IBA–VN005	Kien Luong	North-west Mekong Delta	7,624	Seasonally flooded grassland	Sarus Crane, other large waterbirds. KBA307	Habitat loss
National Park	U Minh Thuong	North-west Mekong Delta	8,053	Encompasses part of U Minh Thuong IBA	As for U Minh Thuong IBA	As for UMT
National Park	Phu Quoc	Phu Quoc island	31,422	Forest, Melaleuca swamp	Dugong, sea turtles	Development
Proposed MPA	Phu Quoc	Phu Quoc island	18,700	Sandy/rocky beaches, coral reefs, seagrass	Cetaceans, Dugong, sea turtles, coral reefs	Hunting
Proposed MPA	Nam Du	South-west of Ha Tien town	10,400	Archipelago of 21 islands, coral reefs	Coral reefs, sea turtles	Development
Proposed MPA	Tho Chu	Tho Chu archipelago (5 islands)	22,400	Sandy beaches, seagrass beds	Coral reefs, Dugong, sea turtles	?Military access
Proposed NR	Kien Luong	Ha Tien Plain, 25 km from coast	14,605	SFG. Within Ha Tien IBA	Sarus Crane, other large waterbirds	Habitat loss
Vietnam: Ben Tre Province						
IBA–VN062	Binh Dai	Mekong Delta	30,000	Sand/mud flats, mangroves, seagrass	Migratory shorebirds-most important Delta site. KBA #277	As above
IBA–VN063	Ba Tri	Mekong Delta	6,000	Sand flats, aquaculture ponds	Migratory shorebirds. Adjoins Binh Dai IBA. KBA #265	As above
Nature Reserve	Thanh Phu	Mekong Delta	4,510	Inter-tidal sand/mud flats, mangroves	Migratory shorebirds	As above
Vietnam: Can Gio Province						
IBA–VN051	Can Gio	North-east of Mekong Delta	75,740	Inter-tidal mudflats, mangroves	Large waterbirds, shorebirds, LTM. KBA#280	Habitat loss
MBR	Can Gio	As above	75,740	This site encompasses Can Gio IBA	As above	As above
Vietnam: Soc Trang Province. No IBAs, Ramsar sites, coastal protected areas						

Key. Compiled from ICEM (2003), Seng et al. (2003), BirdLife International (2004, 2007), Tordoff et al. (2002, 2004), CEPF (2007), and Ramsar (www.ramsar.org) and BirdLife (www.birdlife.org/datazone) databases. AD-Asian Dowitcher, HNO-Hairy-nosed Otter, IBA-Important Bird Area, KBA-Key Biodiversity Area (CEPF 2007), LTM-Long-tailed Macaque, MBR-Man and the Biosphere Reserve, MPA-Marine Protected Area, NG-Nordmann's Greenshank, RT-River Terrapin, SFG-seasonally flooded grassland.

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Climate change is a global challenge but a lot can be done at the local level to minimize impacts and capture opportunities. IUCN's Building Resilience to Climate Change Impacts–Coastal Southeast Asia Project, funded by European Union, aims to increase adaptive capacity of people and the ecosystems on which they depend to cope with the anticipated impacts of climate change and plan for DRR, through sound governance and planning.

The project will strengthen the ability of local government and local people to plan for, and adapt to, future climate risks in eight coastal provinces between Ho Chi Minh City and Bangkok: Can Gio, Ben Tre, Soc Trang, and Kien Giang in Vietnam; Kampot and Koh Kong in Cambodia; and Trat and Chanthaburi in Thailand.

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