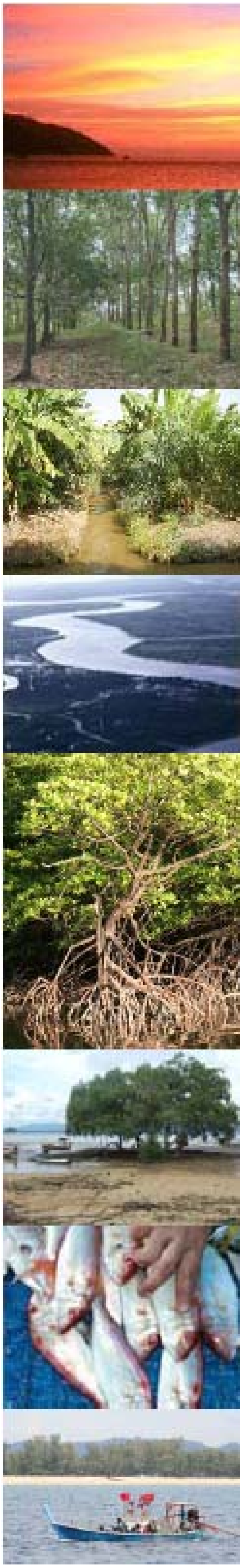

Climate Change impacts in Krabi Province, Thailand.

A study of environmental, social, and economic challenges

DECEMBER 2008

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Preface

The WWF Greater Mekong Program (WWF-GMP) is concerned about the environmental transformation of the Greater Mekong Region (GMR) as a result of trade liberalization, demographic expansion, and rapid economic growth resulting in the degradation of natural habitats and biodiversity. Climate change is adding to these challenges, which will be exacerbated by a lack of integrated planning and a failure to mainstream the consequences of these environmental challenges into economic policies and development assistance.

To strengthen regional climate study capacity WWF-GMP signed a memorandum of understanding (MOU) with the South East Asian - Global Change System for Analysis, Research and Training organisation (SEA-START) to cooperate in studying climate change impacts across the region. Under this MOU, the two parties have started to cooperate in research, development and capacity building activities regarding climate change and adaptation and routinely share knowledge, information, exchange data, technical publications and study results.

As part of its region-wide initiative to better understand the implications of climate change impacts for economic development, livelihoods, and its conservation programs, the WWF-GMP with support from WWF's Macroeconomics Programme and in collaboration with SEA START launched two pilot studies in early 2008 in coastal Vietnam and Thailand (Ca Mau and Krabi provinces). These studies aimed to promote greater discussion of these implications within government and among foreign donors; and to build an analytic foundation for WWF's current work on climate change adaptation and related issues in the region.

Ca Mau, Vietnam and Krabi, Thailand were selected because their biophysical and socio-economic contexts differ substantially. Ca Mau's average elevation is only 1 m above mean sea level and is subject to both tidal flooding as well as cumulative effects of climate change impacts and human activities in the Mekong River and its tributaries. At present, like much of the Mekong Delta, its economy depends heavily on agriculture and aquaculture. In contrast, Krabi's terrain has more elevated relief and its economy is more diverse, with tourism a major contributor. Assessing climate change impacts and vulnerabilities in these different contexts has yielded a richer understanding of the impact of climate change on coastal areas across the region.

As well as understanding the impacts of climate change on biophysical and socio-economic context, local people's understanding and preparations for the possible impacts of climate change was also evaluated. The study organised a local stakeholder feedback session in Krabi town as part of the study, at which provincial stakeholders and local people where encouraged to participate. This provided the opportunity to explore two key issues. Firstly, participants understanding of the relevance of climate change, many people view climate change as a global phenomenon, that is taking place somewhere else, and thus something that they can do little about and doesn't affect them. This feedback session talking about issues close o their homes provide the opportunity for local people to learn more about climate change and the possible consequences for their locality, their livelihoods and the future. Secondly, participants learned that sea level rise isn't the only manifestation/consequence of climate change; changes in temperature and precipitation are also important to consider and for many stakeholders in the province these will cause the greatest impacts.

DESCRIPTION OF PROPOSED WORK

- Collaborate with a respected research institute in each of the two countries to produce a detailed assessment of climate change/economic development linkages, with a focus on rice and aquaculture production in WWF priority areas in coastal Thailand and Vietnam. The assessment would include the development of scenarios that identify likely impacts of climate change on these economic sectors in 10 and 25 years time and suggest specific recommendations for both policy and institutional change (economic and environmental);
- Present these assessments and the key findings at provincial level consultations in both countries, with the participation of relevant government ministries, donors, and other NGOs working on similar issues; and
- Use this initial activity as the basis for development of further activities, partnerships, and funding opportunities for WWF GMP and the Thailand and Vietnam country offices.

Executive Summary

Background, Rationale, and Objectives

The coastal areas of Vietnam and Thailand are considered particularly vulnerable to climate change and its impacts. The Greater Mekong Region (GMR) will likely experience more frequent and severe extreme climate events, greater variability of rainfall, and high rates of coastal inundation associated with rising sea levels and storm surges. Likely impacts include reduced agricultural productivity, damage to infrastructure, and, in the worst case, a reversal of recent economic gains. To better predict how coastal areas of the GMR will be affected, their social, economic, and environmental contexts must also be understood.

In early 2008, the WWF Greater Mekong Programme (GMP), with support from WWF's Macroeconomics Program, collaborated with the Southeast Asia Regional Center of the Global Change System for Analysis, Research, and Training (START) to assess climate change vulnerability and its implications for economic development in the coastal province of Krabi, Thailand. WWF chose Krabi as an example of a biologically rich coastal province with a diversified economy and heterogeneous geomorphology (to contrast with a similar study in Ca Mau, Vietnam, in the Mekong Delta).

The study's principal goals were to build capacity for adaptations that build climate change resilient systems, and to integrate climate risk management into development strategies. To achieve those ends, the study aimed to improve current knowledge about climate change and its potential impacts on local people's lives as well as on natural resources and the ecosystem services they provide. The specific objectives of the study were to

- Develop scenarios that identify likely impacts of climate change on key economic sectors in Krabi in 10 and 25 years time;
- Suggest specific recommendations for both policy and institutional change (economic and environmental); and
- Engage local stakeholders in the assessment process.

Study Design and Methods

The study team assembled data from a number of government sources and mapped it (using GIS) for the province's upland, coastal and urban areas. Climate scenarios for 10- and 25-years in the future were simulated with the Max Planck Institute's ECHAM global circulation model (GCM). The scenarios were based on IPCC projections (A2 scenario) of greenhouse gas emissions (and other global change drivers). The Hadley Centre's PRECIS model was used to increase the resolution of the GCM's output to 25 km^2 so that results would be meaningful for Krabi province. The mean and variability of monsoon driven temperature, precipitation, and prevailing winds were analyzed for the present and two future periods. Estimates of mean sea level and tropical storms were incorporated from the model outputs and from extrapolation of trends.

The study team also reviewed provincial planning documents and interviewed a cross-section of stakeholders in Krabi's upland, coastal and urban zones, to gauge their awareness of climate changes and their vulnerability. In addition, 130 local, regional and national officials, business and NGO leaders, scientists and local people participated in a workshop (broadcast nationally on Thai public TV). Participants discussed the report's findings and their implications for the province's development path.

Current Situation of Krabi Province

Krabi Province lies on the west coast of peninsular Thailand and its robust economy relies primarily on agriculture and tourism. Palm oil and rubber, the principal crops, cover 95% of Krabi's cultivated area with many smallholder farms amidst industrial plantations. Despite the December 2004 tsunami, tourism income has almost doubled since 2002.

Krabi covers 4,710 km^2; in 2007 its population was 411,000. Per capita income was $2,800 in 2006. However, not all residents have shared in the agriculture and tourism boom. Inhabitants of small coastal communities continue to depend on harvesting fish and shellfish from Krabi's coastal waters. Some have added family-scale shrimp and fish aquaculture as a source of income.

The seas offshore have particularly high biodiversity, including globally endangered marine mammals and sea turtles, abundant mangrove forest, 13.5 km^2 of coral reefs and substantial seagrass beds. These resources remain plentiful and generally well protected.

RESULTS

Interviews, provincial development plan review, and stakeholder workshop

In these interviews and at the subsequent workshop, it was evident that while many participants were aware of climate change as a global phenomenon, hardly any had considered its likely local impacts on the lives and livelihoods of their families. Similarly, in the province development plan, there was no mention of adaptation to likely climate change impacts though about 30% of planned projects are vulnerable to such impacts.

Climate scenarios

Temperature change: modest – According to the model results, inland temperatures in Krabi province will rise by slightly more than 1˚C over the next 10 and 25 years while, due to the moderating influence of the ocean, coastal temperatures will rise slightly less than 1˚C.

Rainfall change: very significant. The annual monsoon will be shortened by two weeks by 2018, and by four weeks by 2033. Total rainfall will likely decrease by 10% by 2033.

Sea level rise: substantial, with implications for Krabi's extensive mangrove wetlands. The mean level of the sea off Krabi coasts is expected to rise by about 1 cm annually over the next 25 years. Depending on local geomorphology, if sea level rises by 20 cm over the next 25 years, current shorelines will retreat from 10-35 m.

Intense tropical storms: fewer. The declining trend in cyclone frequency over the past 30 years reflects a shift induced by warming of the Andaman Sea and is likely to persist at or below recent levels. However, as sea levels rise, storms may do more damage to coastal infrastructure.

Beyond 25 years from now. This study did not project possible changes and impacts at the provincial level beyond 2033. On a regional and global scale, however, the evidence indicates that climate change effects will intensify for at least the next century. Thus, the study's results and recommendations are relevant for successful socioeconomic and land use planning in Krabi province, not just for the next 25 years, but also well beyond.

IMPACTS, IMPLICATIONS, AND RECOMMENDATIONS

Fresh Water Availability

As a near-term consequence of global warming, provincial authorities should give more attention to sustainably managing Krabi's water supplies and allocating available water among competing claimants. Urbanization, deforestation and land use conversion for agriculture have already put some pressure on natural water sources and stores. At the same time that rainfall is decreasing, a longer dry season will increase the tourism sector's demand for water. If demand for palm oil remains high, whether as a consequence of market forces or government policies, producers may resort to irrigation. Finally, rising sea levels will increase salt-water intrusion into shallow aquifers in coastal areas.

Integrated river basin management (IRBM) for the province's many small rivers and streams will be essential to maintain sufficient supplies of fresh water to all stakeholders. This could require some further impoundment of stream flow, but great care should be taken in designing dams and reservoirs to minimize their impact on coastal mangrove areas dependent on flows of fresh water and sediments. Healthy, productive mangroves will be most resilient to rising sea levels. Reduced stream flows are also likely to result in greater saline intrusion into coastal aquifers. Thus in the first instance, emphasis should be placed on developing a realistic conservation plan for each watershed that fairly allocates resources to both upstream and downstream users.

Coastal ecosystems

The mangrove forests that fringe much of Krabi's coastline play an important role in buffering coastal settlements and croplands from storm surges. They are also spawning grounds for fish and shellfish, a source of food and firewood for subsistence communities, and by filtering out nutrients flowing from upstream, a contributor to improved water quality. The mangroves will need to retreat inland as water levels rise. Preliminary calculations suggest that Krabi's mangrove forests may by thinned by an average of 18 meters on the seaward side. Thus it is critically important that roads and other structures on the landward side not be sited close to the current mangrove forest boundaries, to allow room for their inland migration.

Storms and Storm Surges

Although catastrophic weather events will increase on a global scale, the displacement of historical storm tracks by warming seas suggests that fewer severe storms (and attendant storm surges) are expected to make landfall in Krabi in the next 25 years. However, Krabi's coastline, as the 2004 tsunami demonstrated, is steadily growing more vulnerable to storm impacts than in the past as a consequence of tourism development, urbanization, and investments in small-scale aquaculture. A 100 km/h typhoon passing within 100 km of the province could raise sea level by as much as 2 m, eroding beaches and flooding valleys for several kilometres inland. Consequently, planners should zone to avoid urban and industrial development in the lowest-lying areas; plan the relocation of vulnerable populations and infrastructure to less exposed locations; and preserve, restore and rehabilitate coastal and marine habitats wherever possible. "Hard' engineering solutions (e.g., seawalls and levées) outside of urban areas should be avoided because in the longer term they are not likely to be sustainable.

Vulnerability by Study Zone

Coastal Communities. Krabi's 48 coastal villages are especially vulnerable to climate change impacts due to their proximity to the sea and their fisheries-dependent livelihoods and limited agricultural land. They are of significant social and cultural value as they are among the last communities in Krabi characterized by a traditional lifestyle. At the stakeholder workshop, several villagers noted that they'd already lost land and asked for assistance in dealing with coastal erosion.

Although this study did not examine the direct effects of climate change on offshore fisheries in Krabi province, the indirect effects may be substantial. Longer dry seasons will permit additional days of fishing, increasing the pressure on available stocks of fish and shellfish. This adds to the urgency of developing, thorough consultations with all concerned parties, an equitable, enforceable and scientifically-based regulatory system to ensure that coastal marine resources are not depleted by either commercial or subsistence fishing.

Upland Areas. In contrast to the coastal communities, the study's results suggest that upland communities will be less vulnerable to climate change. Rubber growers, in particular, may actually benefit over the next 25 years from climate change. Although rainfall will decrease during this period, it will remain sufficient to meet the needs of rubber cultivation, and the shorter monsoon season will permit additional days of tapping. Productivity per tree is expected to rise by 10-15 percent. Reduced rainfall, on the other hand, may reduce the productivity of oil palms. This provides another incentive to Krabi smallholders, already vulnerable to abrupt income swings traceable to market conditions, to diversify their crop base so as to increase resilience to economic and climate changes.

Rising temperatures will most likely force upland ecosystems – in particular Krabi's hill evergreen forests, protected in Khao Phnom Benja N.P. – to retreat to higher elevations where possible. Research is needed to develop a strategy that protects the high conservation value of these ecosystems.

Urban Areas. A lengthening dry season will increase the demand for tourism services, and hence place additional burdens on coastal resources and key ecosystems. Urban zones are likely to face water scarcity during the dry season, in response to which basin-wide water management systems will be essential. Engineering for infrastructure, including a municipal water supply as well as storm and wastewater management, should anticipate increasing climate change impacts over a 100-year horizon. Provincial planners should engage stakeholders in a discussion of the province's capacity for tourism growth that takes into account near and long-term climate change impacts; the best strategy may be to cap or slow growth in visitor volume while emphasizing migration to higher value and 'greener' services for tourists.

1. Introduction

GENERAL

Climate change is already beginning to present major environmental, social, and economic challenges for Vietnam and Thailand. Nearly 11% of the Vietnamese population lives near the Red and Mekong River deltas. According to a much-quoted recent World Bank report[1], up to 12% of Vietnam's coasts would be impacted by a 1 meter rise in sea level due to climate change. According to UNDP, this would lead to economic losses of US$17 billion per year as well as 17 million people homeless. The issues are equally pressing in Thailand, whose 2,600 km of coastline are increasingly vulnerable to flooding and coastal erosion.

Vietnam and Thailand are among the most developed economies in the region, with a strong emphasis on the production of agriculture and aquaculture products for export. They are, for instance, the top two rice exporters in the world. Both countries have begun taking steps to anticipate and address the threat of climate change, including mitigation and adaptation activities. But they are not yet making difficult linkages between climate change and economic development strategies, e.g. mainstreaming expected impacts of climate change into planning and policy decisions. In fact current plans (as expressed through poverty reduction strategies and programmes, five-year plans, and similar documents) are for continued growth and investment in the aquaculture and agriculture sectors. For example, Vietnam plans to expand its aquaculture area from 980,000 ha to 1.1 million ha by 2010; and to increase overall fisheries exports from $3 billion in 2006 to $4-$4.5 billion by 2010.[2]

Yet climate change is likely to have critical impacts on these sectors. A 2005 study by Robert Mendelsohn of Yale University[3] found that agricultural GDP in Thailand and Vietnam could decrease significantly under a variety of potential climate change scenarios. There are special risks for rice and aquaculture production in low-lying coastal areas due to sea level rise, saltwater intrusion, and an increased risk of natural disasters like the 2005 tsunami. This could put ambitious plans for further trade expansion and economic growth in jeopardy, in addition to posing urgent challenges for food security and poverty alleviation objectives

STUDY RATIONALE AND OBJECTIVES

The Greater Mekong region is incredibly diverse with globally important terrestrial, freshwater, and marine biodiversity. This richness of life is so important locally that the Mekong River is known as the "mother of all rivers". Similarly, the richness and abundance of large mammals in the region's dry forest complex has earned it the nickname, the "Serengeti of Asia". However, climate change, poses an uncertainty for the future survival of these unique ecosystems, the many endemic species that they comprise, as well as the humans who depend on them.

Recent projections by universities and institutions all indicate increased frequency and severity of climate extremes, greater variability of rainfall, rising sea levels and staggering rates of coastal inundation in the region. Dry seasons will be drier and longer; wet seasons will be wetter

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[1] "The impact of sea level rise on developing countries : a comparative analysis " http://econ.worldbank.org/external/default/main?ImgPagePK=64202988&entityID=000016406_20070209161430&pagePK=64165259&theSitePK=469382&piPK=585673

[2] http://www.thanhniennews.com/business/?catid=2&newsid=23419

[3] "Climate Change Impacts on Southeast Asian Agriculture" http://www.aeaweb.org/annual_mtg_papers/2006/0107_1430_1601.pdf

but shorter, storm events will be less frequent but more extreme. The exact impacts of these changes are unknown, although they are likely to affect agricultural productivity thus deepening poverty, destroying infrastructure, and in some cases, halting economic development or even reversing recent economic gains.

WWF in partnership with START SEA see a compelling need for improving current knowledge, building capacity towards adaptation management and integrating climate risk management into development strategies, to effectively build resilient systems. To start building such a system, a better understanding of the key climate stimuli and their impacts are required. Thus this short analysis of the impacts of climate change in Krabi province was undertaken.

The specific objectives of the study were to

- Develop scenarios that identify likely impacts of climate change on key economic sectors in Krabi in 10 and 25 years time;
- Suggest specific recommendations for both policy and institutional change (economic and environmental); and
- Engage local stakeholders in the assessment process.

To achieve these objectives, the study focused on climate change stimuli including temperature, rainfall, sea level rise and tropical storm scenarios, and explored their impacts on forests, biodiversity, water resources, fisheries, aquaculture, agriculture, industry, the service sector, tourism, public health and infrastructure. To ensure local engagement the study's initial findings were presented to local stakeholders to engage them in the assessment process. This local consultative process included:

- Central government representatives responsible for local and regional planning;
- Local government, especially policy makers and infrastructure planners;
- Local and regional non governmental organizations, active in the province; and
- Local communities and people especially in the involved sectors, including farmers and fishermen.

STUDY METHODOLOGY

- *Baseline Data Collection*

  Initial desktop survey and assessment were done on secondary data and relevant publications by several relevant authorities. Historical climate data indicate that the province does have two distinct climatic zones, the coastal and inland zones, where social and economic sectors are also quite different. The third zone, the urban zone, despite it being much smaller in size relative to the other two, is important for its economic and political significance and thus it is addressed as its own domain.

  Based on national and provincial development plans for the province, major economic and social sectors were identified including tourism, agriculture, aquaculture, water resources, infrastructure, and forests. The study also assessed ecosystem services on which the livelihoods of coastal communities especially depend. All these sectors are sensitive and vulnerable to changes in climate mean, climate variability and climate extremes especially the monsoon and tropical storm driven rainfall, temperature and wind strength.

- *Systems and Sectors in the Assessment*

Zone	Principle Climate Change Impacts	Key Sectors
Coastal zone	Coastal inundation, Erosion and Sedimentation, Rainfall, Wind and Storm effects.	Water resources, Ecosystem Goods and Services, Tourism, Agri-culture, Aquaculture, Forests and Biodiversity
Inland zone	Storms, Rainfall changes, Seasonality and Temperature	Agriculture, Infrastructure, Slopes, Flooding, Forests and Biodiversity
Urban zone	Coastal inundation, Storm surge, erosion and groundwater supply,	Tourism, Infrastructure

- *GIS and mapping, data sourcing*
  States of climate vulnerable systems and sectors in Krabi province in the context of climate change was spatially described using data at provincial, district and local levels geo-referenced and converted to GIS at scales between 1:25,000 to 1:2,500. A variety of data sources were used including; Ministry of Natural Resource and Environment (Tsunami Project), Department of Land Development, Marine Department, Meteorological Department, Krabi Provincial Government and various published documents and maps.

- *Future Climate Scenarios*
  Climate means and variability at two future time slices represented by years 2020 and 2035 were derived. Monsoon driven climates were projected by the downscaled ECHAM4 GCM at ~22 km resolution. Tropical storms magnitudes and frequencies were estimated by extrapolation of historic and current trends. Future mean sea level was projected from IPCC global sea level rise scenario plus local/seasonal drivers of sea level, especially the prevailing monsoon wind speed and direction.

- *Field Verification and Stakeholder Surveys*
  A field survey to the Province by the research team was conducted on 8-11 May 2008. Coastal terrain and sub-tidal bathymetric slope derived from the model were verified and ground-truthed. Selected stakeholders in each of the 3 impact assessment zones (coastal, inland and urban) were interviewed for their awareness and sensitivity to current climate and weather, and their perceptions and awareness about future climate change the potential impacts and the vulnerabilities of the stakeholders were also analyzed.

- *Provincial Workshop*
  A workshop was conducted at the Pakasai Provincial Conference Hall on 9th June 2008. The workshop was opened by the Deputy Governor of Krabi province and was attended by more than 130 participants representing national and provincial governments, local administrative organizations, business and professional associations, civic society and NGO's, community leaders, international organizations, and academics. (Figure 1) Projected impacts from future climate means and variability on various systems and sectors were presented. Groups breakout sessions for the Coastal, Inland and Urban Zones where undertaken to explore each of the identified zones in detail with local practitioners (Figures 2,3 and 4) and for each group adaptive options to reduce vulnerability were discussed. The event was also televised live nationwide by the Thailand Public Broadcasting Service (TPBS) who were interested to cover the event as this was the first time in Thailand that such an assessment had ever been conducted at the provincial level, actively engaging local stakeholders in the assessment process.

Figure 1. The stakeholder consultation workshop was conducted at the provincial conference hall on 9th June 2008

Figure 2. Sectoral break-outs for discussion and feedback on the project findings; Group 1: coastal zone.

Overall this workshop was a great success highlighted by energetic discussion and the numerous citing of examples where people had experienced climate change impacts first hand. One account of note was a group of villagers who had travelled from Koh Lanta Island who requested assistance from the local government to compensate the loss of land due to coastal erosion, one of the villagers reported that 1.5 meters of land had been lost in the previous twelve month period.

In addition, to listening to local peoples experiences follow up steps were also discussed. Several national and internal agencies, such as Office of Natural Resources and Environment Policy and Planning (ONEPP), the Ministry of Natural Resources and Environment, and the United National Development Programme (UNDP) Thailand office expressed interest to support additional studies at national and provincial levels.

Figure 3. Sectoral break-outs for discussion and feedback on the project findings; Group 2: urban centres and tourism.

Figure 4. Sectoral break-outs for discussion and feedback on the project findings; Group 2: inland system and agriculture.

STUDY TEAM

Anond Snidvongs	Project design and supervision, overall data analysis and reporting
Tosapon Ketwut	GIS, data coordination and data management
Kulpitar Phruksawan	GIS and data processing
Wirote Laongmanee	Data analysis (inland zone), reporting
Suppakorn Chinavanno	Data analysis (urban zone), reporting
Jariaya Thitiwate	Project coordination, reporting
Chanchai Yangdee	Stakeholder coordination (community and civic society)
Jennara Tuatikulchai	Stakeholder coordination (government and business sectors)
Suratta Boonsomboonsakul	Field survey team leader
Chalermrat Sangmanee	Climate scenario and climate data processing

2. Krabi Province the current situation

GEOGRAPHIC SETTING AND POPULATION

Krabi Province is located on the western part of the Thai-Malay Peninsular at the uppermost part of the Strait of Malacca, opposite the Indonesian island of Sumatra. It is bounded to the north, by Phang Nga Province to the south by Trang Province and on the east by Nakorn Sri Thammarat Province (Figure 5)

The Province has a total area of 4,710 sq. km. and is divided into 8 administrative districts, 51 Tambons (Sub-districts) and 389 villages that are home to a total of 127,540 households (Figure 6). There are also one town-level municipality and 9 Tambon-level municipalities. The total population of the Province in 2007 was 410,634 where 202,048 were men and 204,586 were women. Some statistical details for each district are given in Table 1.

	District	Area (Sq. Km.)	Households	Total Population	Men	Women
1	Muang	649	36,616	98,569	48,557	50,012
2	Koh Lanta	340	8,292	28,856	14,623	14,233
3	Khao Phnom	789	13,967	48,270	24,362	23,908
4	Klong Thom	1,043	19,843	69,175	35,049	34,126
5	Ao Luek	773	15,466	52,197	26,189	26,008
6	Plai Phraya	433	10,143	36,197	18,327	17,870
7	Lamthab	321	6,619	21,033	10,680	10,353
8	Nua Klong	362	16,594	56,337	28,261	28,076
	Total	**4,710**	**127,540**	**410,634**	**206,048**	**204,586**

Table 1: Area, households and population by district

Population is most dense in the coastal area in Nua Klong and Krabi city districts both with population densities above 150 people per km^2, the least densely populated area is the inland mountains district of Khao Phnom at 61 persons/km^2. Buddhism is the most observed religion in the district (66%) followed by Muslim (33%). Other religions such as Christianity comprise of about 1% of the total population. Agriculture and tourism are the main occupations of the population.

The total GDP of the province in 2007 was 39,028 million Baht (1,151 million USD), almost equally split between agriculture and non-agriculture sectors. The average per capita income was 95,135 Baht per year (2,806 USD), which was among one of the highest in the country (after Bangkok). The wealth of the province comes from a strong tourism sector, supported by strong agricultural production with Rubber and Palm Oil dominant, supplemented by aquaculture, local industry and other agriculture.

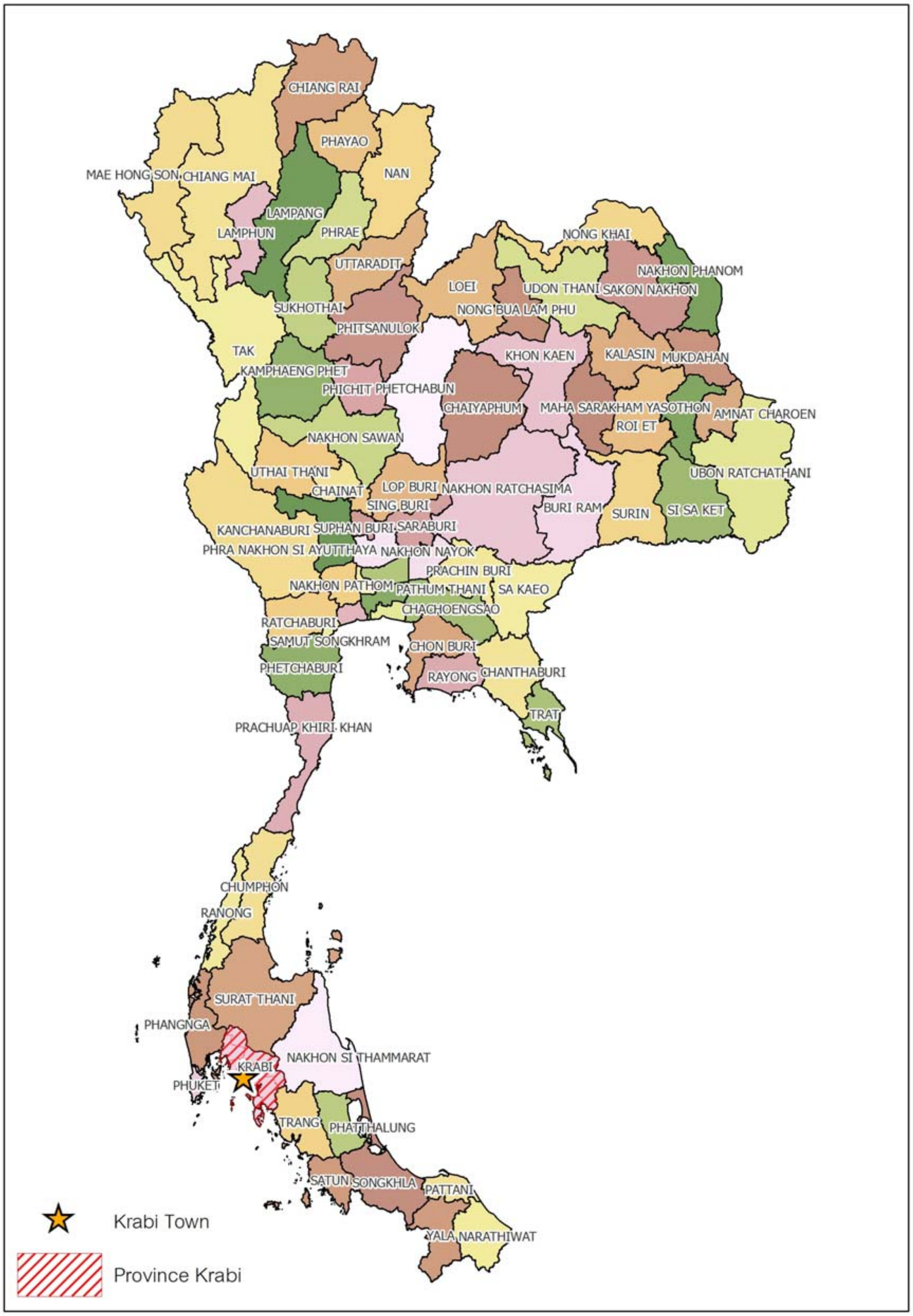


Figure 5 Location map of Krabi Province in Thailand (red hash)

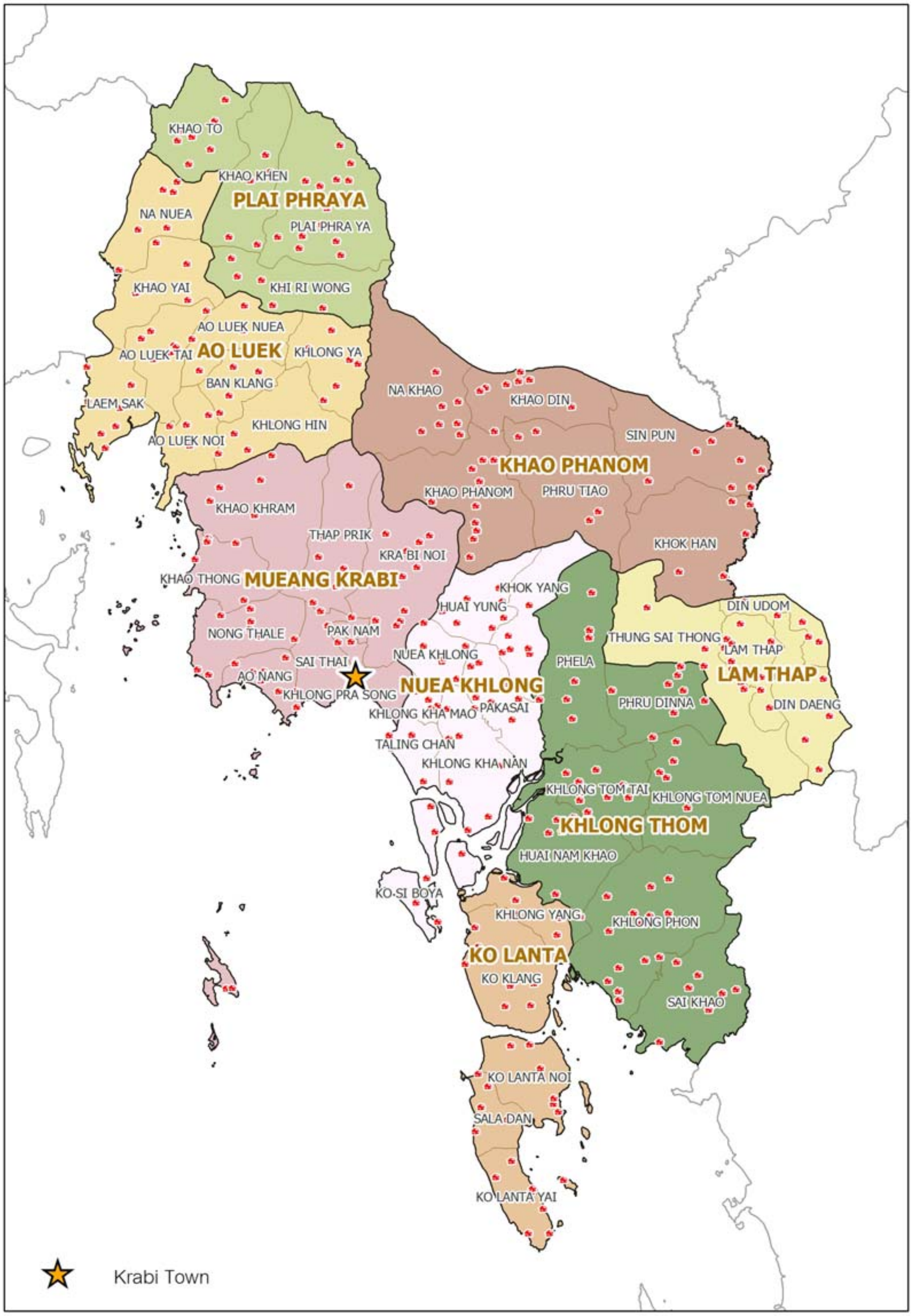


Figure 6 Administrative boundaries of Krabi province by districts (main colours), sub-districts (black lines) and villages (red dots)

BIODIVERSITY AND CONSERVATION PRIORITIES

Terrestrial Forest Ecosystems

Due to the high annual rainfall the dominant forest type in the province is tropical evergreen rainforest, in lowland and montane areas. The majority of the lowland evergreen forest in Thailand has been lost with the most significant patch of lowland rainforest remaining in Thailand, in Krabi province at Khao Nor Chu Chi in Khao Phra-Bang Khram Wildlife Sanctuary. Montane evergreen forest still remains in several locations along with three other forests types including, scrub forest, beach forest and mangrove forest. Many of the forests areas have been degraded or converted for other uses (Figure 7). In 1972 when the national forest reserves were first declared there were 1,415,952 rai[4] (226,552 ha) of forests in the province. From the latest inventory in 2003, 855,325 rai (136,852 ha) remained. Approximately 24% of the provincial area remains covered with forest. Most of these forest areas are under some form of government conservation management schemes (Figure 7), which are:

- Four national parks: Khao Phnom Benja, Than Boke Korranee, Koh Lanta and Had Nopprat Thara-Mu Koh Phi Phi with a total area of 422,512 rai (67,602 ha);
- Two wildlife sanctuaries: Klong Phraya and Khao Phra-Bang Khram with a total area of 235,676 rai (37,708 ha);
- One non-hunting area, Thung Thale with an area of 3,066 rai (491 ha);
- 58 plots of National Reserved Forest cover 2,046,816 rai (327,491 Ha) but without any formal management or protection these areas have been heavily encroached; and
- 226,225 rai (36,196 ha) were declared as the National Mangrove Forest under the jurisdiction of Department of Marine and Coastal Resources.

Coastal Forest Ecosystems

Krabi's coastal forest ecosystems include biologically and economically important mangrove forests and beach forests. About 218,250 rai (34,920 Ha) of mangrove forest remain in the province. One key site is the area around the Krabi River estuary, which is recognized as a Ramsar Site of International Importance (Figure 8). This Ramsar Site covers 10,200 rai (1,630 ha) of mangrove and 5,812 rai (930 ha) of mud flats. The mangrove area in this Ramsar Site accounts for about 5% of the total mangrove area in Thailand and is densely populated by plants and animals including at least 50 species of economically important fishes. It also provides critical habitat for 107 species of migratory birds and 137 resident bird species.

Marine Ecosystems

Coral reefs encompass about 13.5 sq. km. around the islands in Nopparat Tara-Mu Koh Phi Phi and Koh Lanta National Parks. These reefs are important both for their high biodiversity and because of their high value for tourism. The key coral reefs of the Province were mapped and are illustrated in Figure 9.

Seagrass beds can be found in many sub-tidal areas of Muang and Nua Klong districts and serve as important feeding grounds for dugongs, dolphins and sea turtles as well as nursing grounds for many other marine invertebrates and fishes. The key seagrass beds are also illustrated in Figure 9. Many of the seagrass beds are under threat from destructive fishing practices, dredging and land reclamation, and deteriorating water quality especially from suspended sediments caused by land based erosion and agricultural chemical runoff.

Species of Special Concern for Conservation

Several endemic, endangered, and rare species inhabit Krabi province. The Gurney's Pitta (*Pitta gurneyi*), also known as the Black Belly Pitta, is an endemic to the Andaman Ecoregion, and in

[4] rai is a traditional land measurement unit 1 rai = 0.16 hectares

Thailand is only found at Khao Phra-Bang Khram Wildlife Sanctuary (Figure 8). The bird was previously thought to be extinct until it was rediscovered along with several other rare and endangered lowland evergreen forest species in the early 1990's. Recently, it has been recorded in southern Myanmar. Other rare and endangered species found in the province include several marine species including; dugongs, several toothed whales, dolphins and porpoises, and three species of marine turtles (Hawksbill, Olive Ridley, and Green Turtle).

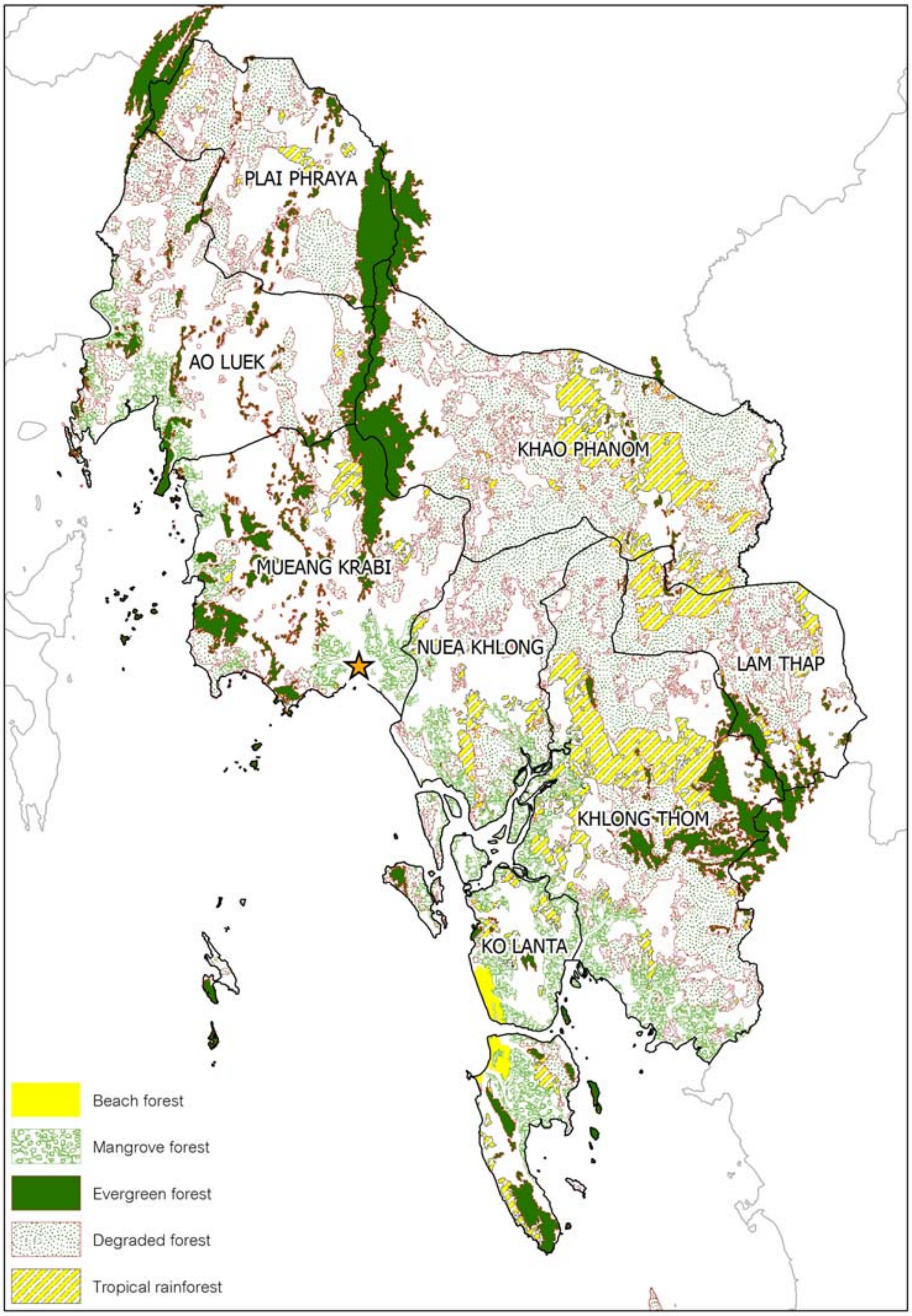


Figure 7 Forest cover by main types; Beach forest (yellow), Mangrove forest (Green dapple), Evergreen forest (dark green), degraded forest (speckled) and tropical rainforest (hashed).

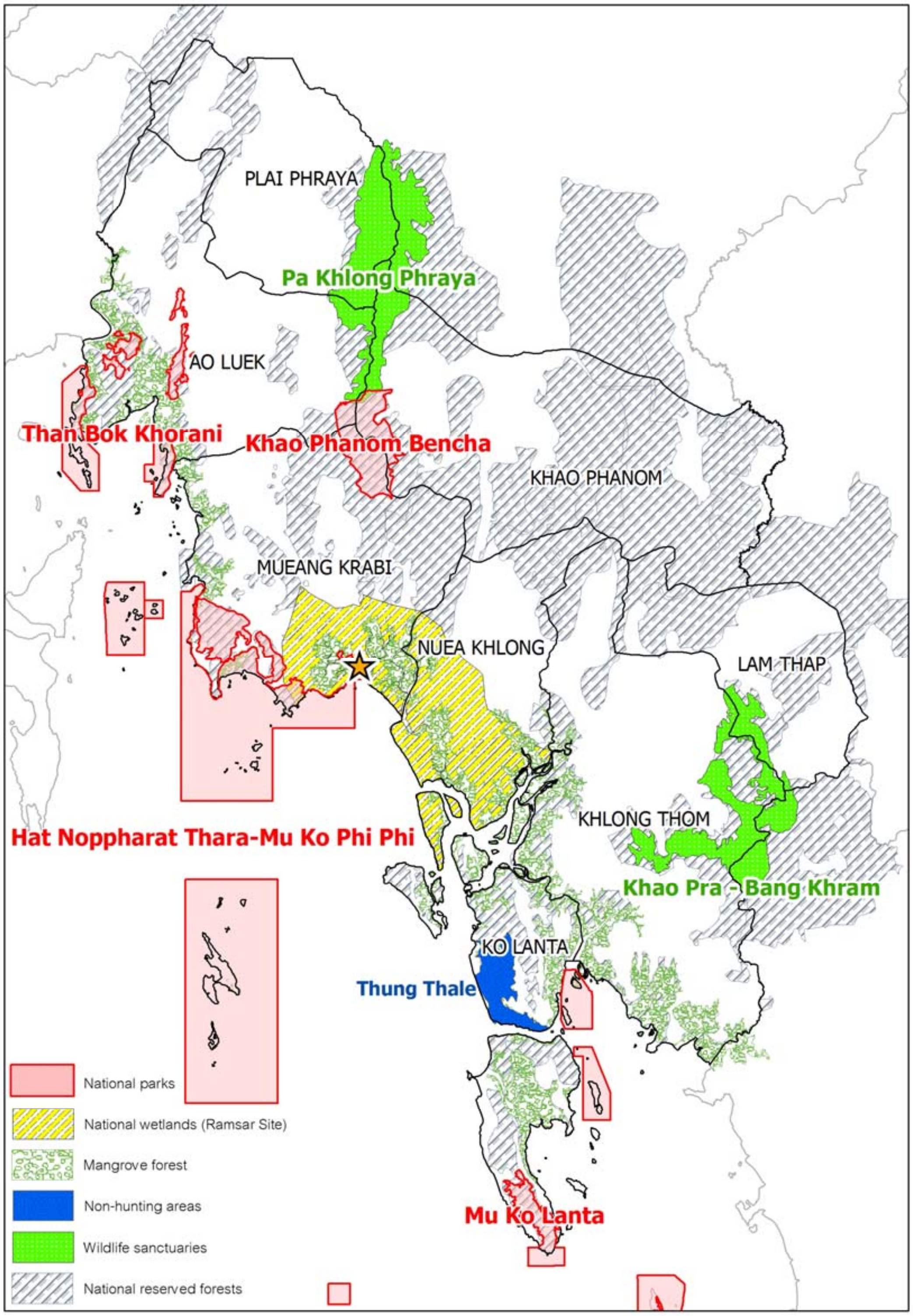


Figure 8 Forest conservation and management areas by jurisdiction; national parks (red), non-hunting areas (blue), wildlife sanctuaries (green), national wetlands (dappled green) and national reserved forests (hatched blue)

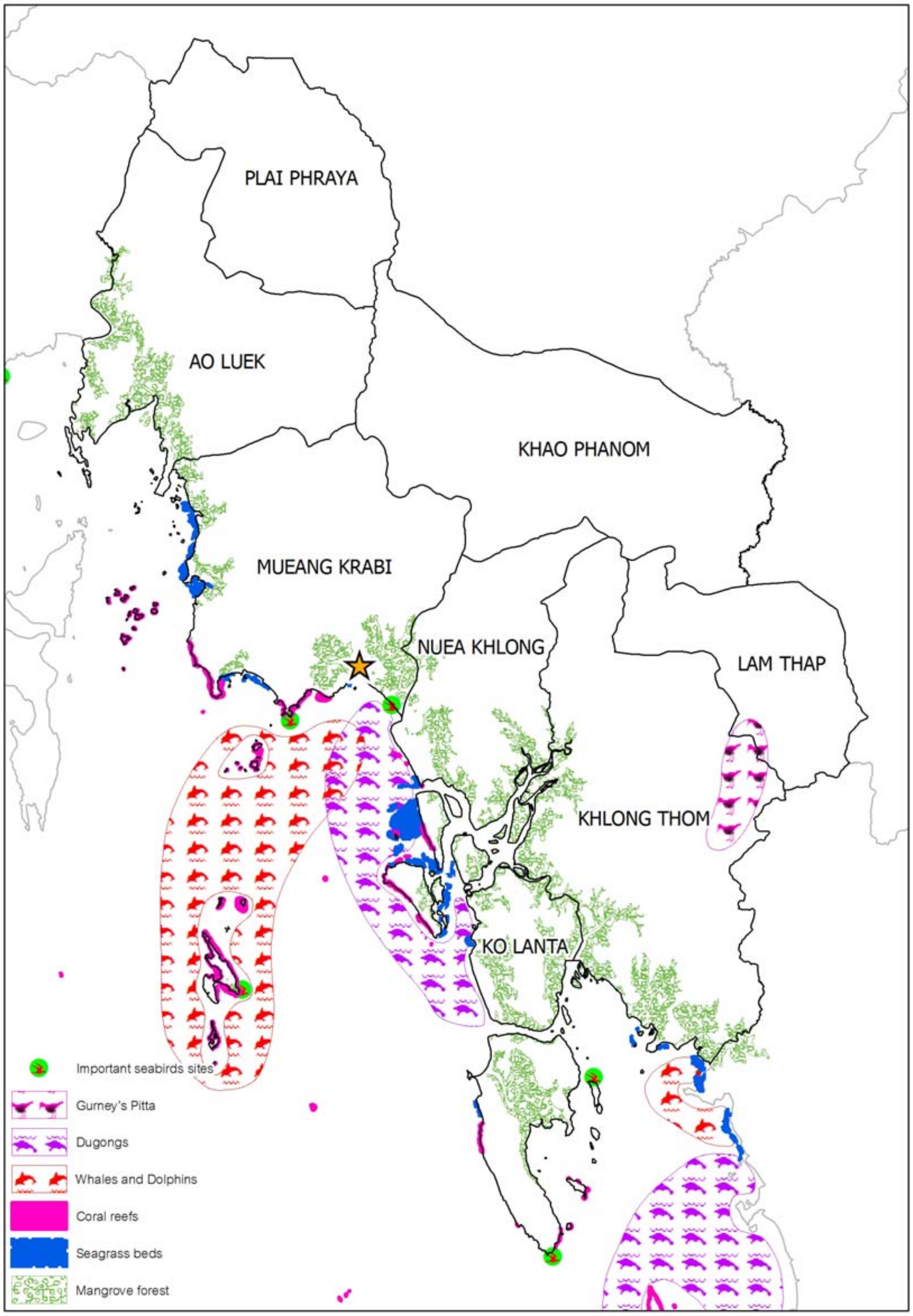


Figure 9 Important biological sites in the province, Whales and Dolphins (red), Dugongs (purple), coral reefs (pink), seagrass beds (blue) and mangrove forest (dappled green) and important seabirds sites (green dots)

KEY ECONOMIC AND SOCIAL SECTORS

Water Resources

Krabi province receives most of its freshwater supply from monsoon rainfall that is collected in the province. The monsoon season spans from April to November. The average rainfall of the whole province is about 1,900 mm per year with the mountainous inland receiving more rain (on average between 1,800 – 2,500 mm per year) than coastal areas (on average less than 1,500 mm per year). The majority of this fresh water originates in the mountainous watershed forests. This rainfall either flows down to the sea as surface water or enters the ground water system. The surface water is drained through streams, rivers and canals (Figure 10). Most waterways flow westward toward the Andaman Sea, such as Krabi River, Sin Poon Canal, Krabi Yai Canal, Krabi Noi Canal, Klong Thom Canal, and Pakasai Canal.

The groundwater resources of the province are classified by aquifer geology into 3 types:

1. Unconsolidated aquifers mostly in the lowland and coastal areas where water quality is generally fair except during the dry season when coastal aquifers may become contaminated by seawater intrusion;
2. Semi-consolidated aquifers associated with sediment filled cracks and fault zones in Muang, Ao Luek and Khao Phnom Districts; and,
3. Consolidated or confined aquifers found in deep rock layers in Lan Thap, Klong Thom, Khao Phnom and Ao Luek Districts. This class produces good to fair quality water although in some areas they can be high in alkalinity and iron content.

The rainwater the province receives is in a range between 7,500 to 11,000 Million Cubic Meters (MCM) per year. Additional supply of water is via condensation in cloud forests usually found at elevation above 1,000 m. About one half of all the water gained is lost via instantaneous runoff and natural evapotranspiration. Only about 3,500 to 5,500 MCM per year remain as useable water. All manmade reservoirs combined currently have the total capacity of less than 200 MCM and the remainder of the water of the province is stored and slowly released by natural storages in the watersheds, for examples as soil moisture and as recharge into underground aquifers. Deforestation and land use conversions for agriculture in the upper watershed are seriously threatening these natural water sources and stores that may not be fully replaced by additional manmade reservoirs.

On the demand side, the existing rubber and oil palm plantations in the province each consume about 200 MCM of water in total annually through plant evapotranspiration. This is by far the dominant use of water in the province. Domestic use in the major urban centres served by piped water supply consumes about 10 MCM per year. Among this is about 2 MCM to supply the tourism sector while the remaining demand of the tourism sectors especially in the coastal areas is met by groundwater extraction. The rural population of the province, despite being three times the size of the urban population, consumes only about 6 MCM annually.

It is estimated that freshwater needed to maintain brackish water ecosystem goods and services in mangrove and estuaries of Krabi province (e.g., water purification, nursing grounds for fish, molluscs, and crustaceans, and seaweed – a food source) as well as to maintain the freshwater saltwater balance in the coastal aquifers would be about 3,000 MCM per year (based on an assumed requirement of 1 m^3 per km shoreline per second). Therefore in some dry years, when average rainfall fell below 1,600 mm per year, the incoming water of less than 7,500 MCM per year would barely cover the natural losses and consumption inland and thus in these low rainfall years coastal ecosystems and aquifers would be affected by salinity. Small coastal communities and households are most affected as they are not served by piped water supply and because their livelihoods are in many ways dependent on natural products from mangrove and estuaries.

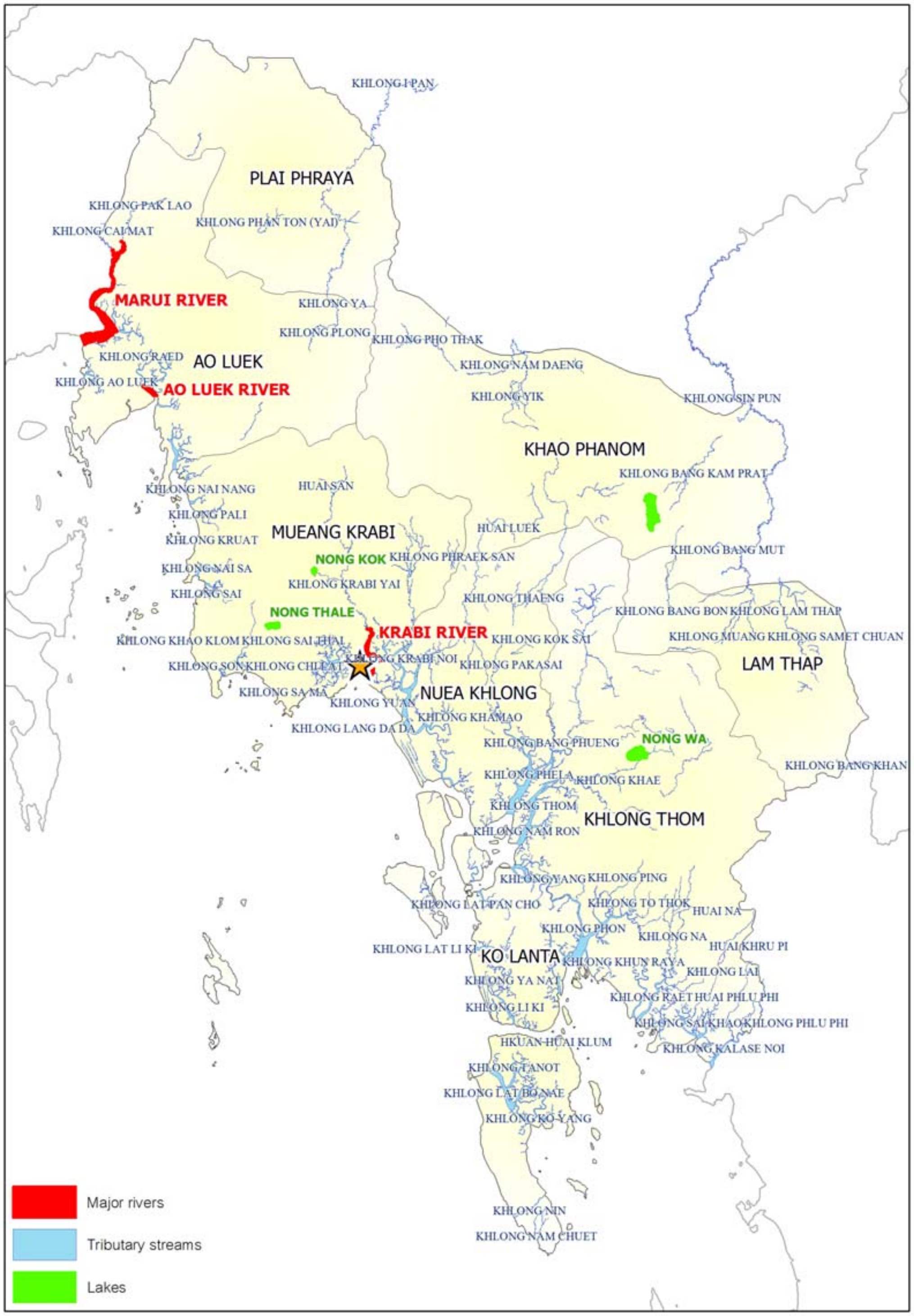


Figure 10 Water drainage network, major rivers (red), tributary streams (blue) and lakes (green)

The quality of surface water in the province has so far been acceptable for domestic use. However, with expansion of various economic sectors and possible reduced water flow from upstream watersheds, water quality could become more vulnerable in the future. Currently only Krabi City Municipality has systematic treatment capacity that is sufficient to treat most of the wastewater produced. Most other towns and urban centres in the provinces do not have enough treatment facilities and most of their wastewater and sewers are released without any treatments except the simple septic system.

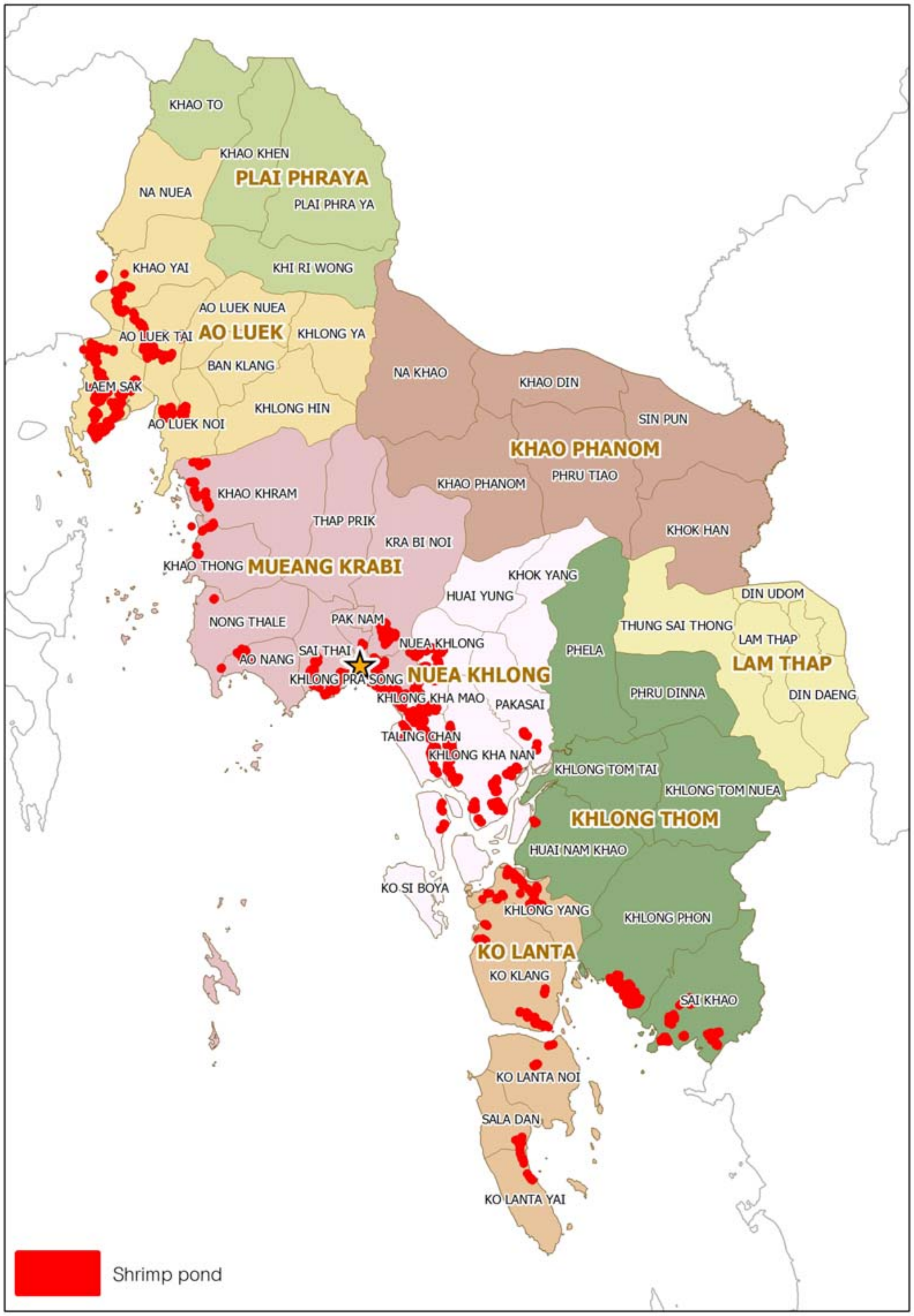


Figure 11: Shrimp pond distribution (red)

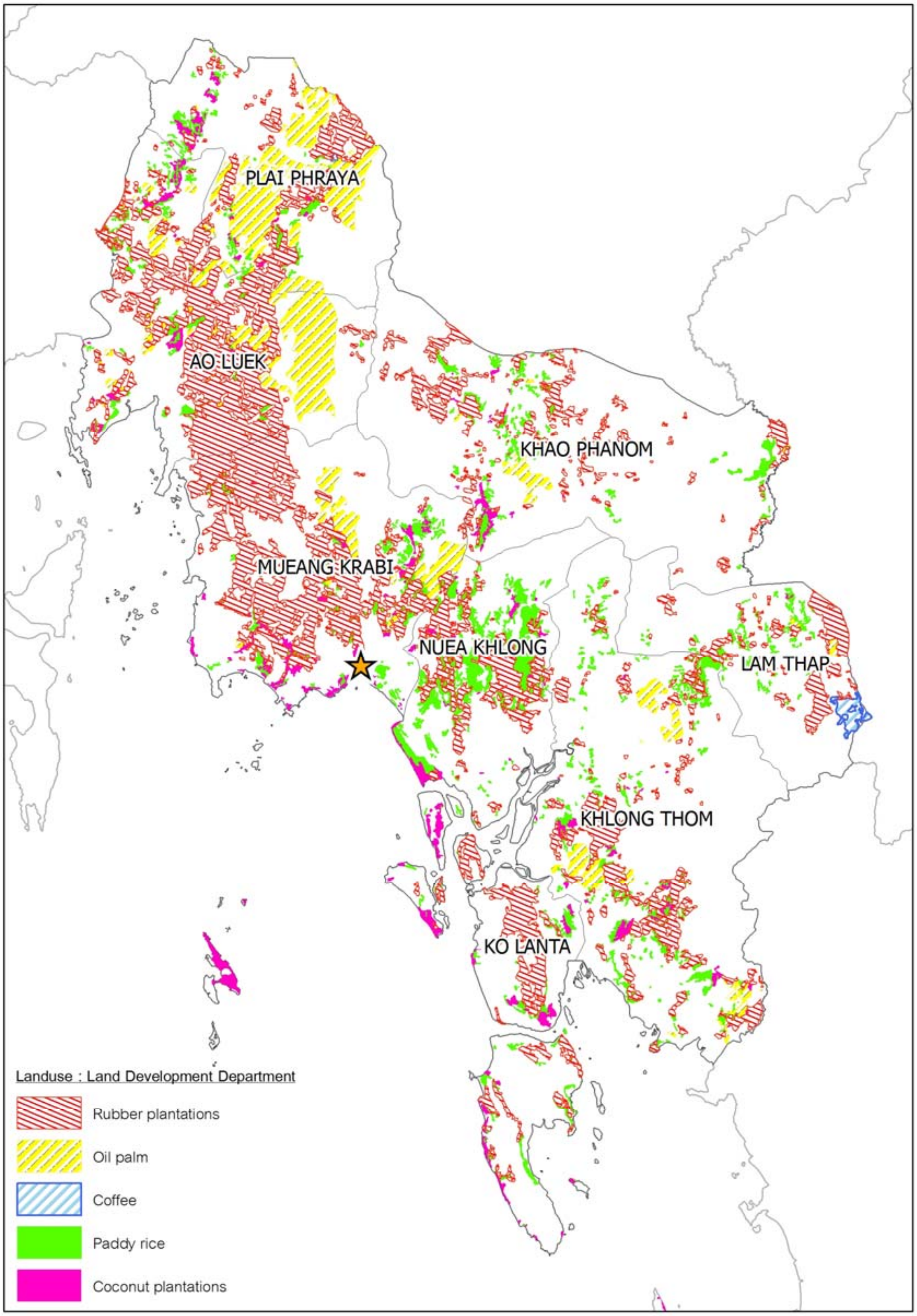


Figure 12: Agricultural land use in Krabi province, rubber plantations (hatched red), oil palm (hatched yellow), coffee (hatched blue), paddy rice (green) and coconut plantations (pink)

Fisheries and Aquaculture

There were 4,979 subsistent fishing households recorded by the Provincial Fishery Office in 2006. In addition, 17 commercial fishing operators are based in Krabi, which is the lowest number among all the 6 provinces along the Andaman coast, an indication that large scale fishery may not be a major economic sector of the province. The total landing of marine fishery products in 2005 was 17,893 tons, which was only a small fraction of the national marine fishery production. However fishery remains to be a main source of income and social livelihood for most coastal communities in the province that use small boats operated near shore and rely on family members as the labour force.

In Krabi province there are 800 shrimp farms which operate a total of 2,478 ponds with a total area of 9,458 rai (1,513 ha) (Figure 11). These ponds produce about 20,000 tons of shrimp annually which is about 5% of the total national shrimp production. In addition, there are also 643 brackish water and 1,064 freshwater aquaculture farms, which produce about 843 and 151 tons of products annually. Major aquaculture products are groupers and sea bass that mostly serve local consumption and supply local tourism seafood demands.

Agriculture

Rubber is the main cash crop of the province with the planting area of 915,152 rai (146,424 ha) or 49.4% of the total agricultural land of the province. Oil palm is now the second largest crop with a planting area of 848,416 rai (135,746 ha) or 45.8% of the total agricultural land of the province. Expectations are that Oil Palm will surpass rubber in the near future due to national and provincial policies to promote biofuel production. Other crops of the province include coconut, fruit trees, coffee, and paddy rice which account for the remaining 4.8% of the agriculture area of the province (Figure 12).

In 2007 rubber and palm oil yields of the province were about 270 and 2,100 kg per rai respectively. These made the annual production of province for rubber to be 247,834 tons with the value of 16,523 million Baht (487 million USD) while the total production of palm oil was 1,750,629 tons with the value of 4,744 million Baht (140 million USD). Production of these two major cash crops for the province is highly dependent on weather conditions and their yields in 2007 were less than those in 2006 due to lower rainfall that year (Krabi Province Development Plan 2008-2011).

Industry, Services and Trades

Most industries in Krabi are agricultural-based such as oil palm extraction, rubber processing, and rubber wood industry. In total there are 423 factories and the number has remained relatively stable during the recent past, while investments for new or improvement of existing factories has shown a decreasing trend over the last few years.

Service sector, especially tourism, has grown significantly (Table 2). Since 2002 the number of hotels and other registered tourism operators has almost doubled. The number of visitors and total spending has also been increasing annually, except in 2005 when the number of tourists dropped by about 40% due to the after effects of the Tsunami on visitor numbers, but tourist arrivals have been steadily recovering year on years since 2006. Major factors contribute to Krabi's tourism appeal including; its coastal location on the Andaman Sea, proximity to the established tourism centre of Phuket and the construction of an international standard airport which opened on the 10th July 1999.

Year	Hotels and Other Tourism Operators	Visitors	Income (Million Baht)
2002	290	1,458,771	15,593
2003	290	1,623,217	17,466
2004	333	1,796,591	19,325
2005	436	1,027,072	14,787
2006	459	1,732,951	19,819

Table 2: Annual tourist arrivals since 2002

Tourism resources of the province are concentrated into 6 clusters (Figure 13):

1. Koh Lanta and its vicinity which focuses on marine tourism and sea gypsy culture
2. Ao Nang and its vicinity which is the main tourism destination of the province
3. Tha Lane Bay and Ao Luek which link to neighbouring Koh Yao and Phang Nga Bay in Phang Nga province, these are well-known for home stay and community based tourism.
4. Health and natural spa tourism based around the hot spring and geothermal resources in the interior of the province around the Khao Phra Bang Khram Non Hunting Area.
5. Eco and agricultural tourism focused on inland areas of the province
6. Phi Phi Islands as a well established and currently exceeding capacity tropical island tourism destination.

Public Health and Wellbeing

The province is reasonably well served by government and private hospitals, health centres and clinics (Figure 14). The ratio between a qualified doctors and the resident population is about 1:7,000. Newborn birth rate in 2006 was 1.76% and death rate was 0.48%. Top three major causes of death were old age, cancer and traffic accidents.

The major causes of non-lethal disease in 2006 were pulmonary diseases (180,489 cases), gastrointestinal diseases (101,892 cases) and blood and vascular diseases (82,772 cases). Diseases that are monitored on a special watch list of the Provincial Public Health Office were acute diarrhoea, pneumonia, chicken pox, venereal diseases, food poisoning, dengue, poisonous snakebites, malaria, and tuberculosis. Among these dengue and malaria are known to be linked to climate variability.

Only 2-3 dengue cases were reported each year in 2005- 2007 while malaria cases were about 130-500 over the same period. Most dengue cases on the one hand were found in the coastal urban zone than in inland mountainous districts and most of the cases were reported during the rainy season. Malaria cases, on the other hand, were reported more from the inland districts than in the coastal zone (Figure 15). Although the situation for these two diseases so far was not very serious in terms of fatalities, elsewhere these diseases had been reported to be linked to climate phenomena such as El Nino, and therefore should be monitored in respect to climate change.

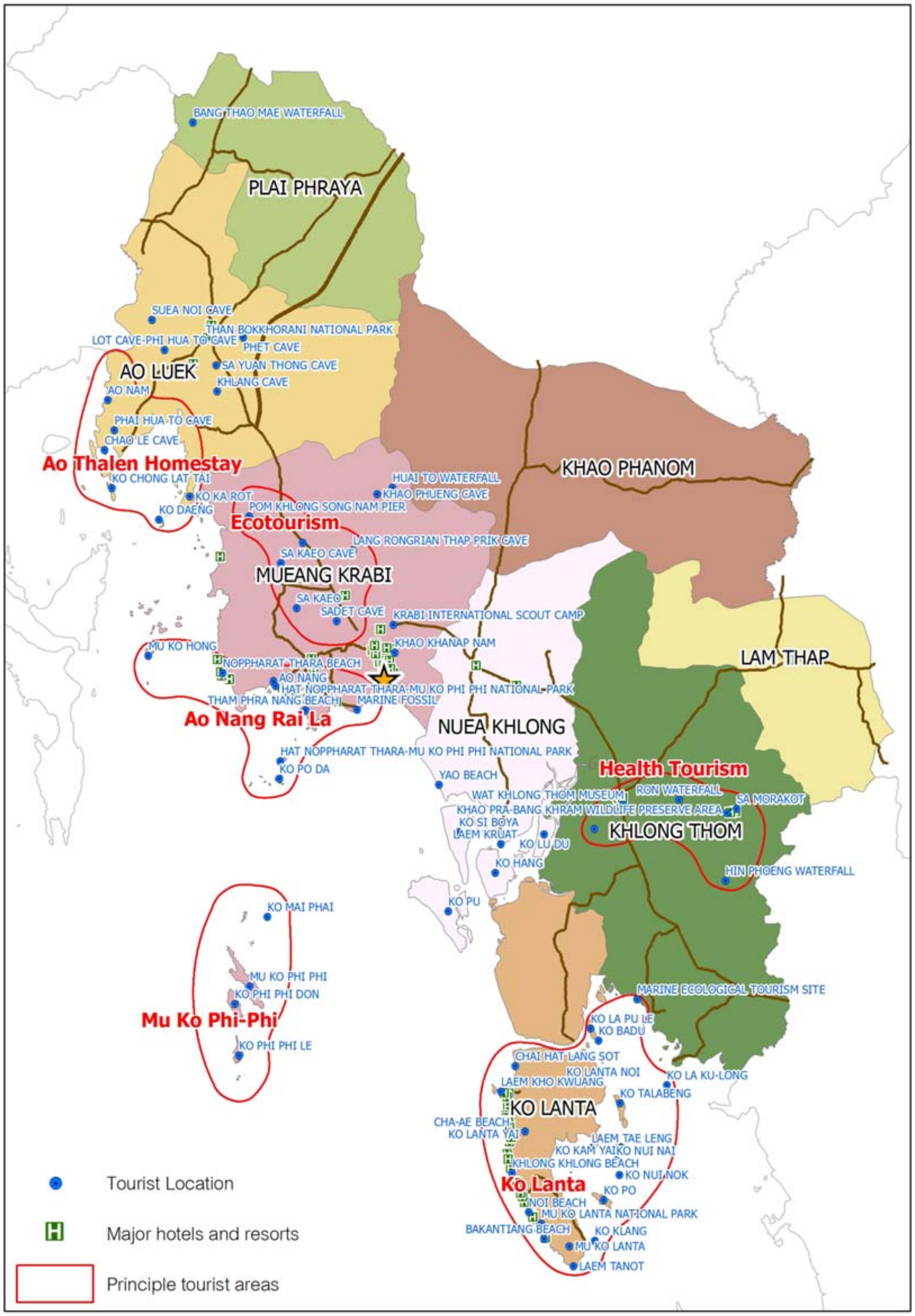


Figure 13: Major tourist areas in Krabi province with tourist centre marked (blue dot), major hotels and resorts (green H) and principle tourist areas (red).

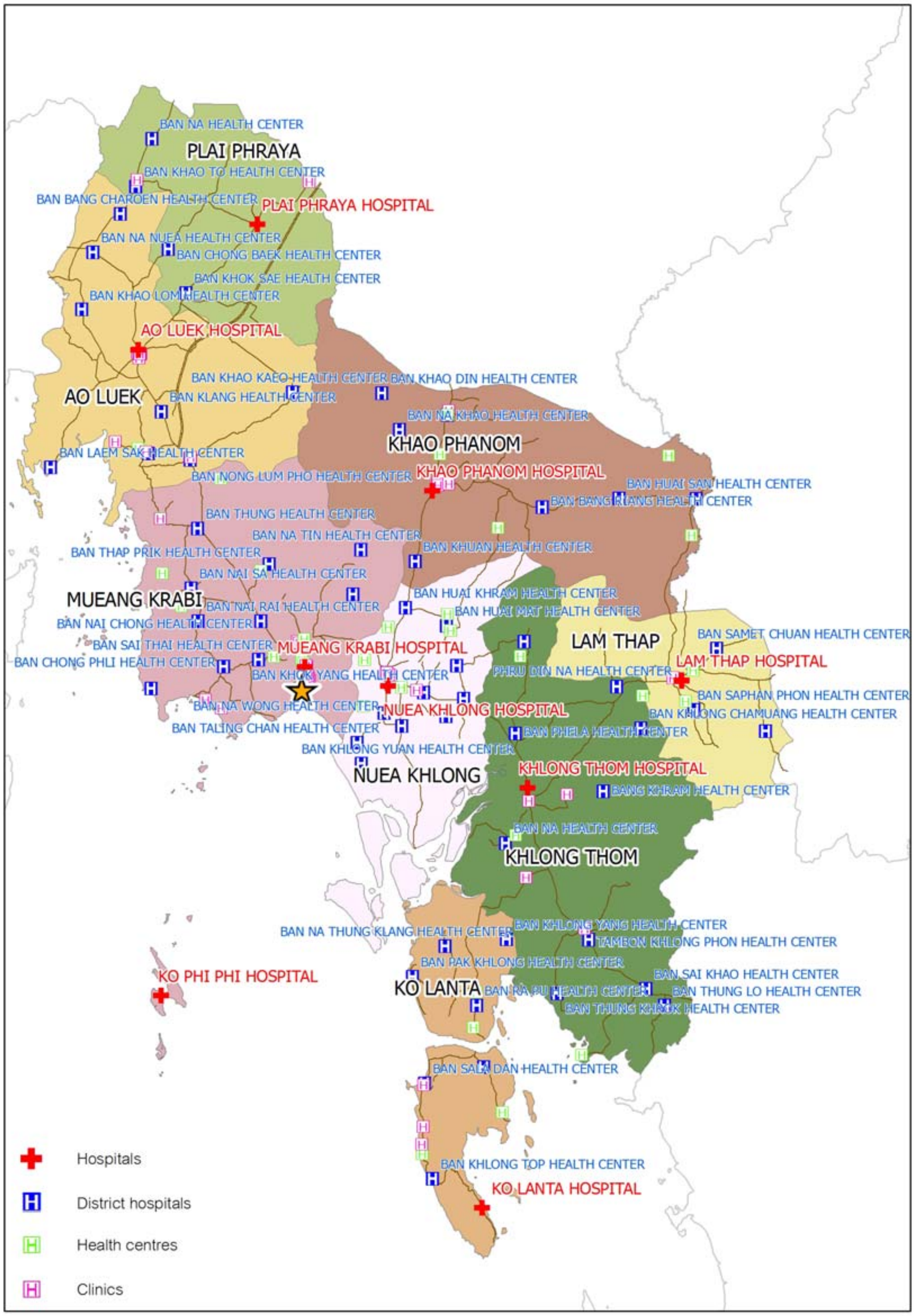


Figure 14: Public health network; hospitals (red cross), district hospitals (blue), health centres (green) and clinics (pink).

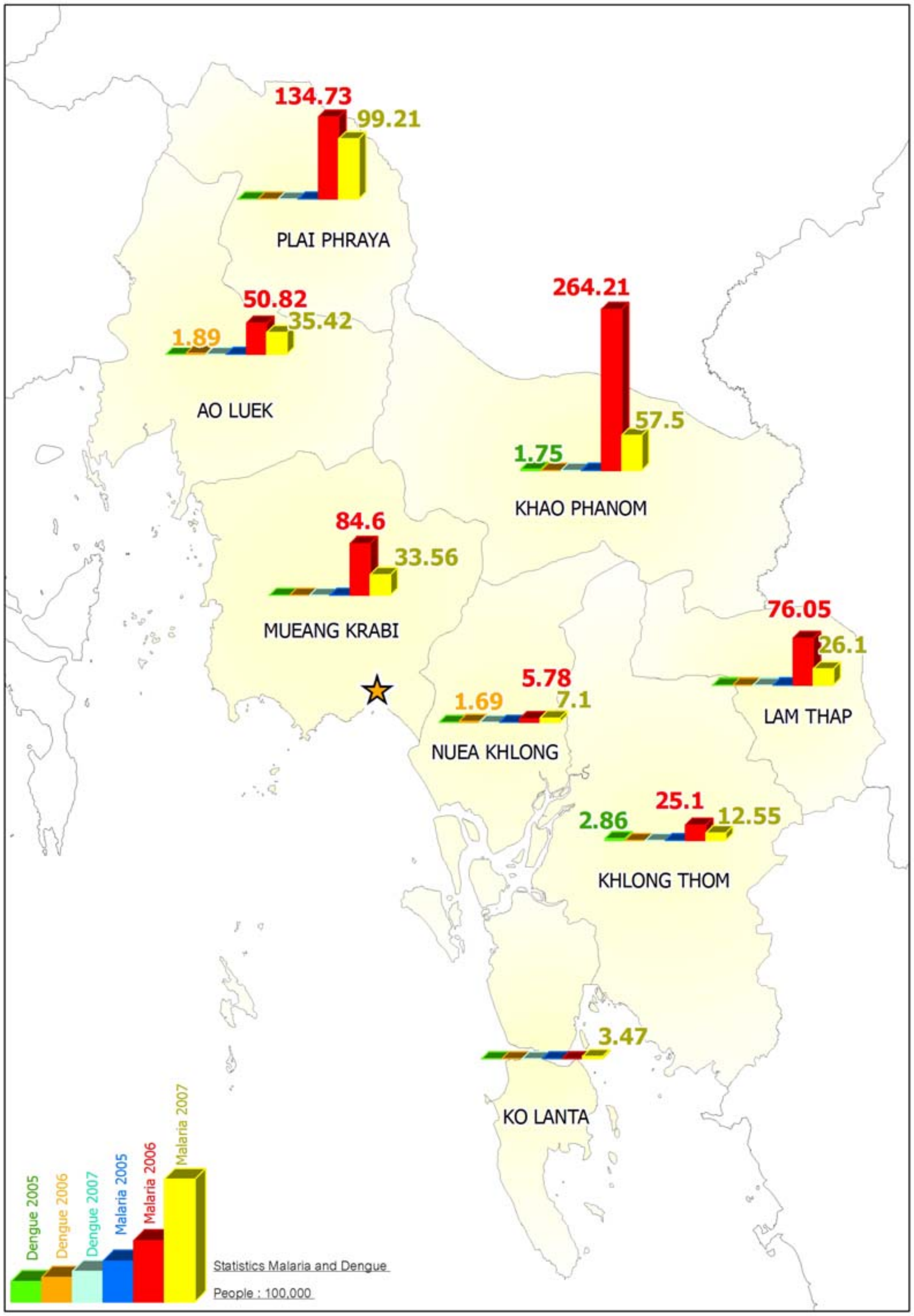


Figure 15: Combined Dengue and Malaria cases for each district for the years, 2003(green), 2004 (orange), 2005 light blue), 2006 (red) and 2007 (yellow).

Public Infrastructures

For transportation there are a total of 3,523 km of road in the province. Among these 122 km are primary road 933 km are secondary road and the rest is the local unpaved road (Figure 16).

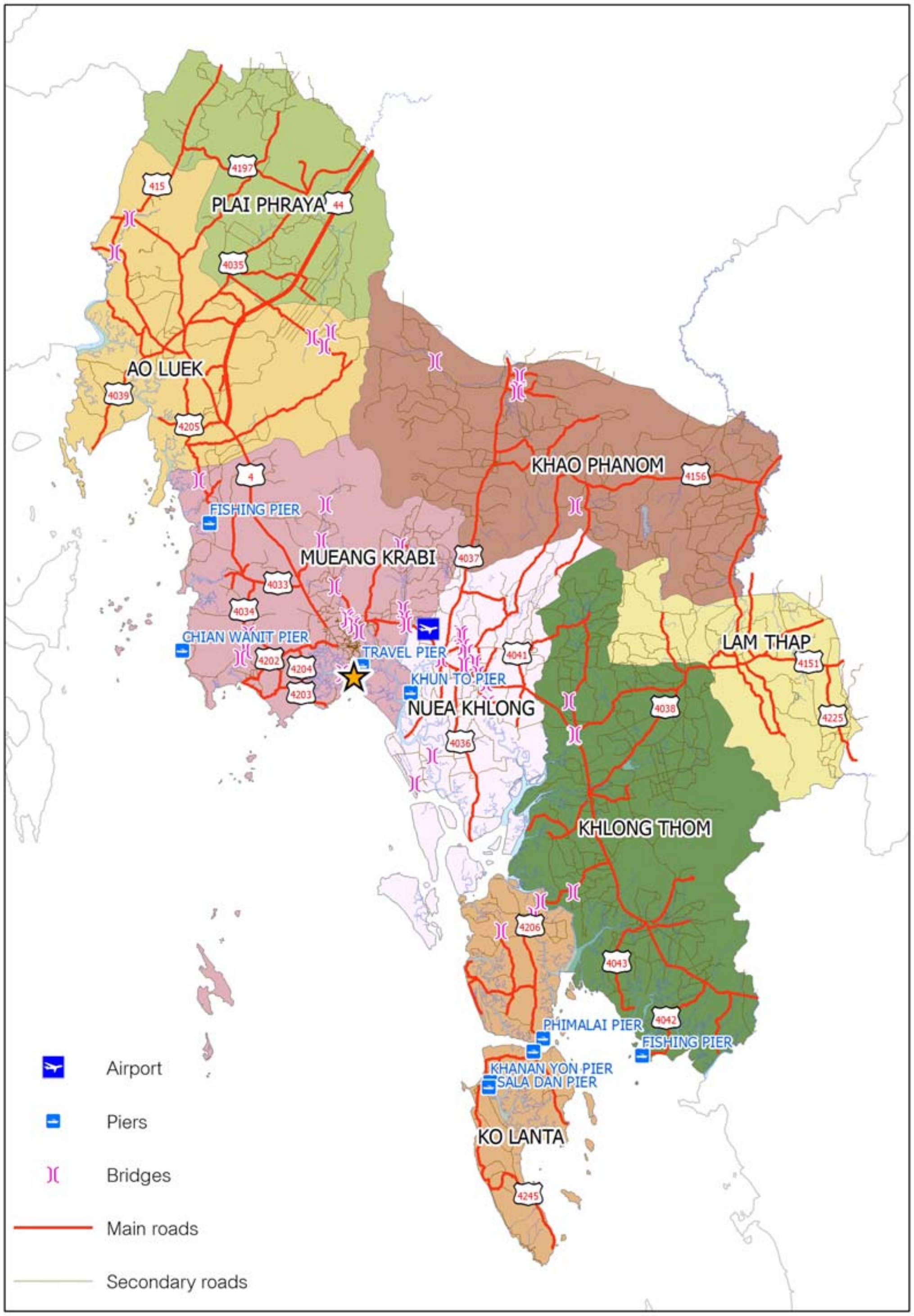


Figure 16: Public transportation network, indicating the airport, piers, bridges, main roads and secondary roads

Primary road principally being double lane highway with tarmac surface, secondary roads are usually single lane roads, also of tarmac or cement construction. In addition there about 46 major bridges. Some of the roads and bridges are located in the zones prone to physical catastrophes such as storm/tsunami surges, landslides and flash floods. Sea transport is served by one deep-sea port in Klong Jilad, Muang District and numerous small, medium and large piers distributed along the coast and on the islands. The province has one airport that caters for both domestic and international flights. In March 2008 there were 73 domestic and 15 International flights per week. (Table 3)

	Destination	Airline	Flights per week
Domestic	Bangkok	Thai airways	21
		Air Asia	21
		One to Go	7
		Nok Air	14
	Samui	Bangkok Airways	10
		Total	**73**
International	Singapore	Tiger Airways	5
	Kuala Lumpur	Air Asia	4
	Sweden	Mytravel	2
		Novair	2
		Tuifly	1
	Finland	Finnair	1
		Total	**15**

Table 3: Domestic and International flights operating from Krabi Airport in March 2008.

The province has one electricity generating plant in Nua Klong District that equips with two 300,000 kW generators that are able to use multiple sources of fuels including lignite, oil and natural gas. The province is also connected to the national power grid system. All villages, except nine located on sparsely populated remote islands, are connected to the national grid through the Provincial Electric Authority's 8 voltage transformation sub-stations (Figure 17).

The province is well served by both landline and cellular telephone telecommunication networks. There are about 83 transponder nodes for mobile communications in the province, mostly located along the national highway No. 4 that runs across the province from north to south (Figure 17).

PROVINCIAL DEVELOPMENT PLAN

The National Economic and Social Development Board has the mandate to produce national and regional development strategies through participatory processes that will be used as frameworks for provincial and local administrations to prioritize their activities and budget requests. The strategy for Thailand's southern region was issued in 2007 has focused Krabi for oil palm plantation and first stage palm oil processing industries as well as to be a destination for high-end tourism. In respect to these focuses, two priorities were identified for this province that need specific actions, namely access to basic education especially among the poorest groups and to reduce risk from natural hazards of landslide and flash floods.

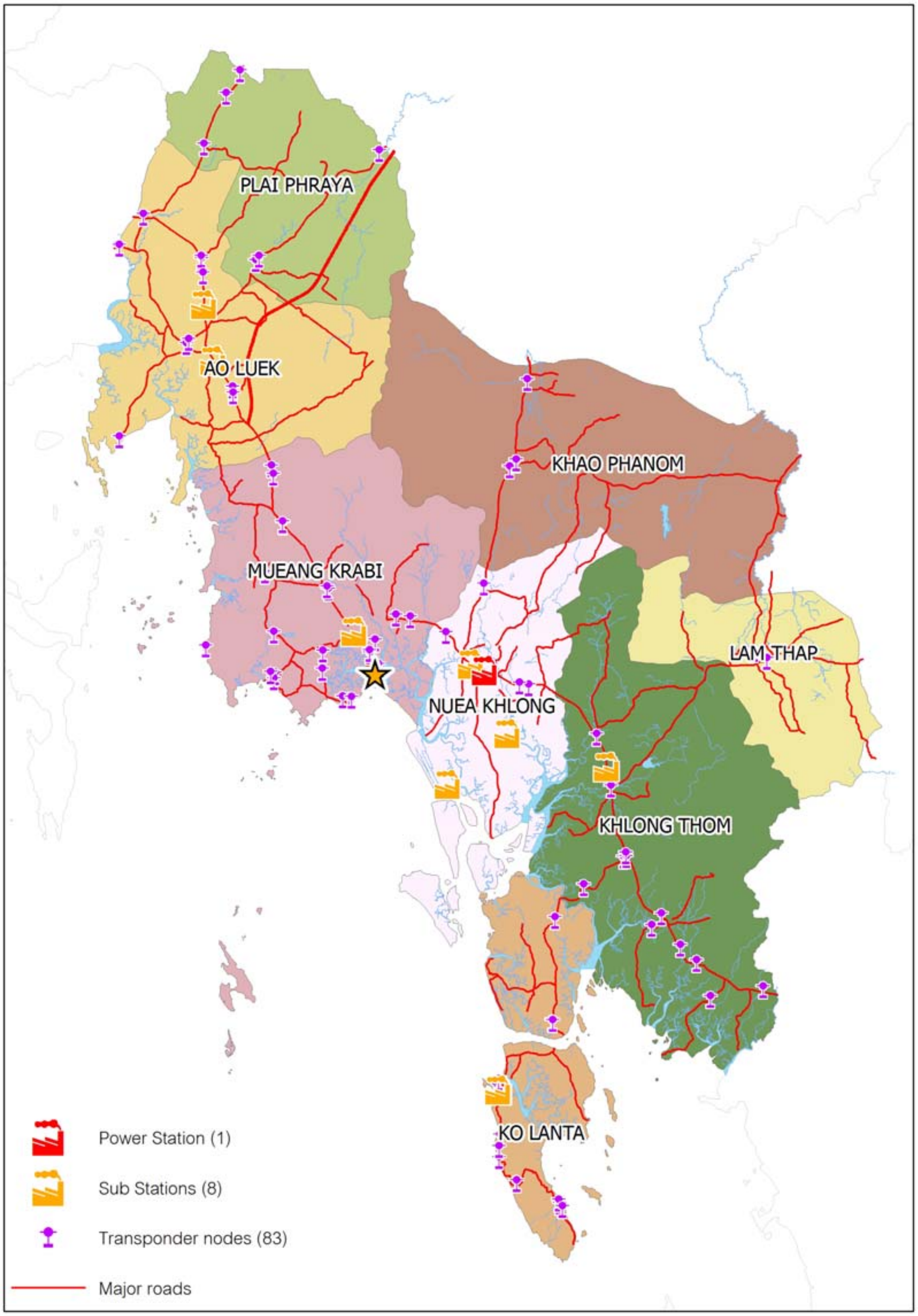


Figure 17: Public utilities and associated infrastructure networks; power station (red), sub-stations (yellow), transponder nodes (purple) with the major roads marked.

The province adopted the regional strategy and transforms it into a four year Provincial Development Plan (2008-2011) that lists all activities and projects that the province and local administrations propose to achieve including budgets and other resources required. After reviewing the plan it was obvious that climate change was not an issue or concern within the provincial development agenda. There were no specific projects for either the mitigation or adaptation of climate change impacts, and interestingly neither the words climate nor weather appear anywhere in the Development Plan. However, although climate change is not explicitly mentioned, the number of projects related to climate change adaptation or mitigation listed was actually quite high. By analysing the plan in detail it was found that among the 1,449 projects proposed in the plan, 427 (29.5%) were vulnerable to climate change (Table 4), for example some projects themselves may be sensitive or vulnerable to climate in some way, while other projects could result in the increased or decreased resilience of the target groups or location to future climate change. However it was clear that in all 427 projects the project designers had failed to mention climate change in their proposal, and thus by default, appeared to be unaware of the climate change consequences.

Issues/Sectors	Projects		Budget	
	Number	Percent Vulnerable	Million Baht	Percent Vulnerable
Natural Ecosystems				
Mangrove	23	1.6	200	1.2
Terrestrial forests	17	1.2	122	0.7
Other ecosystems (coral reef, seagrass, etc.)	6	0.4	17	0.1
Fishery and aquaculture				
All projects	25	1.7	33	0.2
Agriculture				
Oil palm	43	3.0	307	1.9
Rubber	11	0.8	44	0.3
Rice	2	0.1	2	0.0
Tourism				
	47	3.2	297	1.8
Health				
	9	0.6	8	0.0
Infrastructures				
Transportation	117	8.1	12,635	76.2
Water resource/supplies	70	4.8	360	2.2
Sufficient economy/sustainable development				
All projects	57	3.9	106	0.6
Climate related subtotal	**427**	**29.5**	**14,131**	**85.3**

Table 4: Total number of projects and allocated budget by sectors in the provincial development plan along with the proportion (percentage) vulnerable to climate change impacts.

Using the number of projects and their allocated budget as proxy indicators it is very clear that transportation infrastructure is by far the number one priority in the province (Table 4). Discussion with a number of stakeholders in the province indicated that all the infrastructure projects were planned without taking into consideration climate change factors and by default assuming that the historical climate would continue into the future.

Water resource, oil palm and tourism developments receive about the same priority judging from the budget allocated of about 300 million Baht (8.8 million USD) each over the next 5 years. On the conservation side mangrove forest receive the highest attention followed by terrestrial forests. Coral and seagrass ecosystems, which appear to be highly threatened under current development practices, are given quite low priorities.

Projects promoting self-sufficiency, the sufficient economy and sustainable development, such as to strengthen community capacity to sustain their livelihoods and ways of life while harmonizing with globalization and trade economy, get some mention in the Provincial Development Plan 2008-2011. Most actions in this category are to build capacity and raise understanding about these concepts for local communities. A number of proposals also focus on organic farming to reduce community dependency on external inputs in their agriculture.

Activities that will support the province to deal with climate change related health issues, such as dengue and malaria, however are allocated very small budgets, despite risks that these diseases could increase under climate change scenarios in the future.

3. Climate Change Scenarios

GLOBAL AND LOCAL CLIMATE CHANGE AND LINKAGES

By definition 'weather', on the one hand, is the state of the atmosphere over a short period of time and over a relatively small geographic location. 'Climate', on the other hand, is how the atmosphere 'behaves' over a long period of time and a reasonably large geographic domain. Practically 'weather' is normally described by observed or modelled meteorological variables such as rainfall, temperature, wind speed/direction, atmospheric pressure, etc. over short time periods in the range of hours to weeks, while climate is represented by detailed mathematical descriptions of weather variables over longer time periods, e.g. one to three decades, and may cover more than one 'stations' in order to get some ideas on both temporal and spatial variability. Such mathematical descriptions may be as simple as standard statistic parameters, such as means, extreme ranges, and occurrence frequencies, or could employ much more sophisticated mathematical techniques such as Principal Components or Eigenvalue Analyses for example.

Incoming solar reflection with earth surface and interactions with atmospheric greenhouse gases results in uneven and non-equilibrium distributions of heat, moisture and momentum in the atmosphere. Naturally these will be adjusted by distribution mechanisms of which many may influence local weather means and variability on a coastal province like Krabi through 3 main global-local atmospheric linkages:

1. Change in the regional scale prevailing wind driven by large scale temperature gradient between land and ocean, such as the NE and SW monsoon systems (An example of how temperature can change the wind patterns is indicated in figure 27);
2. Changing hydrological cycle due to more evaporation from water bodies as well as more evapotranspiration on land; and,
3. Short-term adjustment of localized accumulation of heat in the surface ocean through tropical cyclonic storms

METHODOLOGY AND SCENARIO BASED APPROACHES

Excess greenhouse gases, especially carbon dioxide, from anthropogenic sources alter these atmospheric processes since human activities has increased carbon dioxide level from about 270 ppm before the industrial revolution to about 380 ppm today. To predict how the global climate will change and the consequences on local weather patterns in the future we need to know how greenhouse gases, especially carbon dioxide levels in the world atmosphere will change in the future. This depends on the total greenhouse gases emitted from all the countries combined and therefore the function of social-economic development status and environmental concerns of all countries of the world.

To project and describe the global development direction and its effects on greenhouse gas emission in the future, the Intergovernmental Panel on Climate Change (IPCC) had devised a simple approach based on a 2x2 matrix between globalization level on one axis and development focus on the other axis (Figure 18). The letters A and B denote globalized and localized future world, respectively, while numbers 1 and 2 represent economic and environment concerns respectively in the development process. Details of these IPCC development storylines may be found in its Special Report on Emission Scenarios (SRES).

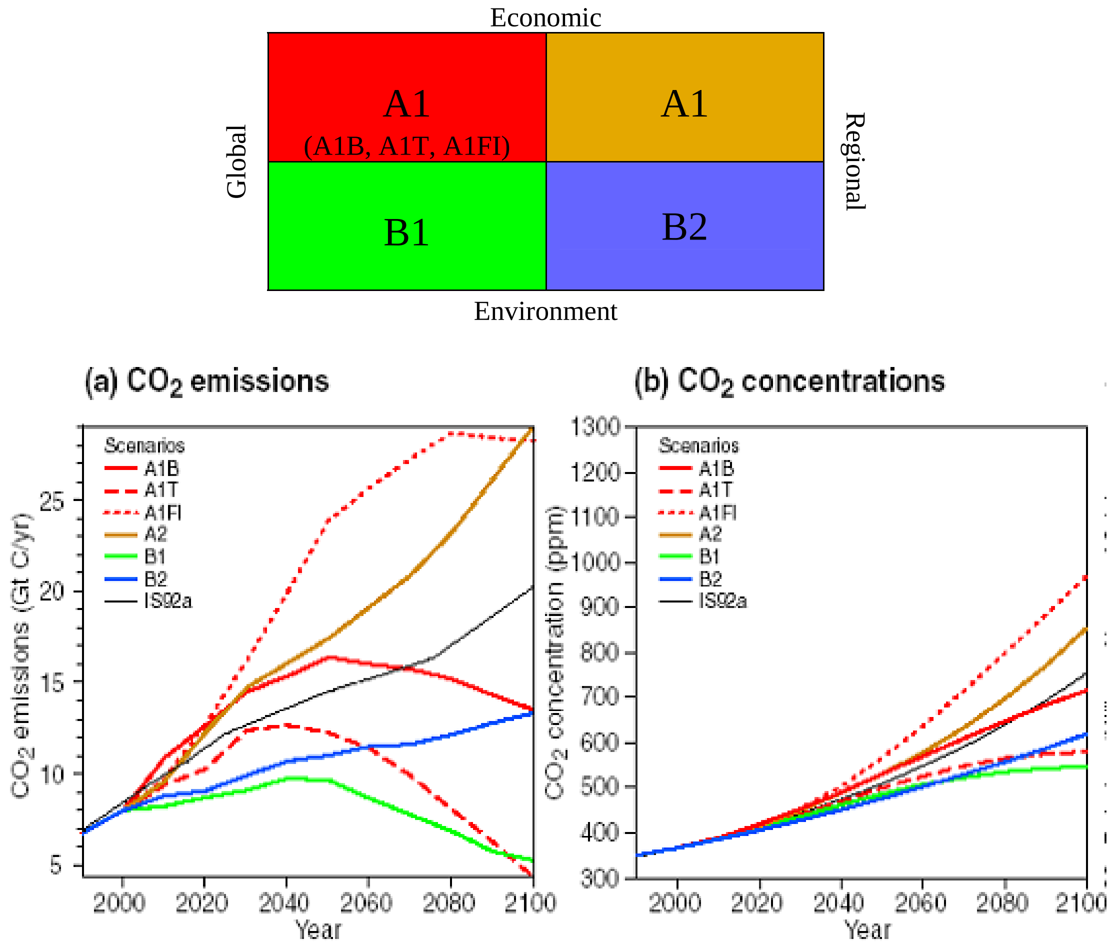


Figure 18: IPCC SRES global development storyline matrix (upper). Projections for carbon dioxide emission (a) and its consequence on atmospheric carbon dioxide levels (b) in the future for each SRES storyline

In this study we selected the future world that will be developed according to the 'A2' storyline, which predicts that the world will be

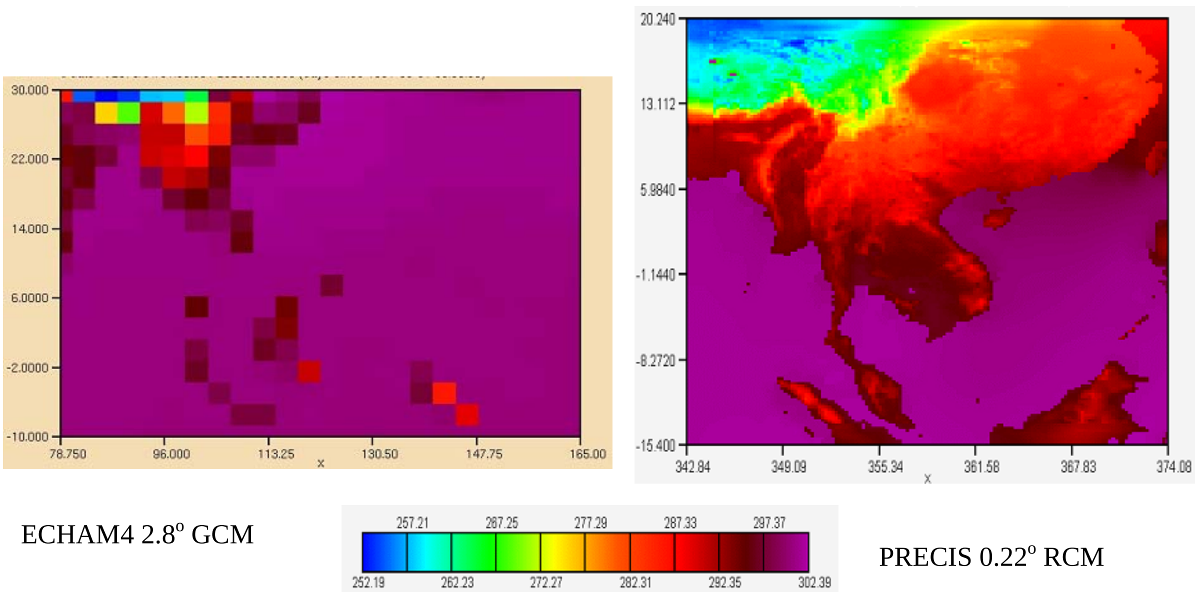
- independently operating, self-reliant nations;
- continuously increasing population;
- regionally/nationally oriented economic development;
- slow and fragmented technological changes; and,
- slow and fragmented improvements in the per capita income.

In simple words, the future world would be a simple extension of the world today but with more population and maybe even more fragmented in terms of economic and technological capacities.

CLIMATE PROJECTIONS

Atmospheric carbon dioxide level projected by the SRES scenario was taken as input to the global circulation model (GCM) to calculate the heat, moisture and momentum distribution in the earth atmosphere horizontally and vertically. Given that the time and resource constraints allowed us to use only one GCM, it made sense to select a model that yielded average (rather than extreme) values (compared with other GCMs reviewed by the IPCC) for these metrics. Therefore, we selected the German Max-Plank Institute of Meteorology's ECHAM GCM, which couples between the atmospheric model of the European Center for Medium-term Weather Forecast (ECMWF) and the ocean model of the University of Hamburg. Specifically, we used Version 4 of the ECHAM for SRES A2. The decision to use ECHAM was also based on the fact that the Hadley Centre had conducted previous analyses with this model.

Due to computer limitation most GCM's to date only provide outputs at resolutions in the range of 200-300 km, which is much too coarse for impact analyses at regional or local scales. To increase the resolution of the outputs, a dynamic downscaling technique using the UK Meteorological Office, Hadley Centre for Climate Change, PRECIS—Providing Regional Climates for Impacts Studies—(precis.metoffice.com) was applied to the GCM outputs. The final resolution of PRECIS output used in this study was 0.22° or about 25 km horizontally (Figure 19) with 19 vertical atmospheric layers.



ECHAM4 2.8° GCM

PRECIS 0.22° RCM

(Surface Temperature in Kelvin)

Figure 19: Comparison between ECHAM GCM output resolution of 2.8° and PRECIS downscaled outputs at 0.22° for surface temperature for Southeast Asia

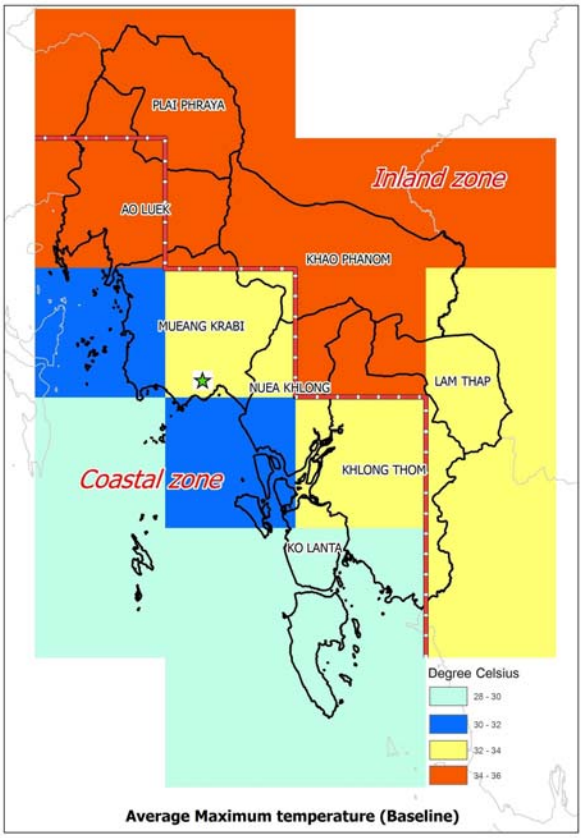
Daily outputs for baseline period (1980-1989) and for two future time slices 2015-2024 and 2030-2039, which were used to represent the next 10 and 25 years, respectively, were analyzed for mean and variability of monsoon driven temperature, precipitation, and prevailing winds. These time slices were selected to provide information that would resonate with local stakeholders and also help inform current provincial planning processes.

TEMPERATURE

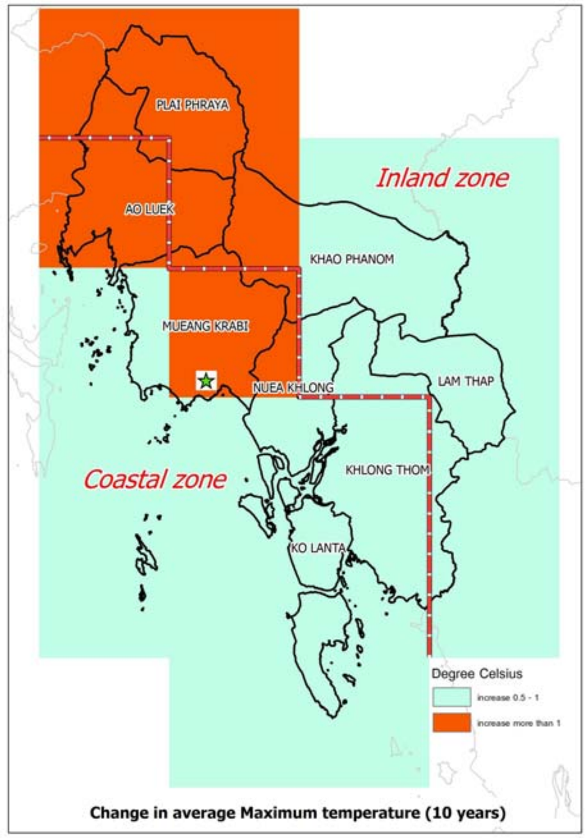
Baseline maximum or daytime temperatures (1980-1989) were on average about 32-36 °C for inland and mountainous parts of the province and about 28-32 °C for the coastal and sea areas (Figure 20). In the future, due to global warming, maximum temperature in the inland area will be more sensitive and increased by more than 1 °C while the coastal and offshore areas will be less sensitive due to the ability of water to absorb excess heat and therefore the maximum temperature will be increased by less than 1 °C.

The average minimum or night time temperature during the 1980-89 baseline period were about 23-25 ^{o}C for the inland and mountain zone and 25-28 ^{o}C for the coastal and offshore part of the province (Figure 21). In the future the night time temperature for most of the land part will be higher by more than 1 ^{o}C from the baseline while night time temperature over the sea will be increased but less than 1 ^{o}C, again owing to the high heat capacity of the water

Today



10 Year



25 Years

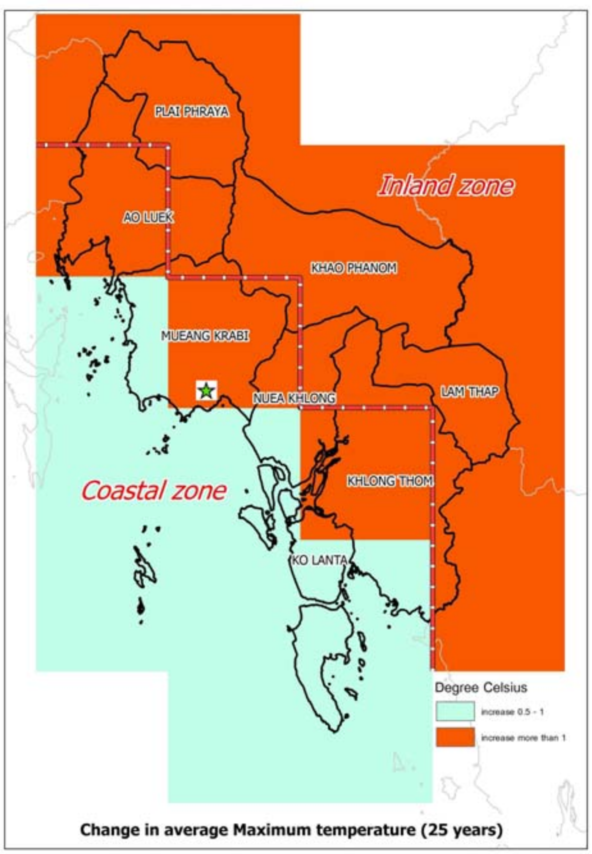
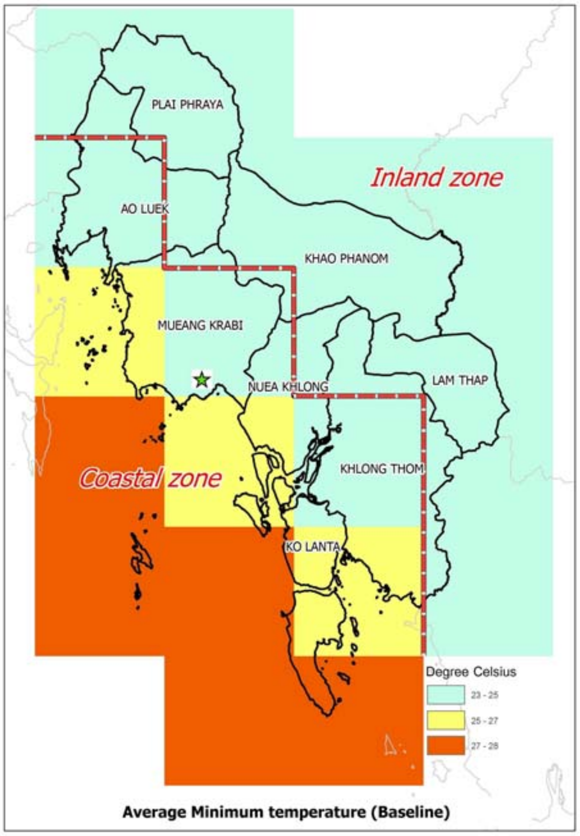
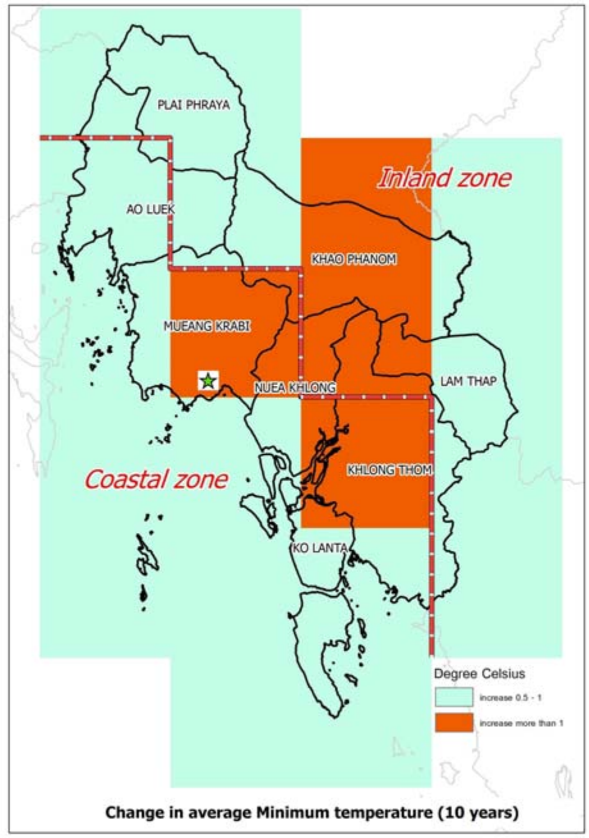


Figure 20: Grids of maximum temperature. Baseline level and future change (as anomaly) compared to the baseline for 10 and 25 years periods in the future

Today



10 Year



25 Years

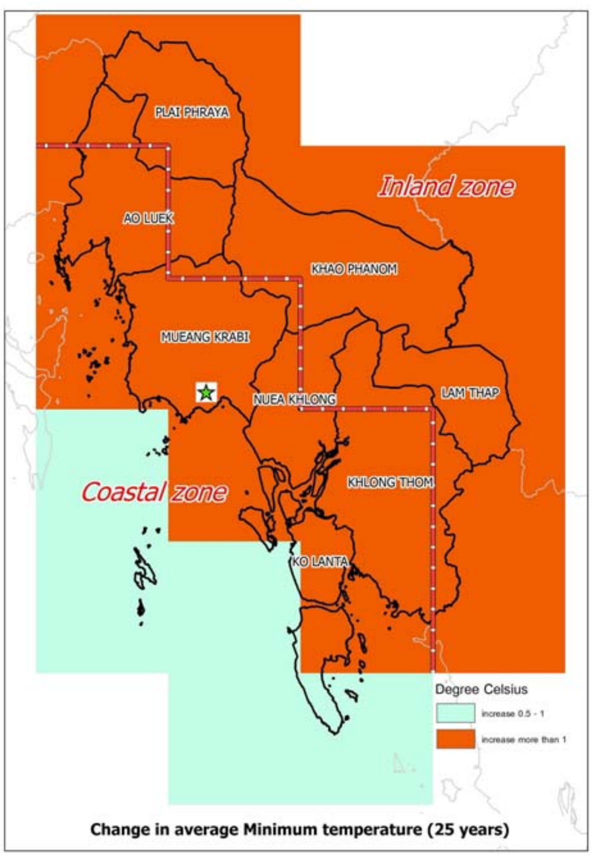
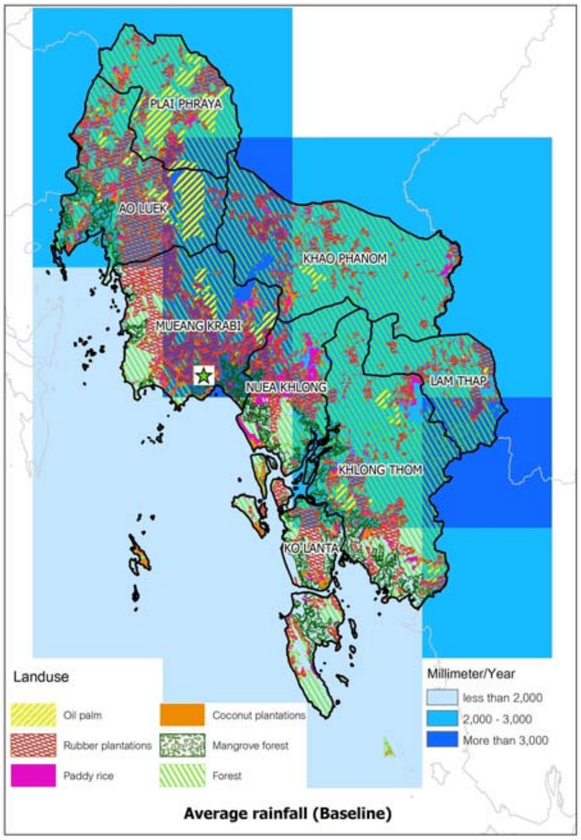
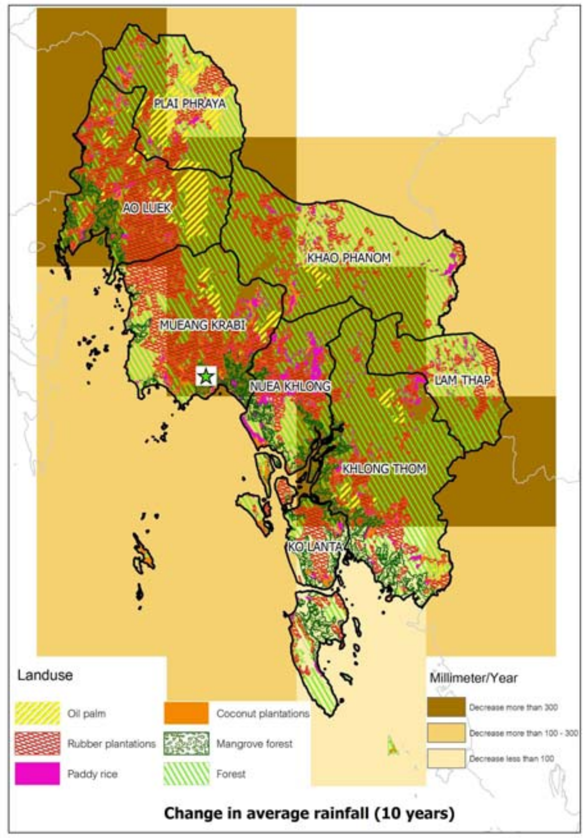


Figure 21: Grids of minimum temperature. Baseline level and future change (as anomaly) compared to the baseline for 10 and 25 years periods in the future

Today **10 Year**





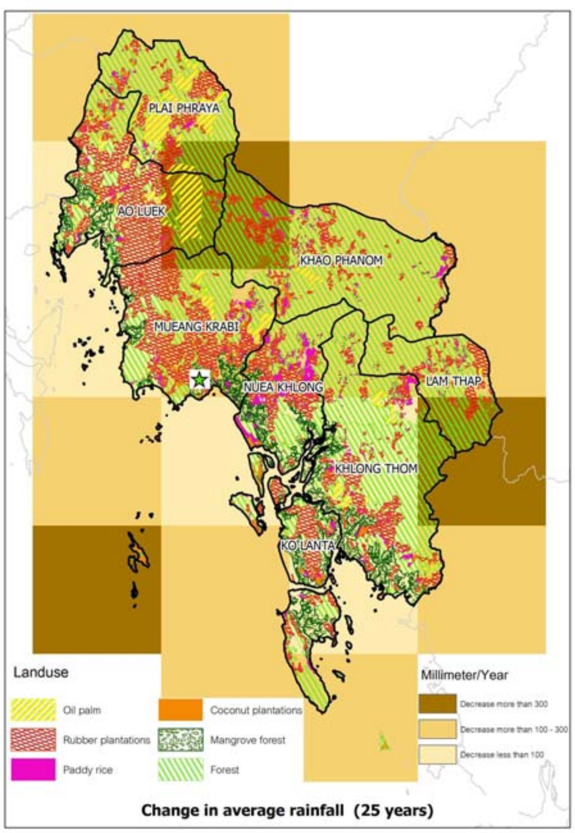


Figure 22: Grids of annual rainfall overlain over the land use map. Baseline level and future change (as anomaly) compared to the baseline for 10 and 25 years periods in the future

RAINFALL

Baseline annual rainfall was on average more than 2,000 mm/year for most of the land part of the province and could be more than 3,000 mm/year for mountainous areas covered by lush rainforests (Figure 22). Rainy monsoon season on average began in the first week of April and ended on about the second week of November each year (Figure 23). The number of rain days (>10 mm) ranged from less than 90 days in the coastal and offshore zones to more than 90 days in the inland agricultural zone and up to more than 120 days in some mountainous parts of the province (Figure 24). Areas that had heavy rainfall (>50 mm/day) were limited to high mountain parts of the province, which are areas most susceptible to flash floods and landslide (Figure 25).

Annual rainfall forecast for 10 and 25 years in the future will be reduced for the whole province by about 100-300 mm/year or about 10%. The rainy monsoon season will be shortened quite significantly due to the earlier offset dates by about 2 weeks over the next 10 years and 4 weeks over the next 25 years. The number of rain days and heavy rain days will also generally decrease for the province (Figures 24 and 25).

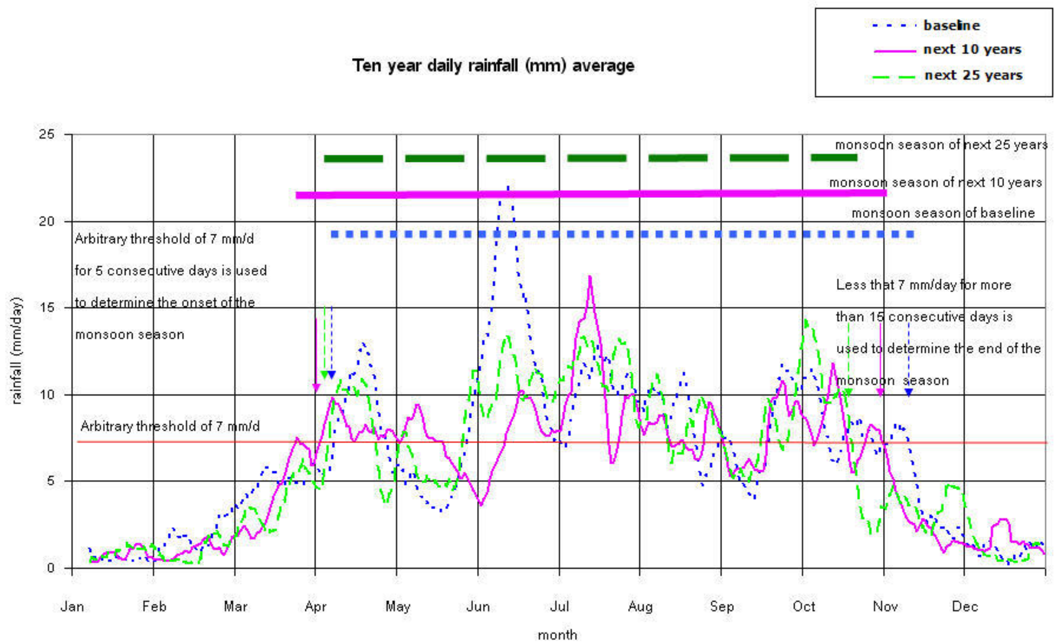
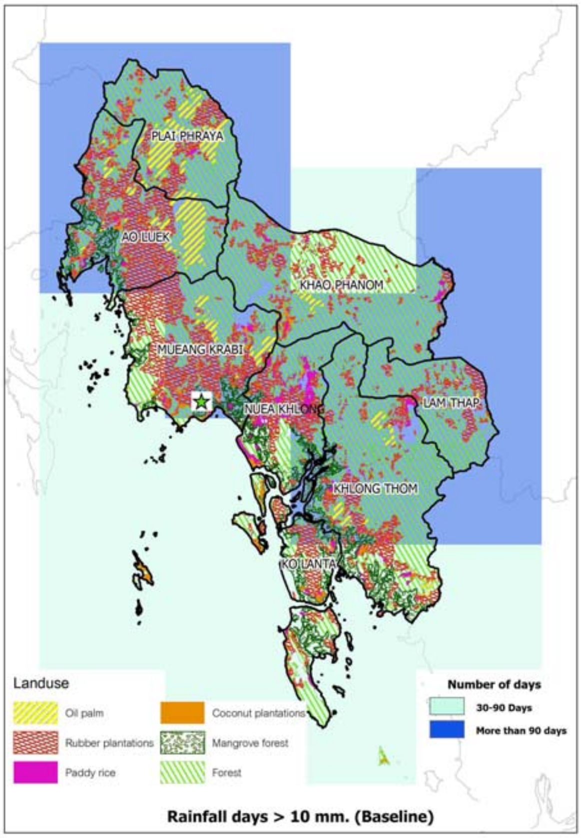


Figure 23: Ten year daily rainfall (mm) averages for baseline (blue), for the next 10 years (pink) and for the next 25 years (green). Arbitrary threshold of 7 mm/d for 5 consecutive days is used to determine the onset of the monsoonal rainfall season and less that 7 mm/day for more than 15 consecutive days is used to determine the end of the monsoonal rainfall season

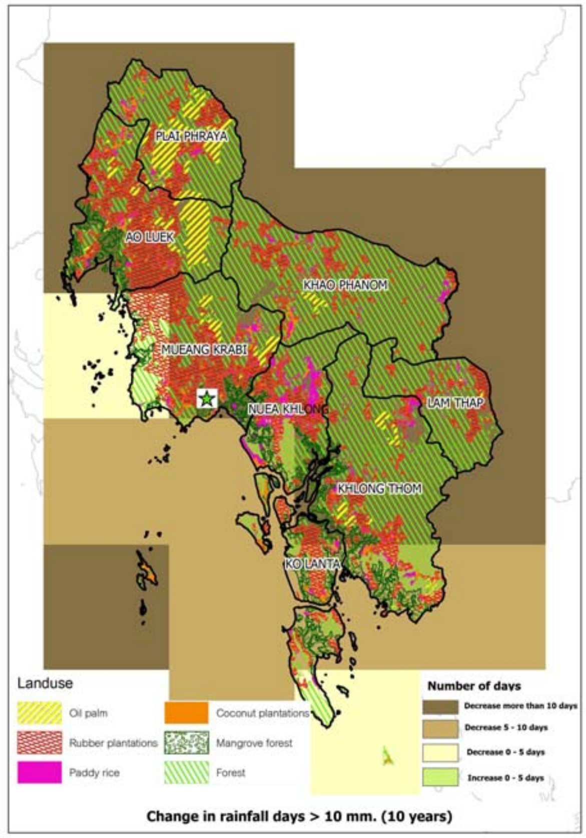
SEA LEVEL RISE

Sea level at any one place and any one time is generally a function of global sea level and many local factors. While global sea level depends on slow processes such as volume expansion due to temperature increase (thermosteric effect) and additional water coming from glacial and ice melt, local factors are more dynamic and usually observe certain cyclic patterns. In this region two most important local factors that influence coastal sea level on annual cycles are wind and buoyancy effect from freshwater inflow. Both depend strongly on climate and weather.

Today



10 Year



25 Years

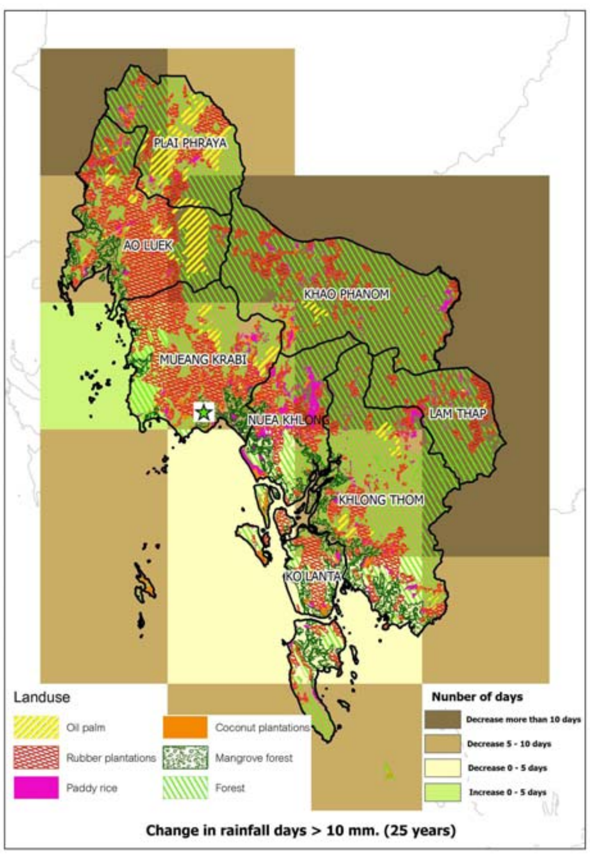
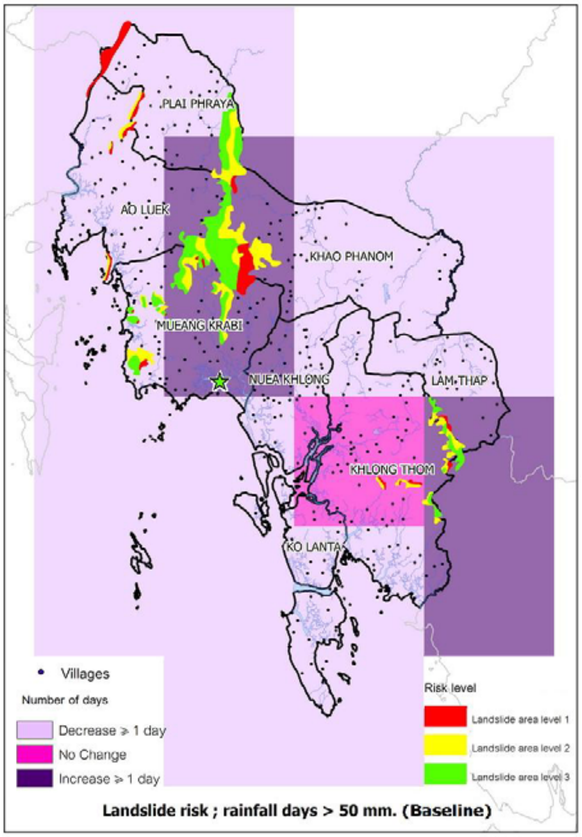
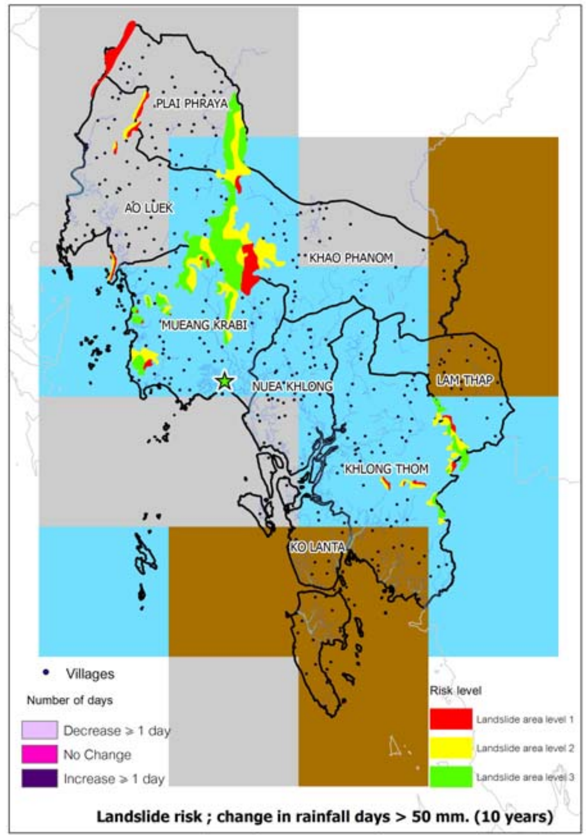


Figure 24: Grid plots of the number of rain days (>10 mm) per year. Baseline level and future change (as anomaly) compared to baseline for 10 and 25 year periods in the future.

Today



10 Year



25 Years

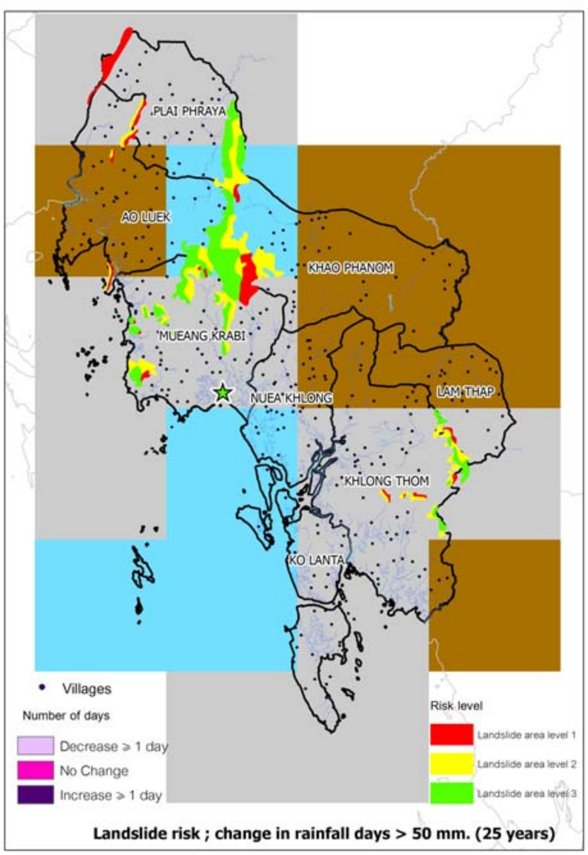


Figure 25: Grid plots of the number of heavy rain days (>50 mm) per year. Baseline level and future change (as anomaly) compared to the baseline for 10 and 25 year periods in the future. This is plotted over a base map of landslide vulnerability classifications one (red), two (yellow) and three (green)

Global component of sea level rise was estimated using DIVA (Dynamic Interactive Vulnerability Assessment) tool developed by DINAS-COAST consortium (www.dinas-coast.net). Based on A2 high sea level regionalized scenario of DIVA the mean sea level rise for Krabi province for 2020 and 2035 are 11 and 21 cm relative to 1995 baseline level (Figure 26).

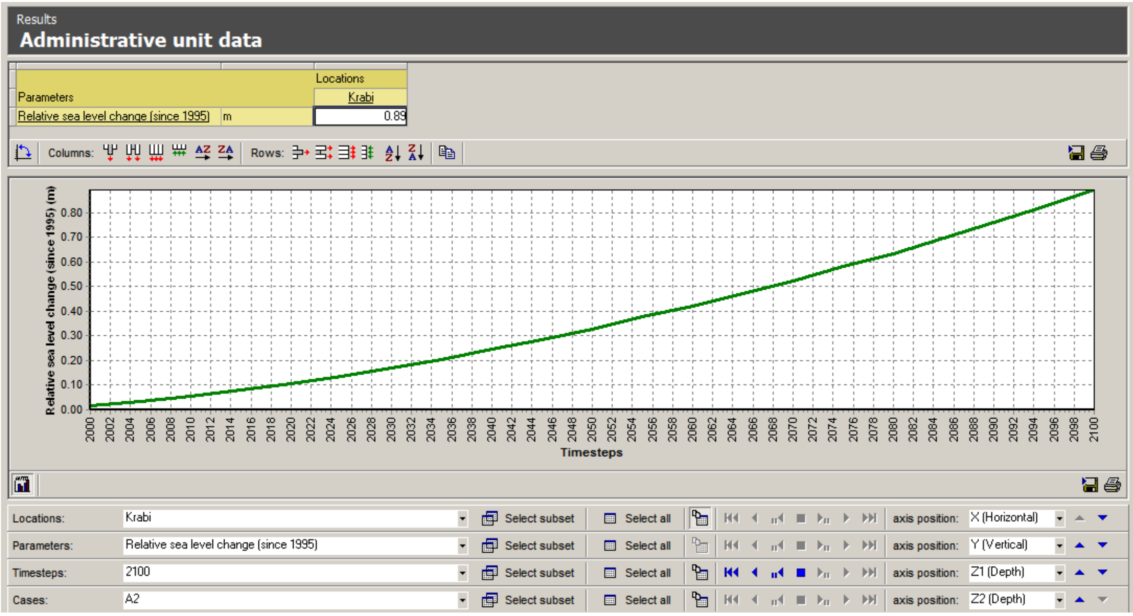


Figure 26: DIVA output for mean sea level rise due to global factor for Krabi under A2 high sea level regionalized scenario.

Local effect from monsoonal wind shear was estimated from monthly mean observed sea level during the 1989-2005 baseline and transfer functions with u and v wind stress (Figure 27). The same transfer functions were applied to future wind stresses and new monthly sea levels that incorporate both global and monsoonal effects were estimated (Figure 28). When compare with the baseline it can be seen that the stronger northeast monsoons in the future will modulate the global effect and thus for most of the northeast monsoon months the net sea level rise will be less than those projected by global factors alone (Figure 29).

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TROPICAL CYCLONIC STORM SCENARIOS

Analysis of all storms recorded between 1951-2008 that have passed near Krabi Province (Figure 30) indicated a significant decrease of both the total number of storms and large storms (typhoon and tropical storms combined). The total number of storms has decreased by one half from 15 to 4 per 30-years cycle and the number of large storms has decreased by three quarters from 4 to 1 per 30-year period. This reduction is probably due to the adjustment of storm tracks in the South China Sea and the Gulf of Thailand more northward as the surface sea water near to the equator warms. Projections of future storm events, based on curvilinear extrapolation of the current trend over the next 25 years are expected to maintain the current situation. More data and improved models are needed to increase confidence in this projection.

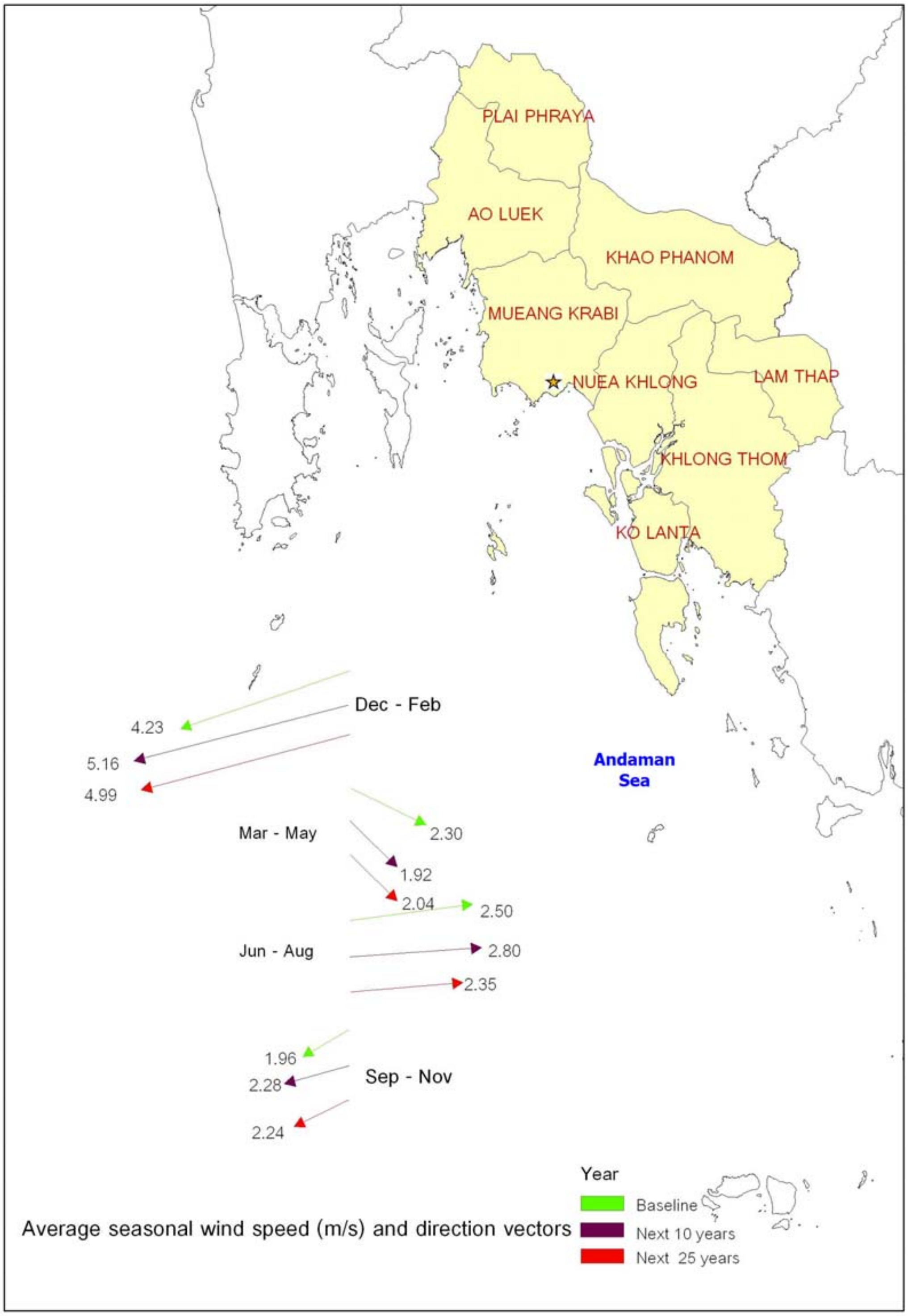


Figure 27: Average seasonal wind speed (m/s) and direction vectors for baseline (green), the next 10 years (purple) and the next 25 years (red) for December-February, March-May, June-August and September-November periods. These are mapped in the Malacca Strait of the Andaman Sea, Krabi province is highlighted.

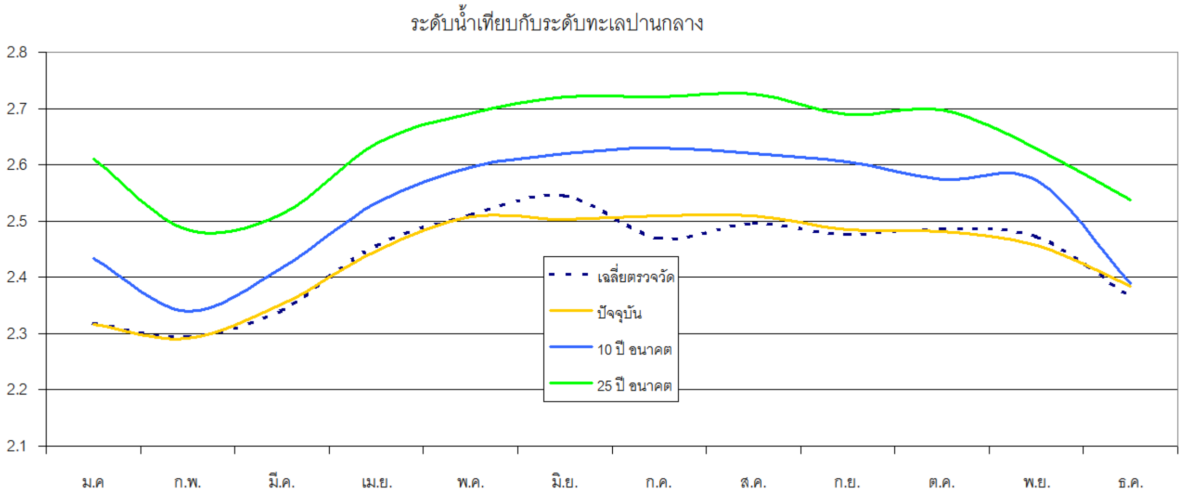


Figure 28: Monthly sea level above national mean sea level reference datum. Shown here are observed (dashed), modelled baseline (yellow), modelled for the next 10 years (blue) and modelled for the 25 years (green). Calculation took into consideration both global mean sea level rise and local wind effects.

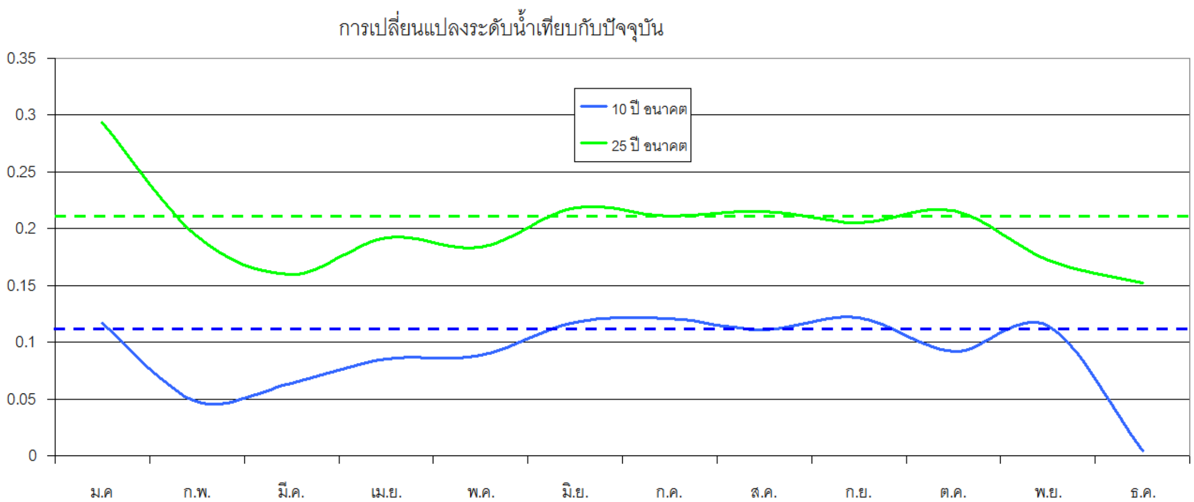


Figure 29: Monthly mean future sea level anomaly relative to baseline level. Dashed lines indicate global mean sea level rise under A2 high sea level regionalized scenario. Solid lines take into consideration also the monsoonal wind stress effects.

SUMMARY OF CLIMATE CHANGE SCENARIOS

According to the scenario used in this study Krabi province over the next 10 to 25 years will receive slightly less rainfall during the rainy southwest monsoon season. The season itself will also be shorter by up to 4 weeks. The trend of tropical cyclonic storms will also be decreasing and the chance of having a typhoon to pass nearby will be about once every 30 years.

Mean sea level will be rising at an average rate of about 0.8 mm per year. However because of the weaker southwest and stronger northeast monsoon projected by our scenario this will compensate with the rise due to global sea level effects and the net increase of sea level will be slightly less than those estimated from global sea level effects alone.

Reduced freshwater supply due to less rain and more evapotranspiration will affect water use and ecological functions downstream. However, a shortened monsoon season could open more opportunity for outdoor activities such as tourism, agriculture, and fishing. Sea level rise could destabilize coastal land and coastal ecosystems, and thus pose threats to sustainable development in coastal zone of the province in general.

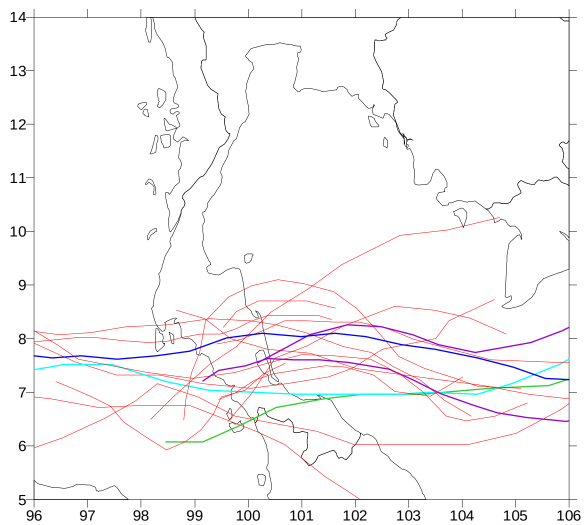
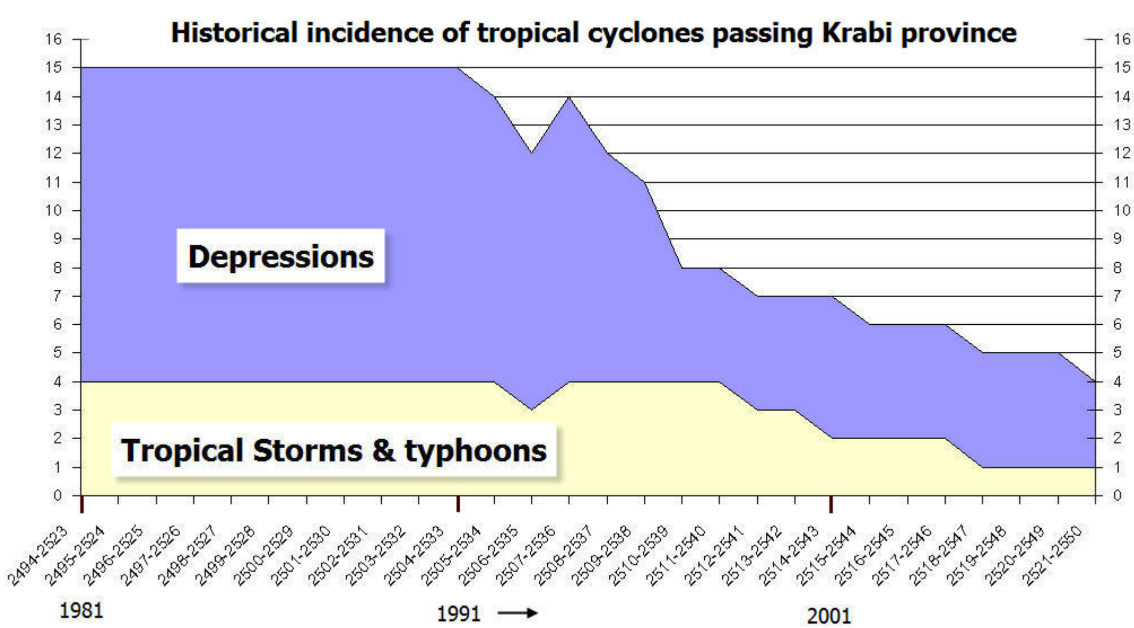


Figure 30: Historical tracks of all cyclonic storms (typhoons, tropical storms and depressions) that across southern Thailand since 1951 (left panel). When examined as a 30-year running mean for depressions (blue) and typhoons plus tropical storms (yellow) the gradual reduction in incidence of cyclonic storms is clearly indicated (below).



4. Impact assessment of simulated climates

INTRODUCTION

In order to facilitate stakeholder engagement in the impact assessment process Krabi Province was subdivided into 3 geographic zones based on their common physical and socioeconomic natures (Figure 31);

(a) Coastal zone, which covers sub- and inter-tidal areas, estuaries and coastal lowlands. Coastal zone covers about 756 km^2 or about 15.5 % of land area of the province.

(b) Urban zone, which covers large settlements and major commercial and tourism areas. Urban zone covers only about 24 km^2 or about 0.5 % of the province but it is home to a large population and is home to the majority of the provinces economic centres.

(c) Inland zone, which covers various types of agricultural land and forests of different types. Inland zone covers about 4,100 km2 or about 84 % of the province but it is sparsely populated

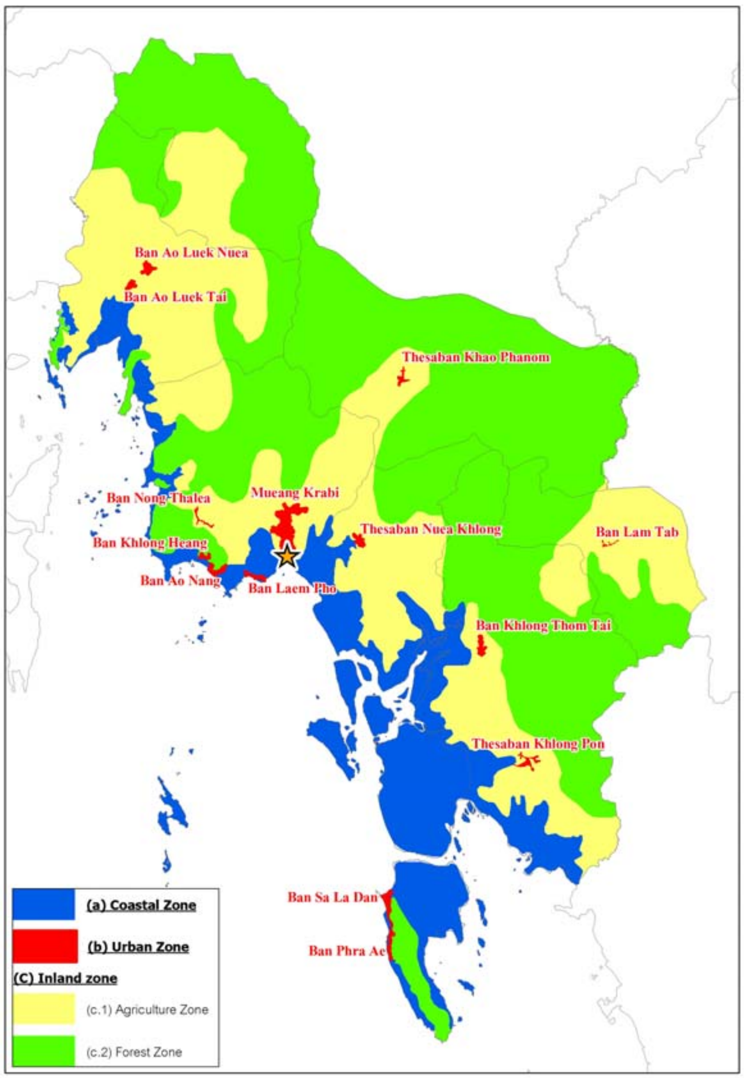


Figure 31: Distribution of geographic zones used in the impact assessments. The inland zone comprises the agriculture and forest zones.

COASTAL ZONE

Coastal zone is defined here as coastal stretches of land that are below 5 meters above mean sea level. The area is highly influenced by interaction between land and sea processes, ecosystems in this zone range from the beach forest and scrublands located above the highest high-water mark, to seagrass and coral community found to a depth of 20 meters. Biophysical issues that are related to climate change are coastal morphologic stability, coastal ecosystem functions under different temperature and salinity regimes, and sea level extremes due to storm surge or unusually strong southwest monsoon.

Coastal Instability and Erosion

No universally accepted model of shoreline retreat under sea level rise has yet been developed, however a number of models have been put forward to predict shoreline. The model proposed by Bruun, although it has not been adequately proven, was used by this study to estimate the new equilibrium between onshore wave action and offshore gradient force due to gravity, with the retreat distance inversely related to the sub-tidal slope of the coastline (Figure 32). Based on this rule a simple analysis was carried out using digitized bathymetric data from various sources, including large-scale navigation charts and many research and survey projects to test the validity of the concept and the application of this data for coastal vulnerability assessment.

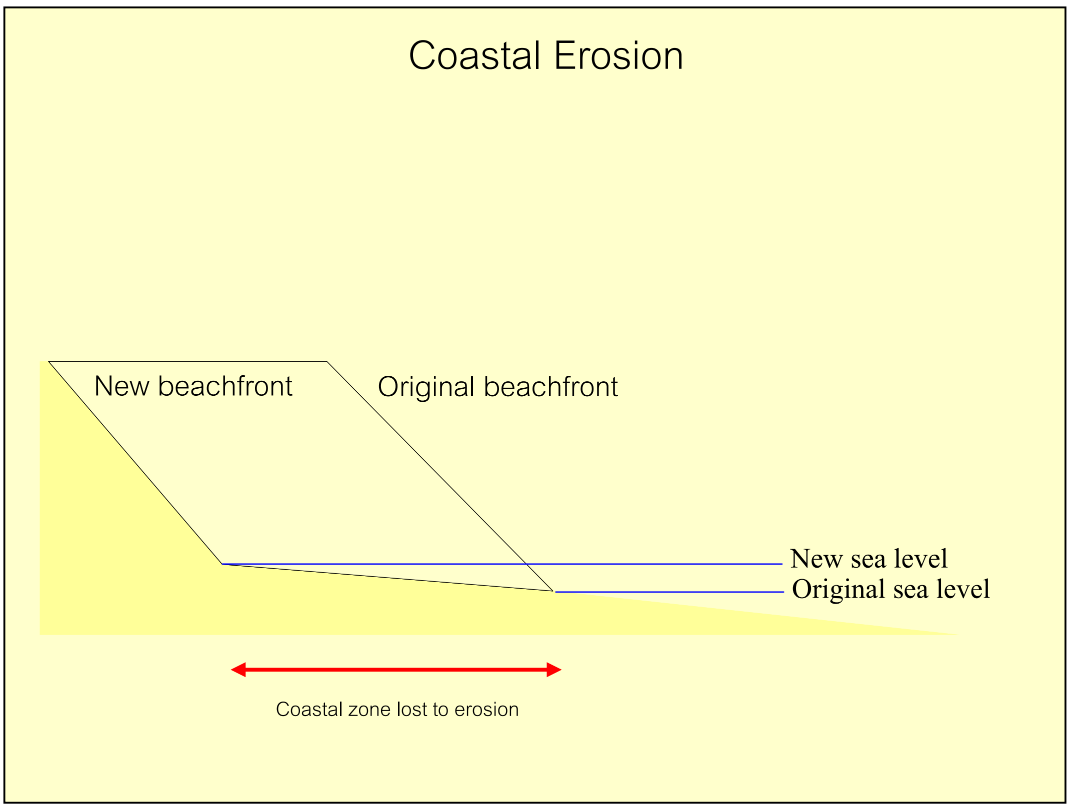


Figure 32: Bruun's Rule on coastal stability at equilibrium relates shoreline retreat with sea level rise

Ten general areas in Krabi were identified as having relatively higher risk for coastal instability due to sea level rise (Figure 33). Our scenario indicated that the net mean sea level rise due to both global and local climate change for the Province will be about 12 and 22 cm for the next 10 and 25 years, respectively. The maximum distance for shoreline retreat at these locations at 20 cm mean sea level rise are given in Table 5.

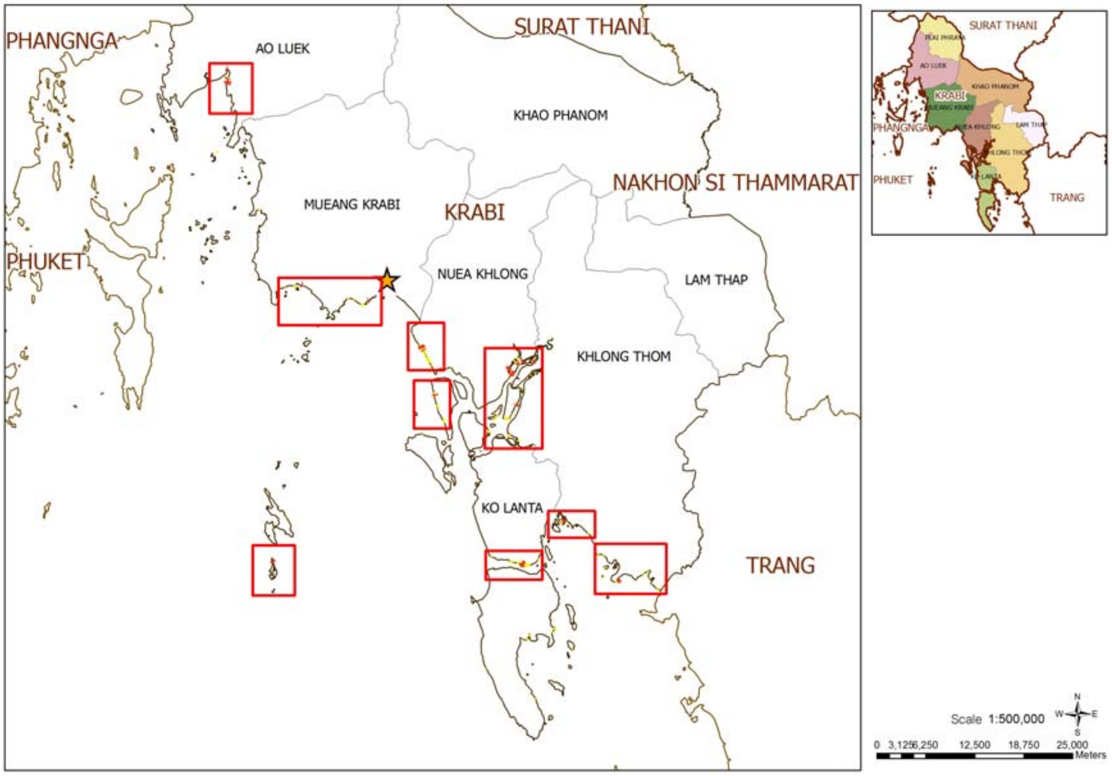


Figure 33: Areas with high risks for coastal instability due to sea level rise according to Bruun's Rule.

Areas	Districts	Coastal Type	Maximum shoreline retreat (m) for 20 cm sea level rise
Ban Bagun	Ao Luek	Mangrove	21
Nopparat Beach	Muang	Sandy Beach	14
Laem Po	Muang	Sandy Beach	11
Koh Phi Phi Le	Muang	Sandy Beach	14
Had Yao	Nua Klong	Sandy Beach	15
Koh Siboya	Nua Klong	Sandy Beach	17
Klong Pelah	Nua Klong/Klong Thom	Mangrove	35
Ban Hua Hin	Koh Lanta	Mangrove	10
Koh Mai Khao	Klong Thom	Mangrove	13
Ban Bo Muang	Klong Thom	Mangrove	11

Table 5: Coastal areas with high risks for coastal instability and shoreline retreat according to Bruun's Rule.

It does not imply, however, that coastal areas other than these 10 locations are not vulnerable to sea level rise. Data used in this analysis was very preliminary and crude. More accurate and systematic surveys of the coastal bathymetry are needed for more detailed assessments to be made along the entire coastline to clarify coastal vulnerability at all points along the coastline to guide mitigation and adaptation efforts.

Ecosystem Goods and Services

Five of the coastal locations vulnerable to sea level rise are covered by mangrove forests that provide important functions as spawning/nursery grounds for marine organisms. Coastal communities also use them as collection areas for subsistence natural resources, especially during the strong monsoon season that prohibits small fishing boats going out to the open seas.

Despite the scenario that southwest monsoon may be weaker and shorter in the future and thus allow fisher folk to have more days out at sea per year, but with less overall ecosystem productivity such opportunity may not benefit small scale fishermen in the province.

Erosion due to sea level rise could destabilize substrate for trees on the seaward side and if this cannot be compensated by reclamation on the landward side the mangrove strip may become thinner than the minimum size needed to maintain the ecosystem integrity and the coastal protection and subsistence products and services may be permanently destroyed. Designation of set back retreat area behind the current high tidal mark to allow young seedlings to settle could be one option to ensure that these mangrove ecosystems can sustain their ecological function and services in response to future sea level rise.

Coastal ecosystem such as mangrove and other brackish water communities will not be subjected only to physical damage due to erosion and shoreline instability. Biological functions and chemical processes also depend on the dynamic balance between seawater and freshwater in the system. Any changes of temporal and spatial distribution of salinity may cause the state of the ecosystem to shift, which may include biological production, biodiversity, sediment and water quality, for example. Reduced freshwater supply from streams and rivers partly due to less rainfall combined with increased demand from cash crop expansion in the upstream watershed could make many brackish water habitats further vulnerable to future climate change impacts.

Reduced freshwater inflow from upstream watersheds, especially during the dry season (November-March), could allow seawater intrusion inland and contaminate surface water and shallow aquifers in the coastal area (Figure 34). These supplies are important sources of water for many coastal communities.

Coastal communities, in general, have traditional ways of life that are closely linked to the ecosystem goods and services. Yet, they are situated at the downstream end of the chain and forced to accept the consequence of the upstream changes due to climate and/or human impacts alike, despite that their basic access rights to the resource is being lost. The situation is particularly obvious in the small and largely self-contained basins in Krabi Province. A systematic and holistic integrated river basin management; IRBM approach that manages and allocates the resources equitably, including water on a basin by basin approach, would be crucial for the Province to prepare for the challenges under future climate regime.

Sea Level Extremes

Under some extreme climate circumstances the sea level along the coast could be surged by as much as 2-3 meters above the normal tidal level. Usually these are associated with large tropical cyclonic storms known as typhoons in the Gulf of Thailand side and cyclones on the Andaman Sea side of the peninsular. Unusually strong monsoons coming from the southwest or west could also raise the sea level along the coast by several tens to hundreds of centimetres.

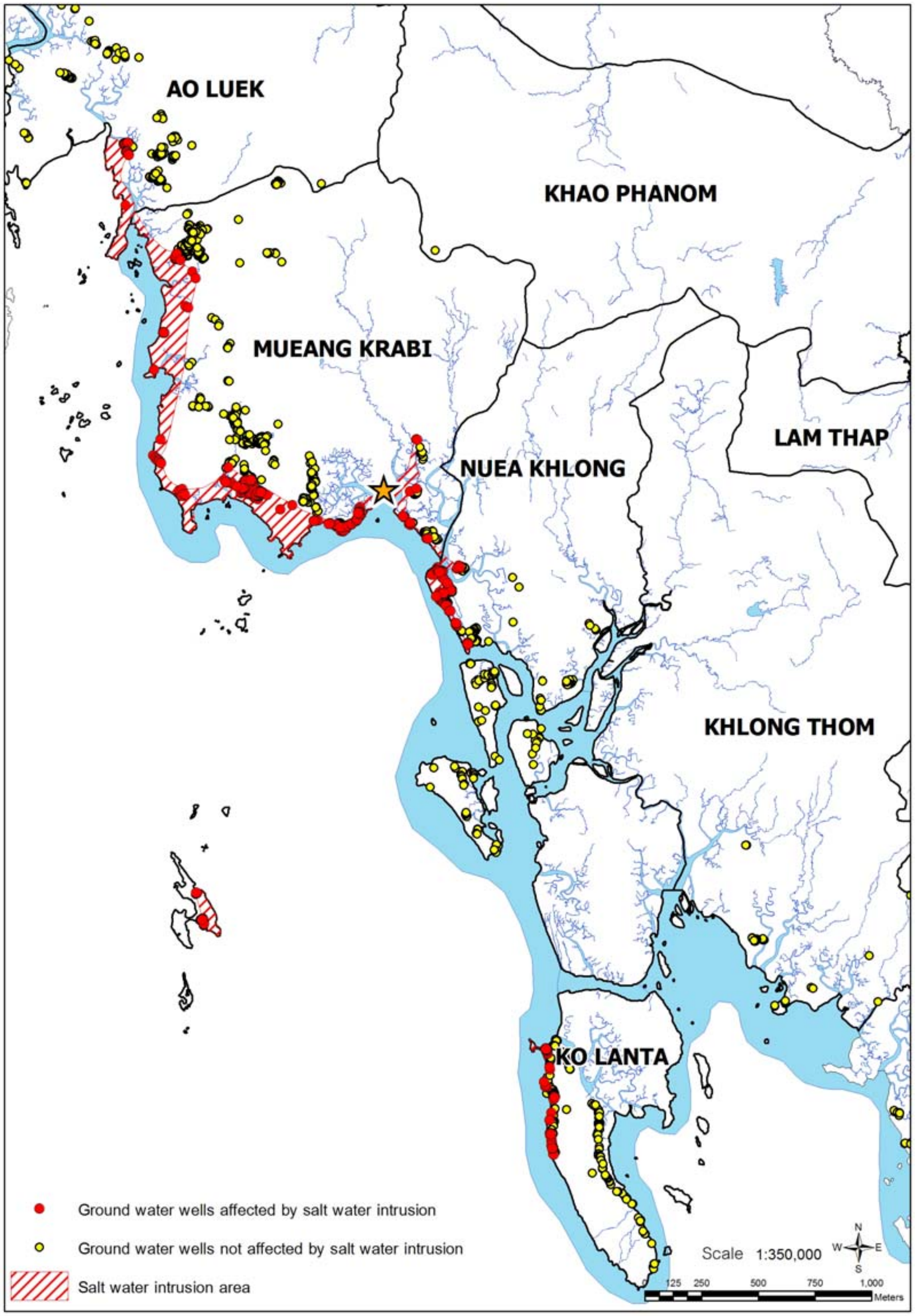


Figure 34: Coastal areas where beach sand aquifers are contaminated by saltwater in dry season (red) and susceptible areas that could be affected by salt water intrusion in the future (yellow).

A strong typhoon with wind speed over 100 km/h that passes within 100 km of the Province could raise sea level by as much as 2 meters. An example would be the Typhoon Harriet that occurred in 1962 and killed hundreds of people in neighbouring Nakorn Sri Thammarat Province. That typhoon also created a storm surge and coastal flood that extended several kilometres inland in Krabi province. However development situation of Krabi 46 years ago was very different from today and therefore casualties and economic losses at that time were relatively low. If a similar storm of that magnitude occurred today causing in a 2-m surge (Figure 35), then today in Krabi province many urban areas, infrastructure and economic centres would be physically affected (Table 6). The tsunami event of 2004 was also a good example on how 1-2 m sea level extremes would do in terms of physical, social and economic damages for Krabi Province.

	1-m Surge	2-m Surge
Shrimp ponds (No. / rai)	1,456 / 5,638	1,835 / 6,978
Oil palm (rai)	7,903	16,797
Rubber (rai)	3,379	4,892
Hotels and resorts (No.)	6	10
Road (km)	162	247
Electric power sub-stations	-	1
Hospitals and health centres	2	5
Other urban areas (rai)	406	565
Other rural areas (rai)	65,000	116,250

Table 6: Economic sectors, infrastructures and land affected by 1 and 2-m storm surge.

Because the scenario predicts that the southwest rainy monsoon will also weaker and the incidence of large storms will be reduced (Figures 27 and 30) Krabi Province may face less of a risk from storm surge. However, the chance will not be absolutely zero and there could be a storm of a significant scale once every 30+ years. With this low probability, options to protect coastal areas from storm surge should include multiple strategies that harmonize with the local ecology, use, topography and oceanography of the area. Long term soft ecological solutions (e.g., protecting and restoring mangrove ecosystems) as well as financial and insurance mechanisms should be considered rather than expensive solutions focused on short term technical infrastructure construction, especially as the model predicts that in 30 years the sea level will have risen an additional 30 cm.

Perceptions of Stakeholders

Some of the stakeholders in the coastal zone of the Province have heard about climate change, especially sea level rise and change in weather patterns. Some of them claimed that some changes have already been observed. However most of them do not realize that changes in the local ecological and morphological settings will also reduce the capacity of the society and ecosystem to cope with climate change and climate extreme in the future. Stakeholders remain to view climate change and local development issues as separate entities.

Despite insufficient awareness about the linkages between global climate and vulnerability of local systems and sectors in the coastal zone, stakeholder were very keen to identify local development issues and have their own perception about causes of current coastal system deterioration. By applying their current experiences to the two future threats from climate change, here are some of the suggested factors and needs to reduce climate risk and increase local coping capacity in the future.

1. Coastal Erosion and Ecosystem Losses

- Effective legal mechanism to enforce land use plans that are harmonize with local system and conditions
- Knowledge based management and common understanding about the systems among all stakeholders, including local focus groups, government, and women

- Information and knowledge sharing mechanisms
- Designated responsible body for integrated coastal zone management
- Shoreline protection strategy that is balanced between hard engineering, soft ecological and social-based solutions

2. Water Resources

- Basin management approach and dialogue that engages both upstream and downstream stakeholders
- Knowledge and information for water management

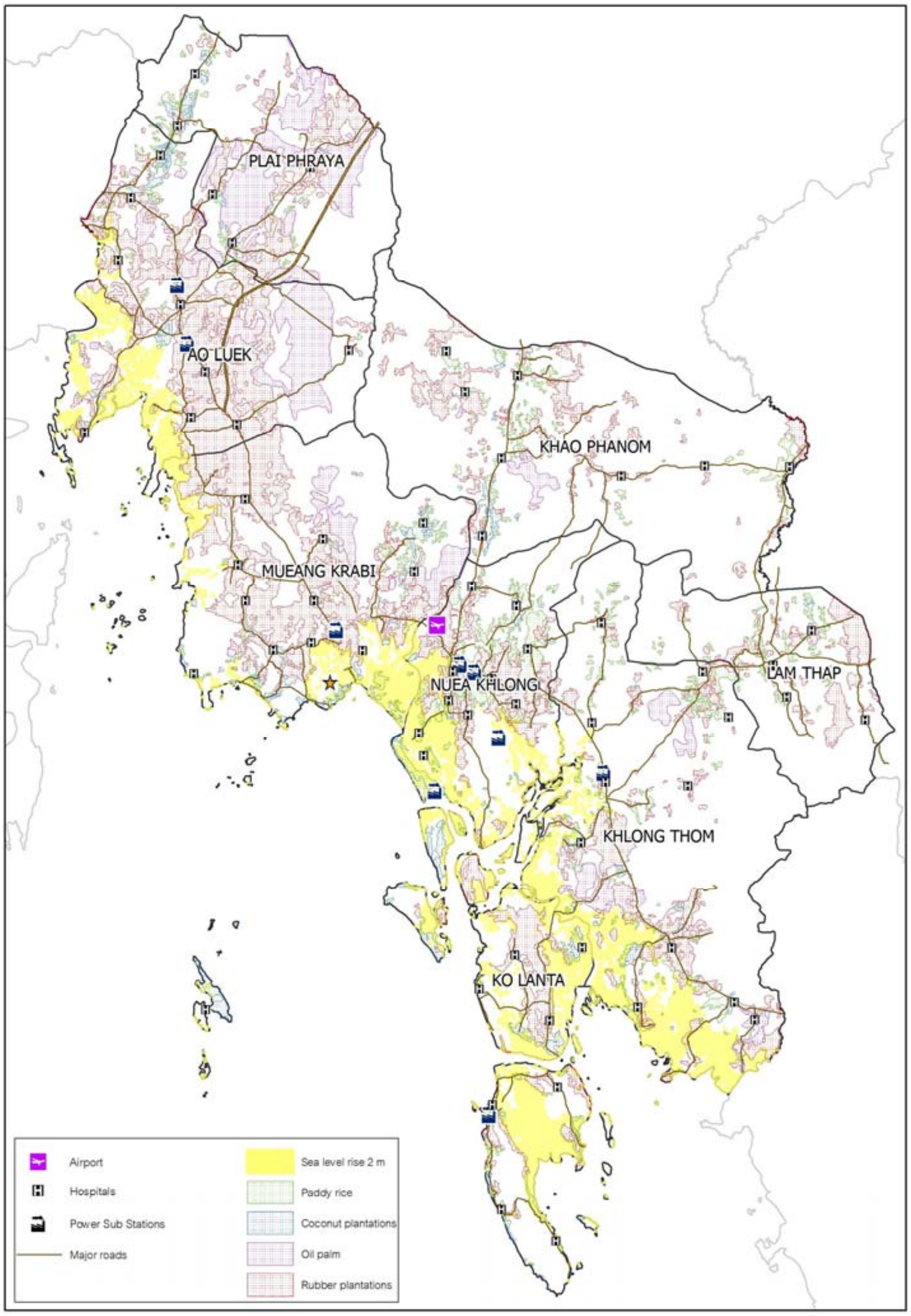


Figure 35: Extent of predicted flooding caused by a 2m storm surge (yellow), overlain on land use and infrastructure maps.

URBAN ZONE

Most large urban areas of Krabi province, such as Krabi municipality, Ao Nang, Koh Lanta, is heavily involved in the tourism industry (Figure 13). Therefore, in addition to extreme events like the tropical cyclones and typhoons that may have a direct impact on the livelihood of the people in the urban area, additional climate change issues that need to be considered in this zone must include weather conditions that may interfere with tourism activities. These include the shorter rainy season and the possibility of having a slightly stronger northeast monsoon.

At first sight, it appears that climate change may provide more opportunities than problems for the tourism industry. Based on the climate scenarios in this study, the rainy season and monsoon period will contract by up to 4 weeks. This reduction in the rainy season will enable an expansion of the tourist season especially for the outer lying islands. Although such an expansion is consistent with national and provincial policies to promote tourism, it also raises concerns from various stakeholders on the impacts of tourism expansion, which may be partially considered as a secondary consequence of climate change. Particularly if this tourism expansion is not properly planned it will affect the socio-economic conditions of the urban area of Krabi province, including town, beachfront and community, both directly and indirectly as follows;

- Water demand from increased number of tourists, and increased demand during periods of low supply
- Change in land use induced by demand to serve expansion of tourism industry
- Impact on community society
- Potential shift and change in tourist behaviour

Water Demand

The major concern of the consequence of climate change in the context of the urban sector is the future water balance between supply and demand. For the time being, Krabi province relies on water supply for the urban sector from the natural sources including the rivers and streams within the province, while in many coastal communities most of their water is from shallow and deep groundwater wells.

Even though the total precipitation in Krabi province may be slightly reduced in the future in accordance with the projected climate scenario, the concern on water balance particularly in urban zone is on the increasing water demand due to the opportunities presented to extend the tourism high season in the province. The future climate and government policy that will favour tourism promotion may push hotel entrepreneurs to increase their water reserve storage capacity, which would pose a serious risk to the communities downstream. This will also create inequality of access to the water resource. Some hotel entrepreneurs may turn to groundwater as the alternative source of water supply and this could pose a serious risk to the communities around the town of Krabi and along the coast, who rely on water from wells as their main water supply source. As more users extract groundwater this will lower the water table and make it more susceptible to saltwater intrusion especially during the dry season.

This situation may cause conflict over water between the urban area and rural communities. In addition, these conflict may not just be limited to the tourism sector, but will also extend across other sectors especially agriculture as palm oil plantations are promoted as part of the national bio-fuel policy a thirsty crop that consume large amounts of water.

Change in land use

Growing tourism industry may induce major land use changes, as there could be an increased demand for accommodation as well as other supporting facilities. This could lead to increased construction for tourism infrastructure into natural forest or on public land, especially in the upper watershed areas. This will result in negative impacts due to natural habitat loss. Increasing, unplanned or uncontrolled, tourism developments would increase risk for the urban area not only due to water quantity reduction but also due to impacts on water quality, etc.

Impacts on Local Society

Growing tourism industry will have impacts on local social systems in numerous ways. Direct and immediate impacts include the interference with local culture and traditions, especially among the Muslim communities along the coast. In addition, secondary impacts would be the higher demand for workers in the labour-intensive tourism service industries. Tourism expansion will exacerbate migration of residents from the rural communities to seek employment in the tourist areas and increase migration of non-locals to the province. These influxes will affect social and cultural structures of the communities. Some key stakeholders also raised concerns on issue about higher crime that could result from tourism expansion.

Potential Shift and Change in Tourist Behaviour

Climate change and secondary effects will change the tourism industry. Currently Krabi tourism offers a niche market that relies on certain local attractions matched to specific target groups. Tourism development must include marketing strategies that consider suitable adaptations to climate change to maintain this industry in the future. One possibility would be for the province to focus their strategy on developing more tourism inland in forested natural sites at waterfalls and in the mountains to reduce pressure on the marine and coastal environments especially during the conventional monsoon low tourism season.

Feedbacks from Stakeholders

- All of the urban zone concerns are issues that already occur in Krabi today, although it is acknowledged that Climate change may drive and/or accelerate these issues further.
- Direction and strategy for tourism development in Krabi province needs to be carefully laid out with focus on the context of Krabi province, especially the carrying capacity of the province must be taken into consideration and it is important to focus on the quality of the tourism rather than just quantity.
- Mechanisms that focus on awareness raising of the impacts of climate change alone will not be sufficient to bring about the changes that are necessary. It is imperative that a strategic and holistic approach is adopted for tourism development, and that a suitable mechanism to ensure adaptation actions are taken. This should include regulation to enforce the controls that need to be put in place. Such regulation could at multiple levels, e.g. regulation set among member of the community, regulation within and among business associations or regulation from the local administration and/or government.
- Process in formulating such mechanism and enforcement of regulation need a thorough understanding of the local context and require continuity with established practices. The local authority who formulate policy, especially the government sector, needs to understand current issues as the starting point and formulate a plan that specifically address the issues of Krabi province. In the same manner, the formulation of regulations in the community also requires the involvement of all members and stakeholders in the community to be appropriate and to address the community issues directly.
- More detailed studies that address the sensitive areas and sector will be required.
- The knowledge on impact of climate change in Krabi province context should also be integrated into the education content for students in the province to aid climate preparedness in future resident populations.

INLAND ZONE

The inland zone occupies the interior of the province and is the least populated and is comprised of a patchwork of natural forest and agricultural area, with rubber and fruit tree crops traditionally dominating although Palm Oil is now also a major and expanding crop. This zone contains all the key upper watershed areas in the province that are important for continued provision of ecosystem services to other areas of the province in a climate-affected context. Management of agricultural expansion and other land use conversion in the upper watershed is a key factor for sustainable development of the province in the future.

Under the climate scenarios the total amount of rain predicted to fall in the future will be reduced slightly but this will not change the general pattern of rainfall for the province. Inland area will receive more rain than the coastal areas (Table 7). However it will be most noticeable in the rainy and dry seasons. In particular the province will no longer experience any areas with more than 120 days with rainfall in a year, and areas with more than 90 days of rainfall in one year will be decreased significantly (Table 8).

	Total area in Rai		
	>1,800 mm/y	1,500-1,800 mm/y	<1,500 mm/y
Baseline	2,449,023	4,903	589,383
Future 10-y	2,441,989	11,935	589,383
Future 25-y	2,441,990	7,033	594,286

Table 7: Area of the province (rai) by annual rainfall (mm/y).

	Total area in Rai			
	> 120 days	90-120 days	60-90 days	< 60 days
Baseline	316,059	1,975,958	149,973	601,319
Future 10-y	0	717,421	1,724,568	601,318
Future 25-y	0	1,117,566	1,324,424	601,319

Table 8: Area of the province (rai) by number of rain days (>10 mm) in a year.

Major crops

Rubber plantations in the coastal areas will be subjected to very little changes in rainfall regime. Most of them will remain to have less than 1,500 mm/y and less than 60 rain days in a year (Table 9). Plantations in the inland and mountainous areas, however, will experience lesser days with rain (Table 10). On the farmer side, this seems to be a positive effect, as it will allow more days for rubber tapping and lesser risk of fungus infection on the tree bark, and thus should increase the overall rubber yield. Rough estimates indicates that rubber production of the province could increase by approximately 10-15% without an increase in planted areas, solely due to the reduced wet days allowing harvest season expansion by about 30 more days per year for the existing rubber estate.

	Total area in Rai		
	>1,800 mm/y	1,500-1,800 mm/y	<1,500 mm/y
Baseline	400,363	635	116,635
Future 10-y	400,368	635	116,630
Future 25-y	400,368	0	117,264

Table 9: Rubber plantation area of the province (rai) by annual rainfall (mm/y).

	Total area in Rai			
	> 120 days	90-120 days	60-90 days	< 60 days
Baseline	31,398	351,783	17,182	117,270
Future 10-y	0	129,428	270,940	117,265
Future 25-y	0	261,392	138,976	117,264

Table 10: Rubber plantation area of the province (rai) by number of rain days (>10 mm) in a year.

Oil palm is a thirsty crop and grows best with plentiful water supply; in Krabi it is therefore grown mostly in the zone where the annual rainfall exceeds 1,800 mm per year (Table 11). Under the future scenarios rain days of the inland oil palm plantation area will be decreased by about 30 days (Table 12). Implication of reduced rain days on oil palm production is not known but longer dry period together with warmer temperature could lead to a higher evapotranspiration and enhance net water loss from soil, resulting in reduced yields during the dry period.

	Total area in Rai		
	>1,800 mm/y	1,500-1,800 mm/y	<1,500 mm/y
Baseline	171,706	0	2,849
Future 10-y	171,707	0	2,849
Future 25-y	171,707	0	2,849

Table 11: Oil Palm plantation area in the province (rai) by annual rainfall (mm/y).

	Total area in Rai			
	> 120 days	90-120 days	60-90 days	< 60 days
Baseline	44,879	124,839	1,988	2,849
Future 10-y	0	66,659	105,048	2,849
Future 25-y	0	94,334	77,373	2,849

Table 12: Oil Palm plantation area of the province (rai) by number of rain days (>10 mm) in a year.

Similar to the other two main crops of the province, rice paddy areas will not be affected by the change in annual rainfall (Table 13), however the number of rain days will be reduced to less than 90 days in a year (Table 14). As all of the rice farming in Krabi province is rain-fed the longer dry period may effect the overall production. However as rice farming is now on the decline in the province, the overall effect may be quite small. It is generally understood that Thailand as a whole will continue to produce excess rice under most future climate scenarios and therefore the threat from food shortage should not be a problem for the country, including Krabi Province, in the future.

	Total area in Rai		
	>1,800 mm/y	1,500-1,800 mm/y	<1,500 mm/y
Baseline	108,080	344	32,495
Future 10-y	108,085	344	32,491
Future 25-y	108,084	0	32,836

Table 13: Rice paddy area of the province (rai) by annual rainfall (mm/y.

	Total area in Rai			
	> 120 days	90-120 days	60-90 days	< 60 days
Baseline	5,317	97,893	4,870	32,839
Future 10-y	0	36,125	71,960	32,835
Future 25-y	0	47,113	60,971	32,836

Table 14: Rice paddy area of the province (rai) by number of rain days (>10 mm) in a year.

Vulnerable Ecosystems

Hill evergreen forest in Khao Phnom Benja National Park can be found at an altitude of 600 meter above sea level, which when compared to others parts of the country this forest type is usually found only at an elevation above 1,000 meters. This unique forest is vulnerable to climate change, as the warmer temperature and rainfall changes could result in the forest retreating up the slopes gradually being replaced by mixed deciduous forest types. There is anecdotal evidence of the upward retreat of certain plant species possibly due to climate change at other locations in Thailand. More research on the underlying causes of these changes is necessary to understand these tentative observations and enable protected area managers to incorporate possible changes in future management planning.

Perceptions of Stakeholders

Most stakeholders realize that the climate is changing especially the daily minimum temperature with the participants agreeing that it is not as chilly at night as in the past. This has had an impact on the traditional gathering of villagers around open fire in their villages during the cold season to keep warm which is now extremely rare.

Direct impacts from changing climate on crop yield and natural resources are still not noticed by the participants who reported that such impacts are difficult to distinguish from effects due to deforestation and land use change in the watersheds. Government policy to promote oil palm, which may be in part an indirect consequence of climate change mitigation, is thought by many as the main reason for the decline in the water resources of the province more than climate change.

Participants responded that the decisions to grow which crops depends more on market demand than the suitability of land and climate. However, some households have started to realize the limitation and disadvantages of monoculture cash cropping and are starting to consider mixed cropping as an alternative to promote independence from the traders as well as to harmonize their production with the local environment and climate. Diversified cropping will also reduce risk of complete wipe out of mono-specific crops due to some climate related extremes such as drought, diseases and insects outbreak, for examples, as different crops have different tolerant and resilient degree to these extremes.

Local wisdoms and traditional knowledge could be useful to help to respond to environ-mental changes and many participants believed this knowledge was available in the past. However, this has been lost by introduction of modern technology. Local research to compile and conserve traditional wisdom is critical for the community and province to strengthening their capacity to adapt and respond to future environmental, including climate, change in the future.

5. Conclusions

Six systems or sectors in Krabi were identified that would be sensitive to future climate risk, these are

1. Inland agriculture
2. Forest biodiversity
3. Coastal urban
4. Coastal aquaculture
5. Tourism
6. Coastal communities and livelihoods

Some of these systems and sectors may receive negative impacts while some may benefit from future climate trend to different degrees. To assess the vulnerability of these systems and sectors to future climate change, not only the climate risks which could be projected from likely impacts of climate scenarios on systems and sectors, but also coping capacity of those systems and sectors which may or may not be directly dependent on climate. Vulnerability as the function of risk and coping capacity of system and sectors to climate change are for each sector below.

Inland Agriculture

Inland agriculture particularly rubber and oil palm plantations, despite possibility of reduced annual rainfall, has geographic advantage in that it is upstream to most other systems and therefore receive sufficient water for plant growth. The rainfall levels in the province are very high with almost year round distributions so although rainfall level is less under the future climate scenarios this isn't reduced beneath the amount required for agriculture. The agricultural system is also backed up by large capital and investment as well as technology and financial capacities to develop coping for climate change and climate variability. This system is clearly one of the winners under the futures scenarios predicted.

Forest Biodiversity

Upland ecosystems, especially the hill evergreen forest, will be more vulnerable as the climate becomes warmer and dryer in the future. Most of this forest type in Krabi is already found near or even below its natural altitudinal level and this is a unique function of the province its locality and climate. This is reflected in the high biodiversity value of the province with several critically endangered species still occurring. The adaptation of plants and animals to the climatic stimuli are uncertain although anecdotal evidence from elsewhere suggests that the forest type transitions will move upslope as temperature increase and rainfall decreases. However, ultimately this upwards retreat cannot continue as the peak elevations in the province and surrounding areas are around 1,000 m in altitude.

Additional threats to natural forest areas could result from indirect climate change impacts. National policies and market forces that increase demand for biofuels may lead to an expansion of palm oil crop area in the future. As no new land is available, current natural areas could be opened up for land conversion to cater for increased market demand. This has already occurred in a couple of wetlands sites in neighbouring provinces where apparently “useless swamplands” have been converted to oil palm plantations, with huge impacts on local water supply, flood control and water quality.

Coastal Urban Centres

Urban centres along the coast, including Krabi Municipality, will be slightly affected by erosion and inundation due to sea level rise in the future. Water supply for domestic uses may also be under more stress, as competition for different uses in the province will be more intense and some coastal water bore holes become infiltrated with saline water, especially in the dry season. The frequency of tropical cyclone will remain low. Most of the projected risks are however within the current capacity of the system to cope with such, by developing coastal protection barriers and installing piped water supply. Therefore the system is considered low in vulnerability to future climate change.

Aquaculture

Industrial scale coastal aquaculture is another sector that will have quite low risk to future climate change. This sector generally benefits from large capital investments, good access to various technologies, and know-how to cope with future climate risks. The sector is considered to have a very low vulnerability to climate change.

Tourism

Tourism sector may benefit, rather than suffer, from shorter rainy monsoon period as this will enable a longer tourist season of the province by up to 4 weeks more than present. Some of the tourist-support infrastructures and buildings along the coast may be affected by sea level rise. However with large financial resource and well access to technology make this sector one of the least vulnerable on the province.

Coastal Communities and Livelihoods

Coastal ecosystems, such as mangrove and estuaries, which are main supplementary sources for foods and income for subsistent communities along the coast, especially during the monsoon period will be threaten by sea level rise and reduced freshwater input from upstream watersheds. Beach sand aquifer which is a main source of water for many local households may be more contaminated by sub-sand saltwater intrusion. The shorter monsoon period may appear to be positive for coastal subsistent communities by allowing more time window to fish in open sea than before. However without an effective management and conservation of marine resource this opportunity may not be so beneficial to the community as it should be. Although this study did not assess the ecological vulnerability of the fisheries themselves, the expected impacts on marine ecosystems suggest that cautious management would be appropriate.

Most communities have insufficient mechanism and capacity to cope with future threats from climate. The lack of long term vision and strategies at national and provincial levels to strengthening community to become self sufficient will push the communities to rely more on the top-down trade driven economy that will further weaken the resilient of the community. Moreover a number of young generation people in the community now are changing their livelihoods from those in harmony with natural resource and environment to become more globalized livelihoods that would depend more on external economy and resources.

Coastal communities and associated livelihoods are considered the most vulnerable system and sectors in Krabi.

6. Recommendations

GENERAL PRINCIPLES

General principles and assumptions applying to all geographic zones;

1. Conservation friendly adaptations offer long term sustainable solutions.

2. Under the existing ten year national economic and social development plan (2008 to 2017) and the current four year provincial development plan there are no proposed changes to land allocation patterns, therefore distributions of land usage will remain similar to today.

3. High conservation value areas will remain protected; protected areas, state forest land, and other reserves will not be converted to other uses. Also, they will be 'effectively' protected from insidious encroachment (e.g., planting rubber trees in forest reserves with the ultimate goal of converting the area from a natural forest to a rubber plantation).

4. Climate impacts on biodiversity and in particular on the composition, structure, and function of natural ecosystems are expected. However, these impacts will have to be monitored and will require further study. The forecasted changes should not be used as a justification for conversion of protected areas.

5. Although there is some uncertainty regarding the magnitude of changes in climate variables, it is assumed that the changes forecast here will occur. These include:
    a. About 1˚C increase in temperature (more inland and less on the coast)
    b. 100-300 mm less total annual rainfall
    c. A contraction of the rainy season / ~ 30 fewer rainy days (where rainy days = days with at least 10 mm of rainfall)
    d. Sea level rise of about 1 cm per year over the next 25 years, with a consequent shoreline retreat of 10 –35 m
    e. A reduction in the number of typhoons making landfall in Krabi, but a potential increase in the strength of typhoons that strike Krabi

SYNTHESIS FOR COASTAL ZONE

Principles and Assumptions

1. Coastal zone inhabitants are highly vulnerable to climate change because of rising seas, greater potential for storm surge damage, and a likely reduction in the supply of freshwater entering the estuaries.

2. At present, aquaculture is important for livelihoods of some coastal residents. There are currently few industrial-scale aquaculture ponds. We assume that aquaculture production in the coastal zone of Krabi will continue to be dominated by small-scale producers and will continue to be an important livelihood for some coastal residents.

3. Current Department of Fisheries policies are for the siting of shrimp ponds above the high water mark to avoid inundation of ponds during high tide, it is anticipated that this policy will be maintained by the Department as sea levels rise. (Although ponds are currently above the high water mark with a 1 cm rise in sea level predicted per year many will soon

become susceptible to inundation, the impact of this sea level rise on shrimp production and migration of ponds to higher ground needs to be further explored).

4. The dry season will expand by about 30 days over the next 10-25 years, which will also expand the fishing season (i.e., number of days fisherman can go out to sea in their boats) in particular access to offshore fisheries will be increased.

5. Mangrove ecosystems provide important ecosystem services for coastal residents, including breeding grounds for crustaceans, mollusks, and fish; coastline stabilization, which in effect provides some resistance to land loss from sea level rise; and filtering nutrients flowing from upstream, which diminishes the nutrient loads in the estuaries and bays. Protecting existing mangrove areas, enhancing those that are degraded, and restoring those that have been lost is an effective adaptation to enhance the resilience of coastal ecosystems (including human inhabitants) to climate change impacts.

Recommendations

1. Mangroves should be protected, restored and rehabilitated. Specifically,
    a. There should be no further development of existing mangrove areas
    b. Coastal areas that once had thriving mangrove ecosystems should be identified and restored where feasible
    c. Existing degraded patches of mangroves should be rehabilitated to increase the value and integrity of the ecosystem services (including livelihood benefits) that they provide
    d. Inland buffer zones (or easements) should be identified and designated to allow mangroves to 'naturally adapt' and migrate inland as sea levels rise. This will require land use zoning – and topographic mapping to allow proper zoning – and effective enforcement of the land use zones. No new roads should be built along the coastal zone to facilitate enforcement.

2. Because fishing communities will likely benefit from the expanded dry season allowing more days at sea, it will be important to develop a fair, equitable, enforceable, and scientifically based regulatory system to ensure that stocks of fish and shellfish are not deleteriously affected by either commercial or subsistence fishing. This effort should be planned and implemented well before stocks become depleted. Although this is a climate-related recommendation, it is a prudent measure even in the absence of climate change.

3. In parallel with the above, the increased access to offshore fisheries and increased demand for local seafood products to cater to increased tourism will require a fisheries management plan that ensures the sustainable management of near shore and offshore fisheries.

4. Relocation of vulnerable human settlements and infrastructure should be considered where feasible. Specifically,
    a. Vulnerable communities, populations (e.g., elderly or infirm), and infrastructure (schools, hospitals, power stations) should be relocated inland away from potential impacts from storm surge, flooding, and effects of coastal erosion.
    b. Any new industrial facilities that must be sited along the coast (e.g., shrimp larvae production facilities) should be built in areas identified as being least vulnerable to sea level rise and storm surge (e.g., the existing fuel delivery terminal for Krabi city which is located at least 10 m above current sea level on a rocky outcrop).

5. Given sea level rise, storm surge, and the general vulnerability of many coastal areas, 'hard' technological and/or engineering solutions (e.g., seawalls, levies, roads) should be avoided because they are unlikely to be sustainable in the long term. In some areas, it might be reasonable to experiment with lower-tech solutions (e.g., bamboo poles sunk vertically into the shore to act as a sediment trap) to facilitate capture of material for accretion of deltas and stabilization of coastlines. These experiments might be most appropriate in areas intended for restoration of mangroves or conversely in areas that already have some infrastructure but which are vulnerable to sea level rise.

6. Water management on a basin level will be critical – so an Integrated River Basin Management (IRBM) plan that considers water inputs under changing rainfall patterns and increased demand for agriculture and tourism expansion is necessary. The crucial factor will be to ensure that freshwater flow to maintain coastal brackish water conditions and sediment input that are vital to healthy mangroves are maintained. Healthy productive mangroves will be most resilient to rising sea level.

7. Installation of dams and reservoirs as a knee-jerk solution to the freshwater problem should be avoided because they could exacerbate the impacts of climate change by impeding downstream flow of sediments. Sediments are important for coastal stability; if sediments are reduced, sea level rise will be exacerbated and mangrove and other coastal ecosystems will have a harder time migrating inland at a fast enough pace to keep up with sea level rise. Rather than building dams, basin-wide water management should focus principally on conservation and efficient use of water.

8. Conservation of the near shore environment is also important as a strategy to strengthen coastal resilience to climate impacts. Following the Indian Ocean Tsunami the role of near shore reefs, in reducing the intensity of waves was realised. Healthy coral reef ecosystems help to protect the coast from the devastating impact of waves driven by a storm surge. In areas where coral reefs have been degraded, coral reef restoration should be considered and in areas of extreme degradation the placement of artificial reefs should be considered to accelerate the restoration of a healthy and diverse near shore environment.

SYNTHESIS FOR URBAN ZONE

Principles and Assumptions

1. The expansion of the dry season will expand the tourism season by about 1 month resulting in an increase in tourist arrival in the province.

2. Current tourism developments are focused on urban coastal areas many of which are reaching saturation. Additional tourists will drive the development of new tourist facilities and infrastructure.

3. Given the predicted increase in tourism, more workers many of whom are in sectors not supplied by the local employment market will be required; tourism will continue to drive in-migration of workers seeking employment in the tourism and related tourism service sectors.

4. With growing population water use will increase, and demands on urban water supplies will increase.

5. Even without expansion of the tourism industry, the anticipated shifts in rainfall patterns in combination with sea level rise will probably mean that the urban zone will face water scarcity especially during the dry season.

6. Predicted changes in rainfall patterns, rising sea level, and population increase will place new and increasing demands on drainage, storm water, and wastewater management systems.

Recommendations

1. To maintain the quality of the services and experiences that Krabi offers tourists as well as residents / service providers, it will be necessary to develop (as soon as possible) a thoughtful plan based upon consultative dialog among current stakeholders.
    a. The plan should establish a vision for controlled growth of the tourism industry in Krabi province. The vision should be based not only on economic and social considerations but also on the capacity of the ecosystems upon which the tourism industry and service providers depend. That capacity should not be exceeded.
    b. Provisions should be established to minimize and mitigate all environmental impacts from the tourism industry, including contributions to global warming. Special efforts should be made to protect coastal resources and key ecosystems.
    c. Population increases will inevitably lead to greater urbanization – more houses, demand for water and food, etc. A plan to accommodate in-migration should be developed so that growth proceeds in a way that maintains quality of life and does not degrade the environment.

2. An expanded tourism industry will inevitably lead to greater urbanization.
    a. Local tourism planning should be developed and implemented to constrain urbanization to areas that are least vulnerable to climate impacts and will cause the least damage to the natural resources and ecosystems on which the sector depends
    d. Areas that are currently developed with substantial investments in infrastructure should be protected if possible via engineering solutions; this will be a compromise solution that increases the likelihood of saving other parts of the coastline from future development
    e. Low lying areas should not be developed because they will be susceptible to inundation and storm surges. The best way to prevent development of these areas is to avoid building roads through them.

3. Changes in rainfall patterns combined with sea level rise will probably mean that the urban zone will face water scarcity especially during the dry season, and especially without basin-wide water management.
    b. The provincial government should work with key stakeholders from all three zones to produce an enforceable, fair, and equitable Integrated River Basin Management (IRBM) water resources management plan. This will be especially important if oil palm and rubber production continues to play a major role in the economy of the inland zone.
    c. Urban planners should work with engineers to devise and construct the infrastructure for a municipal water supply based on as long a planning horizon as possible (e.g., 100 years). Potential impacts of sea level rise, temperature increases, further shifts in rainfall patterns, and potentially more severe extreme

events like floods, droughts, and storm surge should be incorporated into engineering designs.

4. Changes in rainfall patterns, sea level rise, and an increased population in the urban zone will make it challenging to develop effective drainage, storm water, and wastewater management systems.
    a. Urban planners should work with engineers to develop appropriate systems for storm- and wastewater management. Planners should consider building infrastructure with the longest possible horizon possible (e.g., 100 year floods vs. 50 year floods) so that the drainage systems are robust enough to withstand the anticipated climate impacts.
    b. Planners and engineers should also base their designs on existing drainage systems that manage water flow in low-lying areas where relying on gravity alone may be inadequate (e.g., the 'monkey cheek' system in Bangkok).

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SYNTHESIS FOR INLAND ZONE

Principles and Assumptions

1. Despite macro-level land use zoning / allocation set by provincial government policy, actual land use depends on the choices of individual land holders. There are few industrial plantations; for example, Univanich, one of the largest Palm oil producers in southern Thailand, purchase 83% of their raw materials from local farmers.

2. These small holder farmers decide their agricultural activities based on market prices, established practices, and relationships with companies and cooperatives. In addition farmers are exposed to incentives derived by current government policies. These policies which regularly change influence the agricultural crops that are promoted by the government extension service. However due to limited resources these usually influence new farmers or farmers who are looking to diversify their productivity rather then established farmers.

3. Over 95% of the current agricultural lands are cultivated for oil palm or rubber.

4. Climate change forecast – the study's model projections indicate that there will be an expansion of the dry season by about 30 days over the next 10-25 years.

Rubber

1. Assumption 1 – Productivity in Krabi province is currently limited by the number of days trees can be tapped and not by the productivity of individual trees.

2. Assumption 2 – Rubber productivity will increase by about 13% based on the following logic and calculations:
    a. Assumption 1 is correct and productivity / ha increases when farmers can tap their trees on additional days.
    b. The climate change forecast is correct and farmers will have 30 additional rainless days in which to tap their trees.
    c. A motivated, affordable labor force remains available to tap trees on the additional rainless days.

d. Capacity for transporting and processing additional quantities of rubber exist.
e. In 2007, rubber trees produced 270 kg / rai (~43.2 kg/ha) by tapping their trees for 228 days.
f. If productivity of the trees is held constant, but the number of days trees can be tapped increases by 30 to 258, the annual productivity should increase to nearly 49 kg/ha – a 13% increase

5. Assumption 3 – if average productivity increases by 13%, the total area in rubber stays the same, and 2007 is considered to be an average production year, then the potential annual production of rubber should increase from 247,834 tons to 280,052 tons.

6. Assumption 4 – If 2007 prices are used, the total value of the rubber harvest would increase from 16,523 million baht to 18,670 million baht. However, given the expected increase in demand for rubber from China and other growing regional economies, this estimate is probably conservative.

7. Assumption 5 – Demand for rubber for China (the largest local market) will continue to increase. In 2002 China became the world's largest consumer of natural rubber, bypassing the US at 3.45 million tons, or 18.2 percent of total world consumption. China's demand for natural rubber is estimated to reach 11.5 million tons per annum by 2020, about 30 percent of the world's total production.

Oil Palm

1. Oil palm is a thirstier crop than rubber and its productivity will decrease in drought years. Univanich, one of 40 commercial companies producing palm oil in Krabi province, which contributes 11% of the palm oil produced, observed a 2-year lag in the impact of dry years on productivity (www.univanich.com), not increase, as a result of the altered rainfall regime.

2. Demand for palm oil – for food, biodiesel, and other commodities – will continue to increase (or at best remain stable) for the foreseeable future given growing demand from China and Thai government policies that promote biofuels.
3. Given existing capital investments in oil palm plantations, the substantial additional capacity for processing oil palm, and assumption 2, it is difficult to envision a reduction in the land area cultivated in oil palm unless
    a. Market prices drop appreciably, or biofuel policies change in Thailand or elsewhere
    b. Early adopters choose to diversify their crop base as a bet hedging strategy against uncertainties in both market and climate variables
    c. Other farmers can be persuaded to diversify their crop base

Recommendations

1) Given the logical assumptions outlined above, WWF believes that the most prudent development adaptation for the inland zone is to encourage agricultural producers to diversify farms or plantations where oil palm currently dominates. Diversification will achieve three specific benefits; it will:
    a. Maximize productivity within the context of ecological limits of the system and given the anticipated climatic shifts;
    b. Minimize environmental impacts especially on water resources because under the forecast future climate, a continued emphasis on oil palm production will likely have substantial impacts on downstream water availability; and,

c. Provide more opportunities for the labour force

2) Diversification will ensure alternative income streams in the context of dramatic price volatility and will also help provide some risk management due to extreme climatic events for small scale farmers. For example in an unusually wet year, losses in a farmers ability to tap their rubber crop may be compensated by increases in palm oil production and vice versa, in a drought year reductions in oil palm production will be compensated by increased rubber tapping days.

3) Options for integrated water resources management to reduce downstream impacts from increased agricultural water demand. If oil palm area expands the increased water demand will reduce the supply downstream. This could provide the platform for a Payment for Environmental Services pilot, whereby lowland agriculture, industry or tourism compensates upland farmers who desists from expansion of thirsty crops to secure sufficient downstream flows?

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