COMPONENT 1

POLICIES AND MARKET INCENTIVES IN SUPPORT OF NATURAL CAPITAL

THE INTEGRATION OF NATURAL CAPITAL ACCOUNTING IN PUBLIC AND PRIVATE SECTOR POLICY AND DECISION-MAKING FOR SUSTAINABLE LANDSCAPES

NATURAL CAPITAL

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POLICIES AND MARKET INCENTIVES IN SUPPORT OF NATURAL CAPITAL

OUTPUT 1.2.2

ASSESS THE INTER-DEPENDENCIES OF THE TOURISM SECTOR ON NC AND ECOSYSTEM SERVICES

OUTPUT 1.2.3

ASSESS THE INTER-DEPENDENCIES OF THE WATER RESOURCES SECTOR ON NC AND ECOSYSTEM SERVICES

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Acknowledgement

The report **"Output 1.2.2 Assess the Inter-dependencies of the Tourism Sector on Natural Capital (NC) and Ecosystem Services and Output 1.2.3 Assess the Inter-dependencies of the Water Resources Sector on Natural Capital (NC) and Ecosystem Services"** was prepared under the academic leadership of its lead authors, Assoc. Prof. Dr. Tunlawit Satapanajaru, an expert in environmental technology and environmental management, and Asst. Prof. Dr. Pasinee Worachananant, an expert in environmental science and marine environmental management, both from Kasetsart University (KU).

We would like to express our appreciation for their contributions to this assessment. Their expertise contributed to the review and synthesis of available information and the analysis of the interdependencies between the tourism sector, water resources, natural capital (NC), and ecosystem services (ESS) in Krabi Province.

We gratefully acknowledge all relevant agencies and organizations for providing data, reports, and technical information, which formed the basis of this assessment.

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Executive summary

This report assesses the interdependencies between the tourism sector, water resources, natural capital (NC), and ecosystem services (ESS) in Krabi Province, Thailand. The objective of the assessment is to understand how tourism activities rely on ecosystem services and how environmental conditions influence the sustainability of tourism development.

Krabi Province is one of the major tourism destinations in southern Thailand, characterized by rich natural capital including tropical forests, rivers, mangrove forests, coral reefs, seagrass beds, and coastal ecosystems. These ecosystems provide multiple ecosystem services such as water supply, coastal protection, biodiversity habitats, recreational opportunities, and cultural values that directly support the tourism sector.

The assessment indicates that tourism in Krabi is highly dependent on several ecosystem services. Marine ecosystems such as coral reefs and seagrass beds support tourism activities including snorkeling, diving, and marine recreation. Mangrove forests and coastal ecosystems provide coastal protection, improve water quality, and support ecotourism activities. Freshwater resources are essential for tourism infrastructure such as hotels, restaurants, and recreational facilities.

However, tourism development may also generate pressures on ecosystem services. Increasing tourist numbers can lead to higher water consumption, wastewater discharge, marine pollution, and coastal development pressures. These pressures may affect ecosystem health and reduce the quality of ecosystem services that tourism depends on.

Understanding the interdependencies between tourism and ecosystem services is therefore essential for sustainable tourism development and effective policy planning. Integrating natural capital considerations into tourism and water resource management can help ensure that economic development does not compromise ecosystem sustainability in the long term.

1. Environmental Existing Condition of Krabi Province, Thailand

1.1 Location

Krabi is one of the provinces of southern Thailand located on coast of the Andaman Sea. Latitude of center is 8.1112° or 8° 6' 40" north, and longitude of center is 99.1097° or 99° 6' 35" east. It is approximately 814 kilometers from a capital city of Thailand, Bangkok. A total area of Krabi is 4,708.512 square kilometers or approximately 2,942,820 rai bordered with neighboring provinces as follows:

- Northern Krabi: Phang Nga Province and Surat Thani Province
- Southern Krabi: Trang Province and Andaman Sea
- Eastern Krabi: Nakhon Si Thammarat Province. and Trang Province
- Western Krabi: Phang Nga Province. and Andaman Sea

1.2 Administrative classification and population of Krabi province

Krabi is administratively divided into 8 Amphoes (Districts) (Figure 1): Amphoe Mueang, Khao Phanom, Khlong Thom, Plai Phraya, Ko Lanta, Ao Luek, Lam Thap, and Nuea Khlong. The provinces jurisdiction covers not only in-land districts and sub-districts, but also extends to more than 130 large and small islands including the world famous Phi Phi Islands.

For population, Krabi data was reported at 480,057 Persons in 2023. This records an increase from the previous number of 471,705 Person for 2019 even though there was the COVID-19 pandemic, also known as the coronavirus pandemic as show in Figure 2.

1.3 Topography

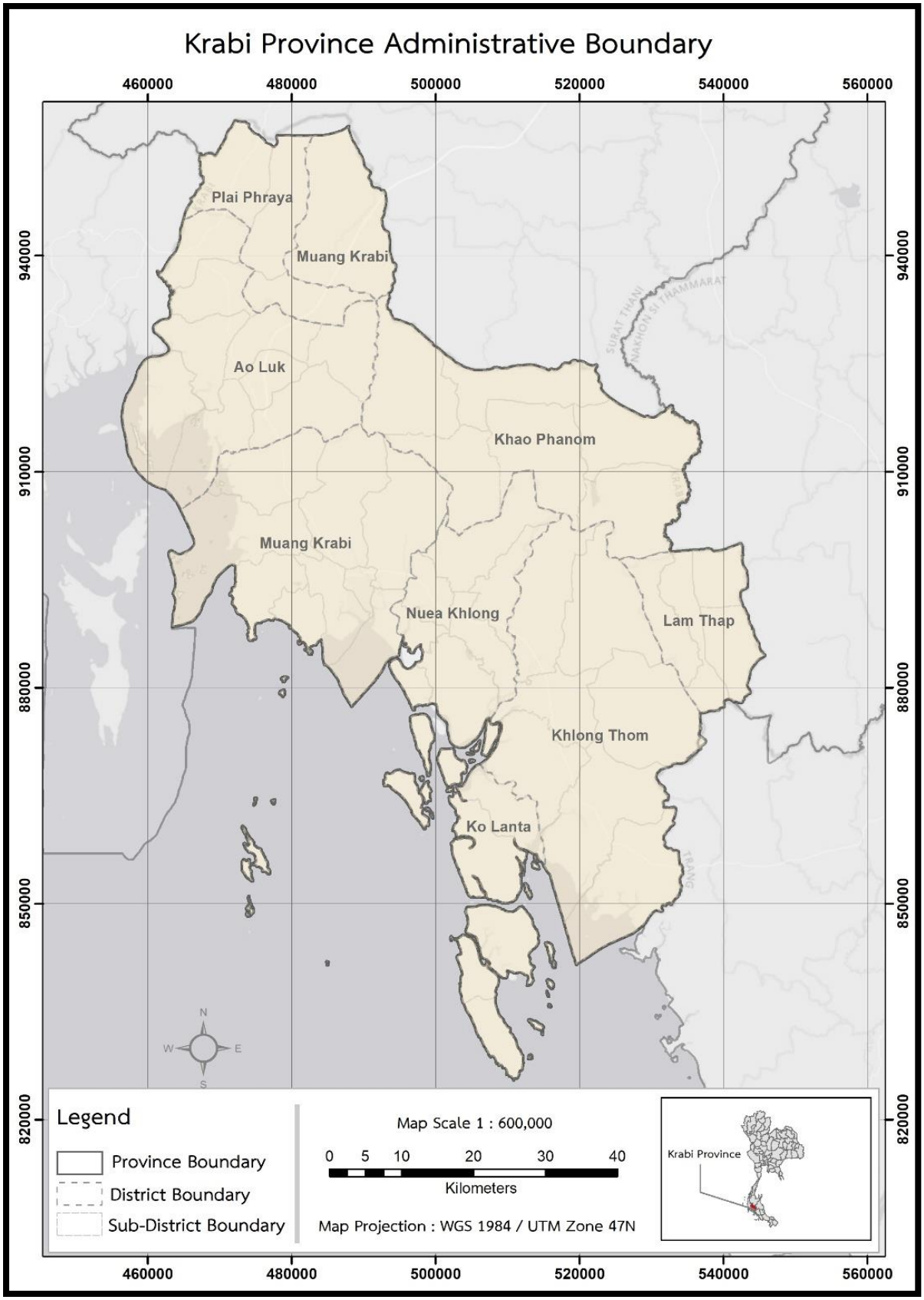
Krabi's landscape can be divided into four types.

1) The plains are a space in the lower middle on the west side and over the north of Krabi (with a height of about 10-30 meters above sea level). On the western part of Krabi, there are lowland areas along the Andaman coast, 160 kilometer shoreline, and flood plain around the Krabi River.

2) Hills, mountains or flat, height is about 50–100 meters above sea level. Undulating, sloping, and steeping terrains are scattered on the northern area. Moreover, there are distinctive limestone-formation mountains which are scattered both inland and along the coast. These geological features are, for example, Ton Sai Beach and Railay Beach on the Phra Nang Peninsula. In addition, the scattered mountainous terrains interspersed with undulating areas are in the eastern and southern part of Krabi.

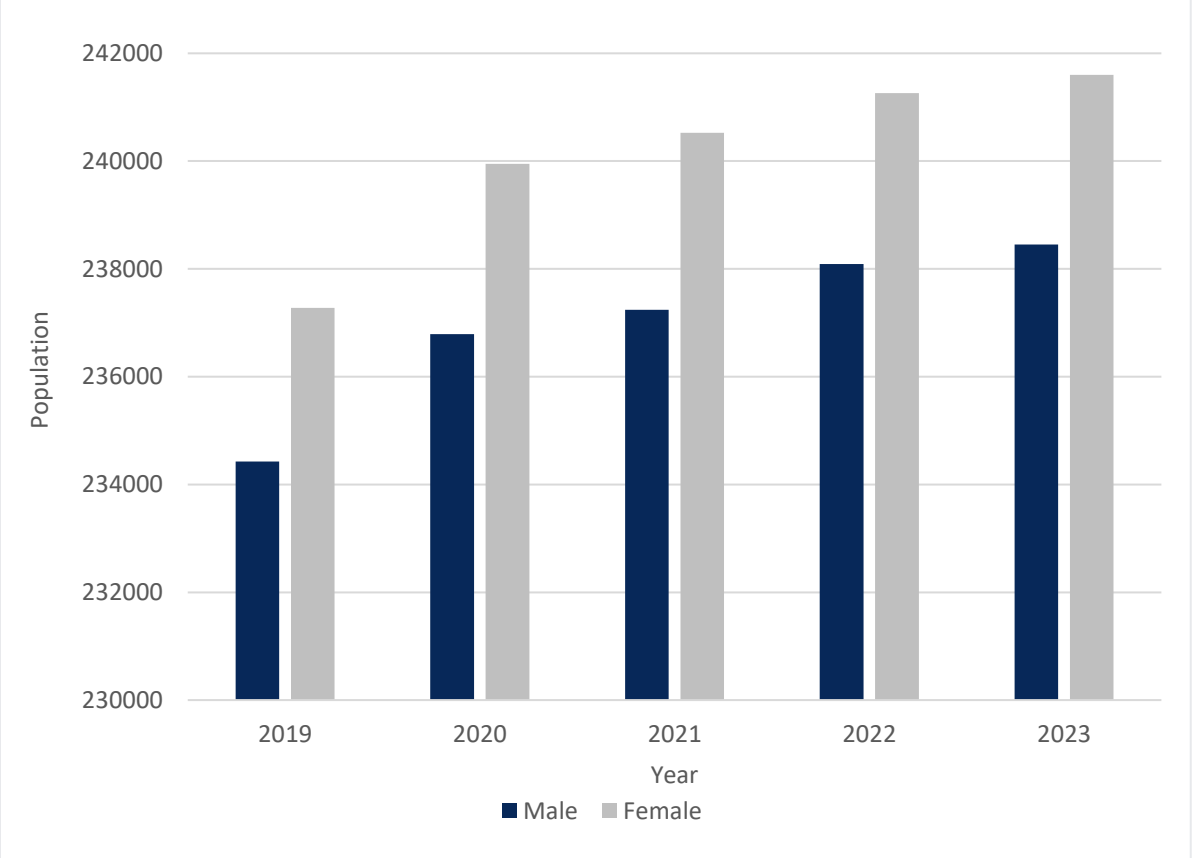
3) High mountain areas mostly are located in the north-south. The peak height to 1,402 meters, above sea level. At Panom Mountain, geological structure favorable properties as a source of water supply such as Faulting, Cracking, and Tracing the curve of the rock. Shale is a layer of limestone rock and absorbs its maximum potential which amount of water available in the 10-20 cubic meters per hour. There are several canals originating from Khao Phanom Bencha including Khlong Pakasai, Khlong Krabi Yai and Khlong Krabi Noi.

Figure 1 **Administrative classification of Krabi province**



Source: Created by the authors using spatial data obtained from GISTDA (2022a).

Figure 2 Populations of Krabi Province



Source: The Bureau of Registration Administration (2019-2023)

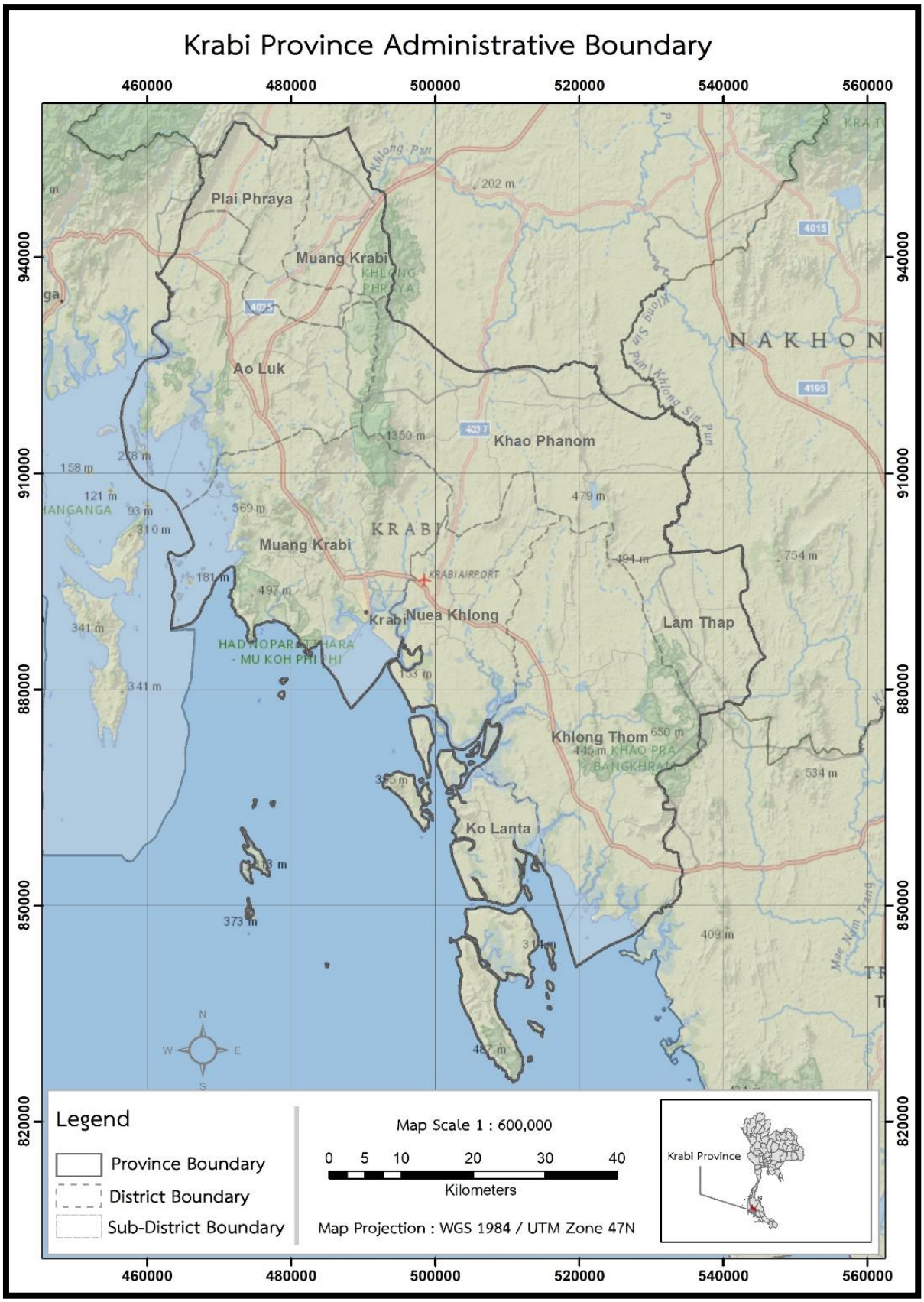
4) Islands, Krabi is consisted of the large and small islands (154 islands), including Koh Poda Island, Koh Lanta, Koh Phi Phi, Koh Ngai, Hong Island, Koh Rok, Mor Island, Chicken Island, Yao Yai Island, Koh Talabeng, Koh Muk, Pak Bia Island, Bamboo Island and etc.

The boundary and geographical feature of Krabi province is shown in Figure 3.

1.4 Climate

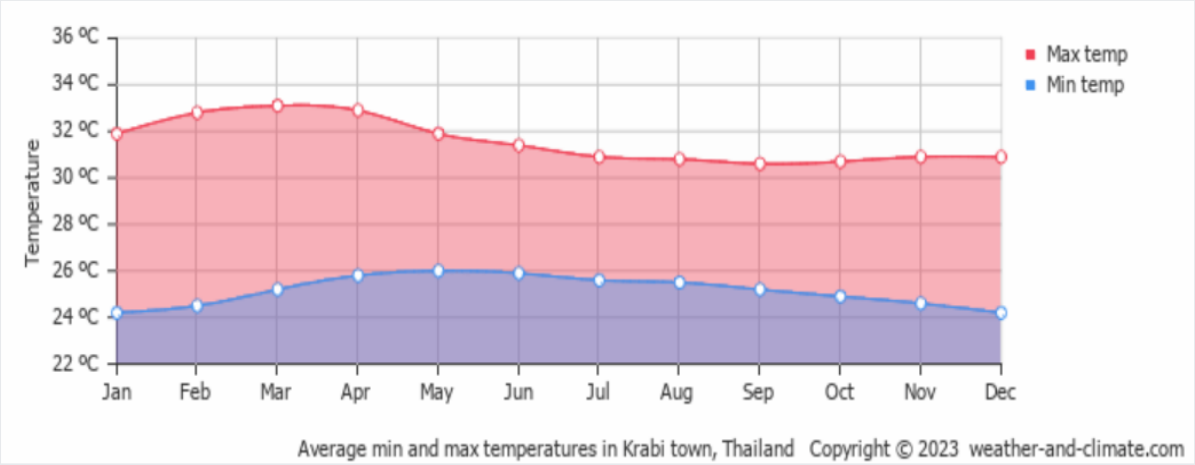
Since Krabi is located in tropical zone, so the climate is hot all year round, with a rainy season due to the southwest monsoon, which starts from May to October, and a dry season from December to March. The temperature is high throughout the year, in fact, average highs never drop below 31 °C (88 °F). However, from December to March. The humidity is slightly lower. At night, temperatures rarely drop below 20 °C (68 °F), although this can sometimes happen between December and March. From February to April, before the arrival of the monsoon, there is a slight increase in temperature; this is typically the hottest time of the year (together with May, the first monsoon month), and the temperature often reaches 35/36 °C (95/97 °F) (Figure 4). It goes a bit better on the islands and the beaches, also because of the sea breeze. For the rain fall, it amounts to 2,000 millimeters per year (Figure 5). Since the south-western winds hit it directly, on this coast overlooking the Andaman Sea, the rains during the period of the southwest monsoon are more abundant than on the other coast of peninsular Thailand, that is, that of the Gulf of Thailand (Weather and Climate, 2023).

Figure 3 **Topographical map of Krabi Province, Thailand**



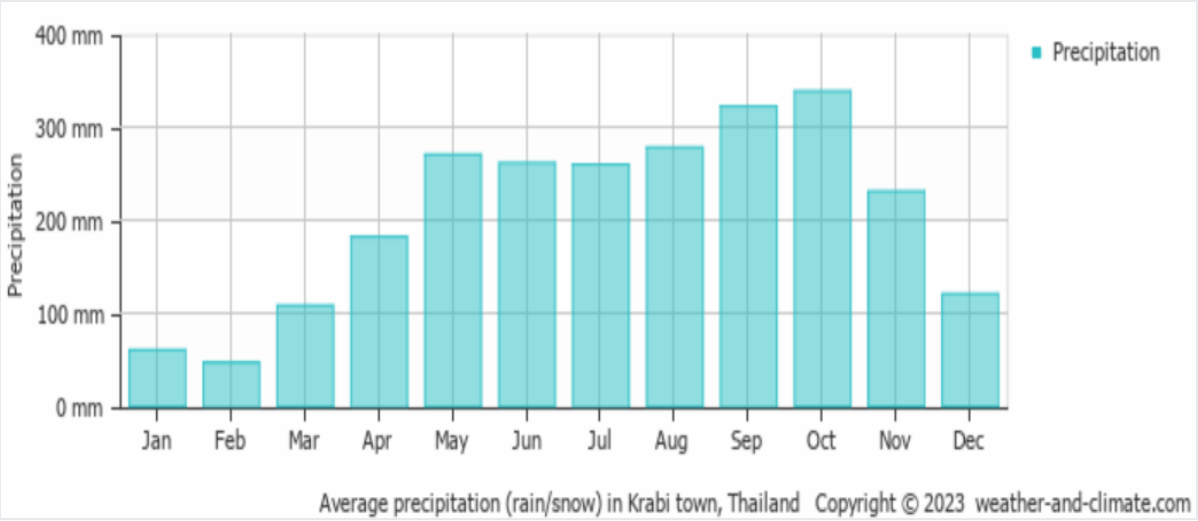
Source: Created by the authors using spatial data obtained from GISTDA (2022a).

Figure 4 Average temperature of Krabi Province, Thailand



Source: Weather and Climate (2023)

Figure 5 Average precipitation of Krabi Province, Thailand



Source: Weather and Climate (2023)

1.5 Soil and land use

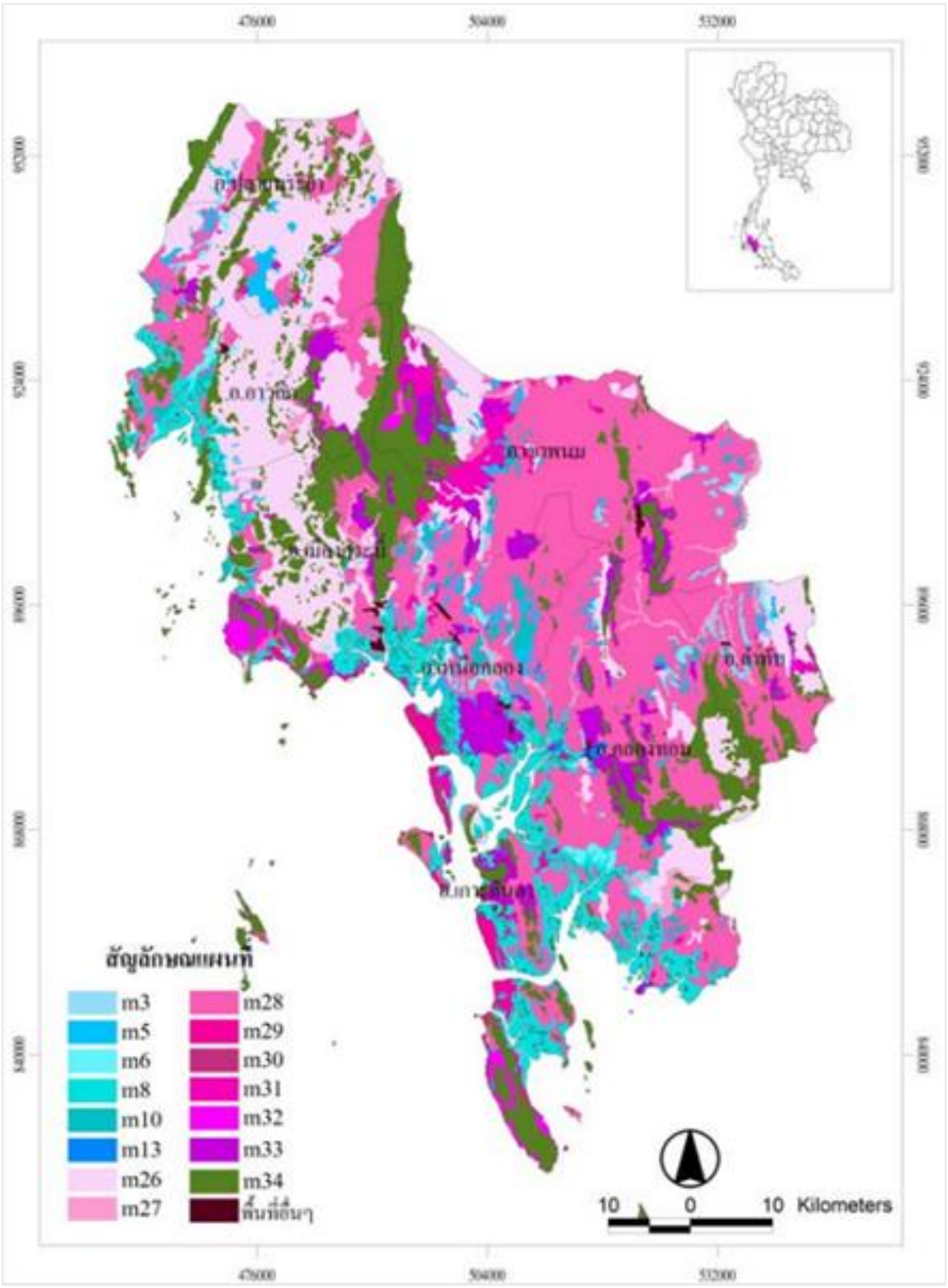
Krabi province soil can be divided into 15 groups based on soil characteristics and properties of soil as show in Table 1 and Figure 6. Most soil is loam soil and suitable for agriculture.

Table 1 **Soil series of Krabi Province**

Soil group	Soil Characterization
M3	Acid soil with moderate depth, Strong acidity is found in the depth between 50-100 cm. from the soil surface.
M5	Clay soil with soil reaction from neutral to alkaline
M6	Clay soil with soil reaction from very acidic to very strong acidic.
M8	Coastal mud soil with regularly flood with seawater.
M10	Loam soil caused by riverine sediment deposit
M13	Shallow soil with gravel found in depth around 50 cm. from the soil surface.
M26	Clay soil with high depth.
M27	Loam soil around the riverbank.
M28	Loam soil with high depth
M29	Sandy soil with organic layer
M30	Thick sandy soil.
M31	Shallow soil with a lot of gravels found in depth around 50 cm from the soil surface.
M32	Shallow soil in which bedrock is found within a depth of 50 cm from the soil surface.
M33	Medium-depth soil with a lot of gravels or rock fragments in the depth between 50-100 cm. from the soil surface.
M34	Soil in the areas with very steep slopes.

Source: Land Development Department (2007)

Figure 6 **Soil series map of Krabi Province, Thailand**

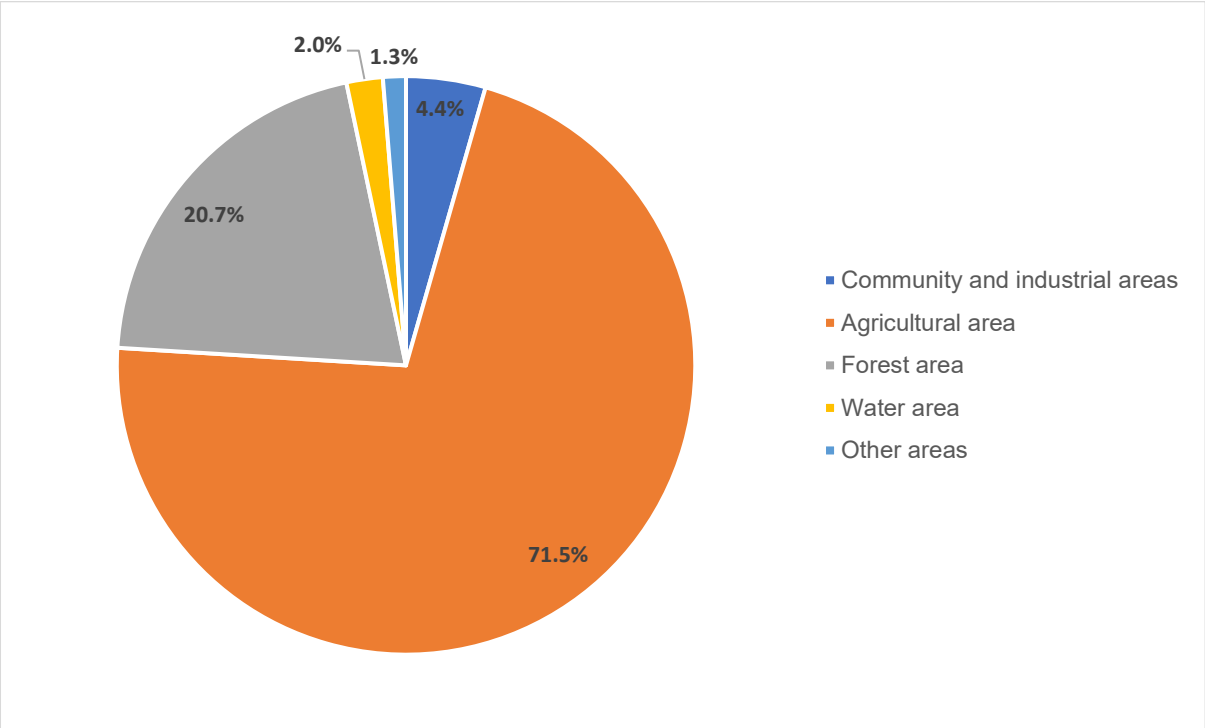


Source: Land Development Department (2007)

Land Development Department, Thailand indicated that the land use in Krabi provides can be major divided in to 5 groups, agriculture (71.5%), forests (20.7%), community and industrial areas (4.4%), water area (2.03%) and other as shown in Figure 7 and map in Figure 8. As the major agriculture land use in Krabi province are rice fields (0.2%), crop area (0.2%), trees especially, oil palm and, rubber tree (70.24%), tropical fruits and vegetable (0.22%), aquaculture (0.84%) and other.

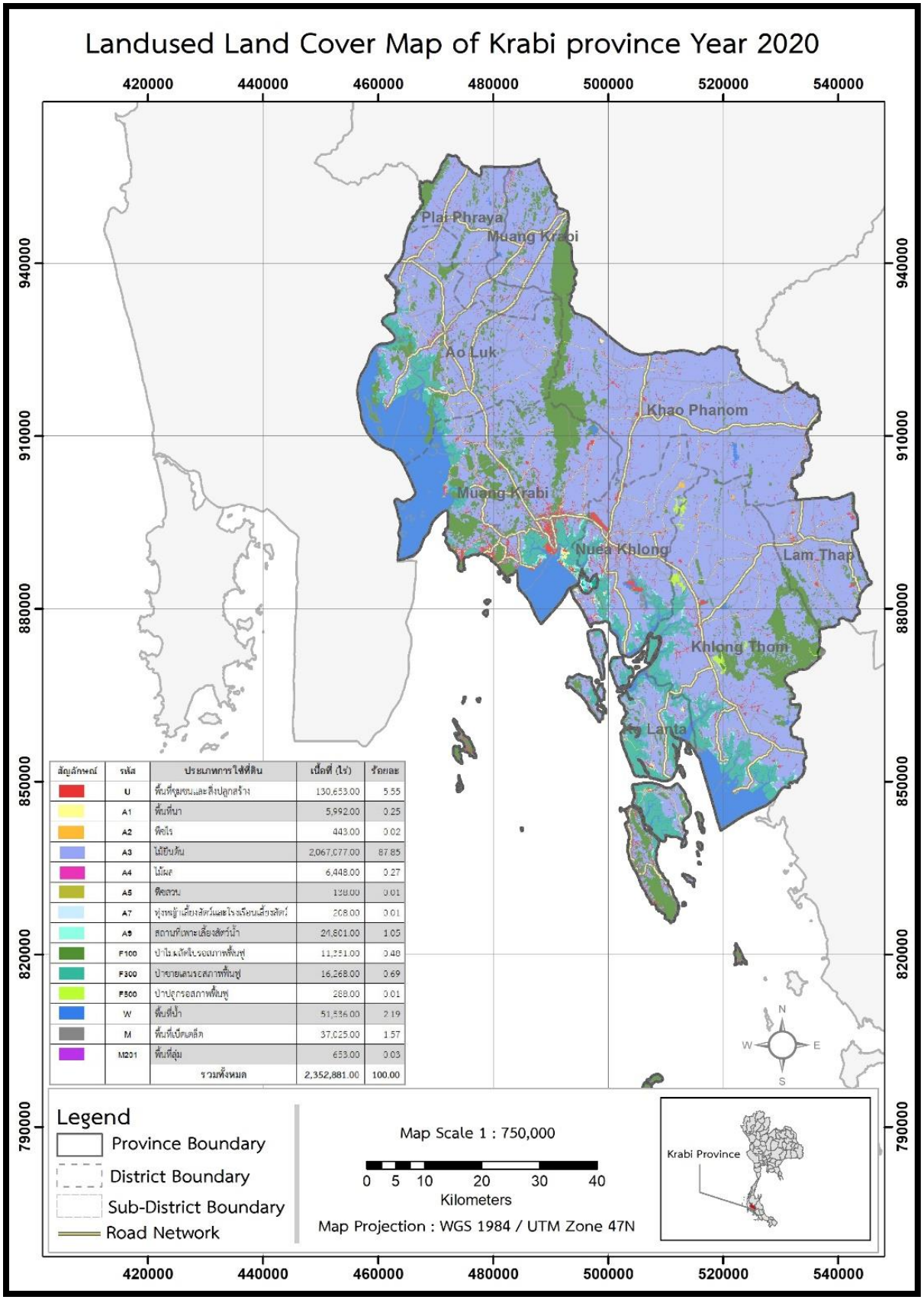
Forest areas are mostly in national parks (tropical forest » 12%) and mangrove (» 7%) along the coastal area, and etc. Community and industrial area can be classified as residential area (3.01%), commercial area and downtown (0.31), industrial area (0.2%), road (0.32%) and resort and hotel (0.08%) and etc. For the water area, most is the river and canals (1.53%), water reservoir (0.22%) and etc. The other areas are for examples, beach, landfill or dumping area, mines, and abandoned mines.

Figure 7 Land use of Krabi Province in 2022



Source: Land Development Department (2020)

Figure 8 **Land Use of Krabi Province, Thailand**



สัญลักษณ์	รหัส	ประเภทการใช้ที่ดิน	เนื้อที่ (ไร่)	ร้อยละ
	U	พื้นที่ชุมชนและสิ่งปลูกสร้าง	130,653.00	5.55
	A1	พื้นที่นา	5,992.00	0.25
	A2	พืชไร่	443.00	0.02
	A3	ไม้ยืนต้น	2,067,077.00	87.85
	A4	ไม้ผล	6,448.00	0.27
	A5	พืชสวน	138.00	0.01
	A7	ทุ่งหญ้าเลี้ยงสัตว์และโรงเรือนเลี้ยงสัตว์	268.00	0.01
	A9	สถานที่เพาะเลี้ยงสัตว์น้ำ	24,801.00	1.05
	F100	ป่าไม้ผลัดใบรอบสภาพพื้นฟู	11,251.00	0.48
	F300	ป่าขยายแนวรอสภาพพื้นฟู	16,268.00	0.69
	F500	ป่าปลูกรอสภาพพื้นฟู	288.00	0.01
	W	พื้นที่น้ำ	51,536.00	2.19
	M	พื้นที่เบ็ดเตล็ด	37,025.00	1.57
	M201	พื้นที่ลุ่ม	653.00	0.03
		รวมทั้งหมด	2,352,881.00	100.00

Source: Created by the authors using spatial data obtained from GISTDA (2022b)

2. Ecosystem types and Ecosystem services of Krabi province

2.1 Ecosystem types

Ecosystem types of Krabi province are divided into 5 realms based on IUCN global ecosystem typology 2.0. (Keith et al., 2020). The major of ecosystem realms are terrestrial realms, freshwater realm, marine realm, marine-terrestrial realm, and marine-freshwater-terrestrial realm. Each realm also has biomes as shown in Table 2.

Table 2 Ecosystem types of Krabi Province

Realms	Biomes
Terrestrial	T1: Tropical-subtropical forests: T1.3: Tropical/subtropical montane rainforest T2: Temperate-boreal forest and wood land T2.2: Deciduous temperate forest T3: Shrubland T3.1: Seasonal dry tropical shrubland T4: Grassland T4.5 Temperate subhumid grassland T7: Intensive Land-use T7.1 Annual Cropland T7.3 Plantation T7.4 Urban and industrial
Freshwater	F1: River and streams F1.1 permanent upland stream F2: Lake F2.1, F2.2, Small and large permanent freshwater lakes F3: Artificial freshwaters F3.1 Large Reservoirs F3.3 Rice paddies F3.4 Freshwater aquafarms F3.5 Canals, Ditches and Drains
Marine	M1: Marine shelf M1.1 Seagrass meadows M1.3 Photic coral reefs M2: Pelagic ocean water (Unable to categorize M2.1 -M2.5) M4: Anthropogenic marine system M4.1 Submerged artificial structures
Marine-Terrestrial	MT1: Shoreline systems MT1.3 Sandy shorelines
Marine-Freshwater-Terrestrial	MFT1: Brackish tidal MFT1.2 Intertidal forests and shrublands

Source: Analysis by TDRI as of 2024

Ecological services of each realm at Krabi province are divided into 3 major services:

Provisioning and cultural services: Provisioning services consist of the products obtained from ecosystems whereas cultural services relate to recreational, aesthetic, cognitive and spiritual activities.

Regulating services: Regulating services are the benefits obtained from the regulation of ecosystem processes.

Supporting services: Supporting services are the services that allow for the other ecosystem services to be present.

2.1.1 Terrestrial (T)

The terrestrial realm includes all dry land, its vegetation cover, proximate atmosphere and substrate (soils, rocks) to the rooting depth of plants, and associated animals and microbes (Keith et al., 2000). Major and minor occurrences of terrestrial ecosystem were initially identified using consensus land-cover maps of Krabi province. It was divided in to 5 biomes.

T1: Tropical-subtropical forests: The tropical-subtropical forest biome features dense, productive ecosystems near the equator with warm temperatures, abundant rainfall, and low seasonal change. Biomass and species diversity are high, driven by nutrient-rich soils and tree-dominated ecosystems that support complex food webs and regulate climate. Trees adapt to high rainfall and periodic canopy gaps, while unique species compositions vary by region within the biome. The tropical/subtropical montane rainforest (T1.3) is one of the sub biomes. This sub biome is the mountain rainforests where are characterized by a single-layered tree canopy, with epiphytic ferns, bryophytes, lichens, orchids, and bromeliads draping tree branches.

T2: Temperate-boreal Forest and wood land: The temperate-boreal forest and woodland biome consists of tree-dominated systems that are moderately to highly productive, with lower biodiversity compared to tropical forests. However, they exhibit significant temporal and spatial variability in productivity, biomass, and leaf traits. Factors such as minimum temperature, soil nutrients, and fire regimes influence ecosystem functions, affecting growth and recovery processes related to reproduction and recruitment. Deciduous temperate forest (T2.2) is its sub biomes, where are characterized as regions with high levels of precipitation and humidity, and a variety of deciduous trees.

T3: Shrubland: The shrublands and shrub-dominated woodlands biome consists of oligotrophic systems with low to moderate productivity, primarily due to nutrient-poor, acidic soils. Shrubs are the dominant producers, supported by mutualistic relationships with soil microbes, while recurrent disturbances like fire regulate biomass and promote biodiversity. Adaptations such as re-sprouting and seed banks help maintain plant diversity in these ecosystems. Seasonal dry tropical shrubland (T3.1) is one of sub biomes where is dominated by small-leaved sclerophyll shrubs and grasses, plants have traits to capture and conserve nutrients, such as cluster roots and carnivorous forms

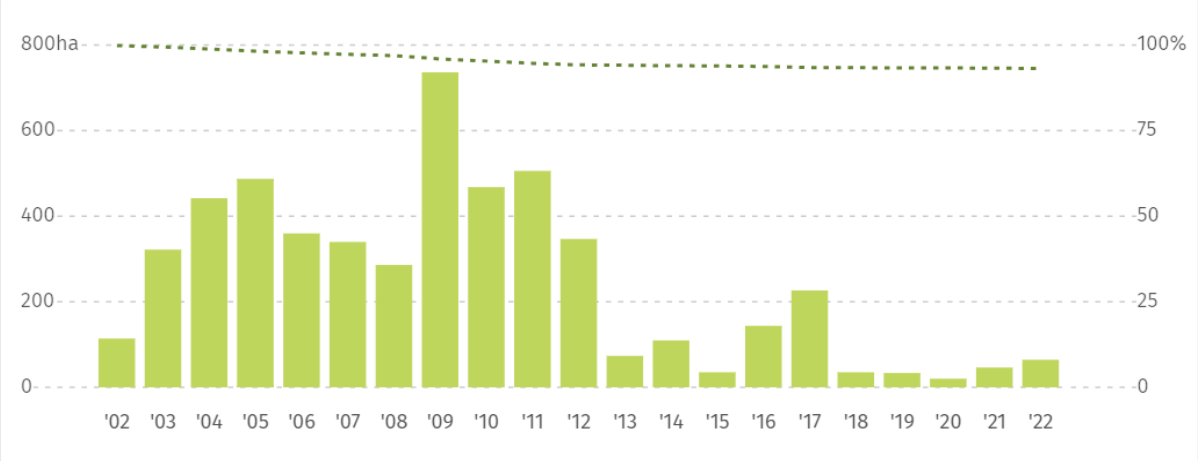
T4: Grassland: The savannas and grasslands biome is characterized by a continuous layer of grasses that supports moderate to high primary productivity, influenced by seasonal water cycles. Herbivory and fire are key factors regulating coexistence between grasses and woody plants, shaping the ecosystem's dynamics. Nutrient

availability and species diversity fluctuate with soil fertility, water, and temperature, contributing to a complex trophic web involving large herbivores and their predators. Temperate subhumid grassland (T4.5) is one of the sub biomes where is simple in structure, composed of tussock grasses with scattered forbs, with few isolated trees and shrubs.

T7: Intensive Land-use: Intensive land-use systems, also known as “anthromes”, encompass human-dominated practices such as agriculture, pastoralism, and urbanization, reliant on ongoing human interventions to manage resources and maintain community structures. These systems typically replace diverse ecosystems like forests and grasslands, resulting in low biodiversity and altered climate feedback processes, impacting local temperatures and contributing to greenhouse gas emissions. It was divided in to T7.1 Annual Cropland, T7.3 Plantation, and T7.4 Urban and industrial. These sub biomes of T7 can refer to land-used map in Figure 8.

Refer to the data of global forest watch, from 2002 to 2022, Krabi province lost 5.20 kha of humid primary forest, making up 3.6% of its total tree cover loss in the same time period. Total area of humid primary forest in Krabi decreased by 6.8% in this time period as shown in Figure 9.

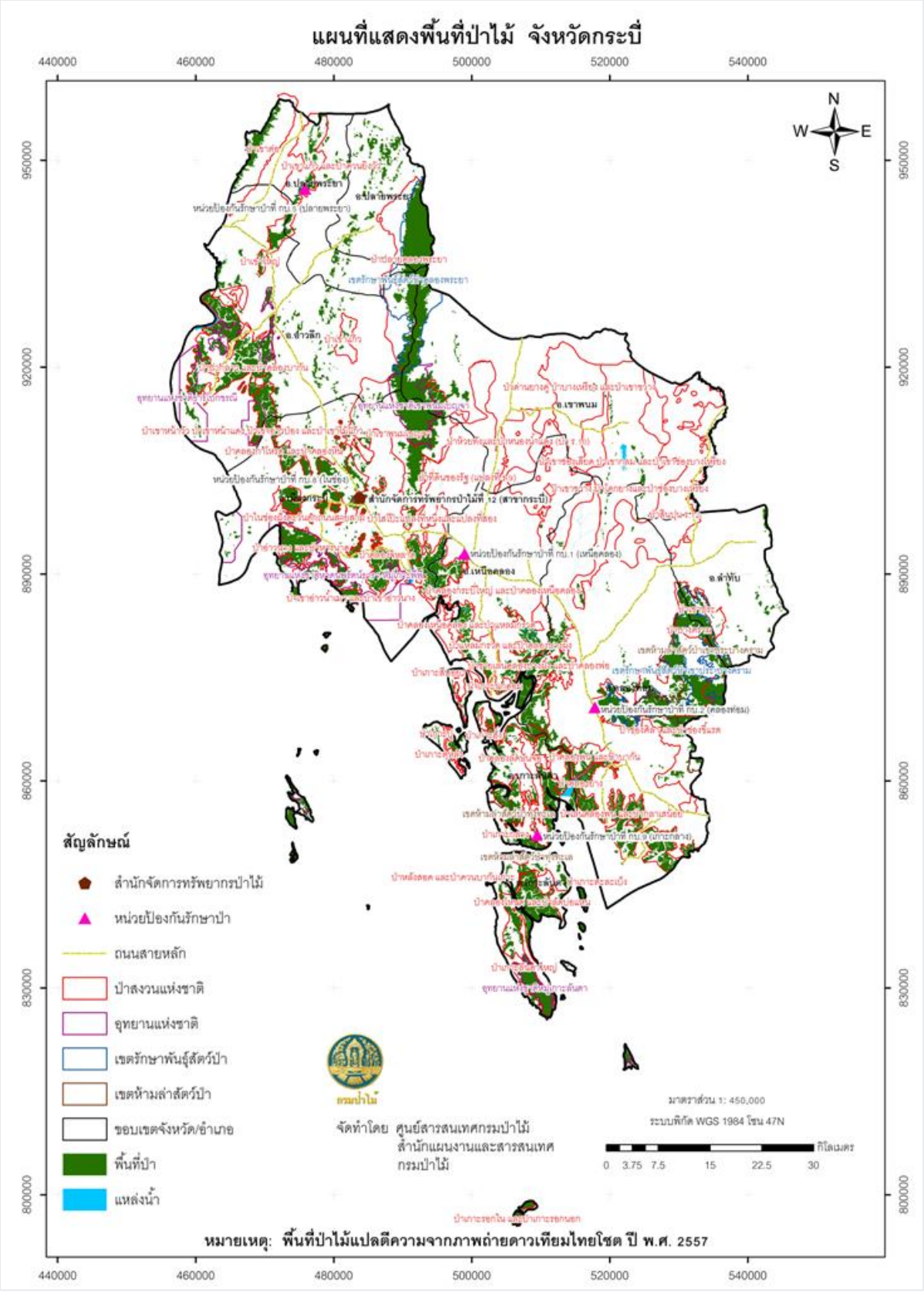
Figure 9 Krabi-forest area loss during 2002-2022



Source: Global Forest Watch (2023)

Forest types are often classified according to topographical characteristics and species compositions of the forests. Forest areas of Krabi Province has been classified as 4 national parks, 2 wildlife sanctuaries, and 45 national reserved forests. The mangrove forest area is divided into a restricted area and public mangrove forests where are allowed to be used for economic purpose. The forest area of Krabi province is shown in Figure 10.

Figure 10 Forest area of Krabi Province



Note. Green is forest area, and blue is water

Source: Royal Forest Department (2014)

Generally, forests in Krabi Province may be divided into 3 major types.

1) Tropical evergreen forest is a forest with very high humidity. This type of forest is dense. The upper part is large trees, and the middle and lower part are small and dense trees such as rattan, vines, and various vines. Generally, this type is generally located in the National Parks that will be mentioned next.

2) Mixed deciduous forest is a type of tropical seasonal forest found in Krabi province, this forest covers large areas and shows much variation in composition and structure. The height of trees do not exceed 20 meters. This type of forest is scattered around the provinces including in national parks.

3) Mangrove forests are composed of trees and shrubs that grow in saline coastal habitats in the tropics and subtropics. It is an unique ecosystem found in the intricate mesh of mangrove roots offers a quiet marine region for young organisms. Shrubs and trees in mangrove belong primarily to the families Rhizophoraceae, *Acanthaceae*, *Lythraceae*, *Combretaceae*, and *Arecaceae*; that grow in dense thickets or forests along tidal estuaries, in salt marshes, and on muddy coasts; and that characteristically have prop roots. Mangrove forests of Krabi province can be found along the coastline around mud flat and river mouth. It has an area of approximately 218,250 rai. (Krabi Provincial Office, 2022).

National Parks in Krabi Provinces

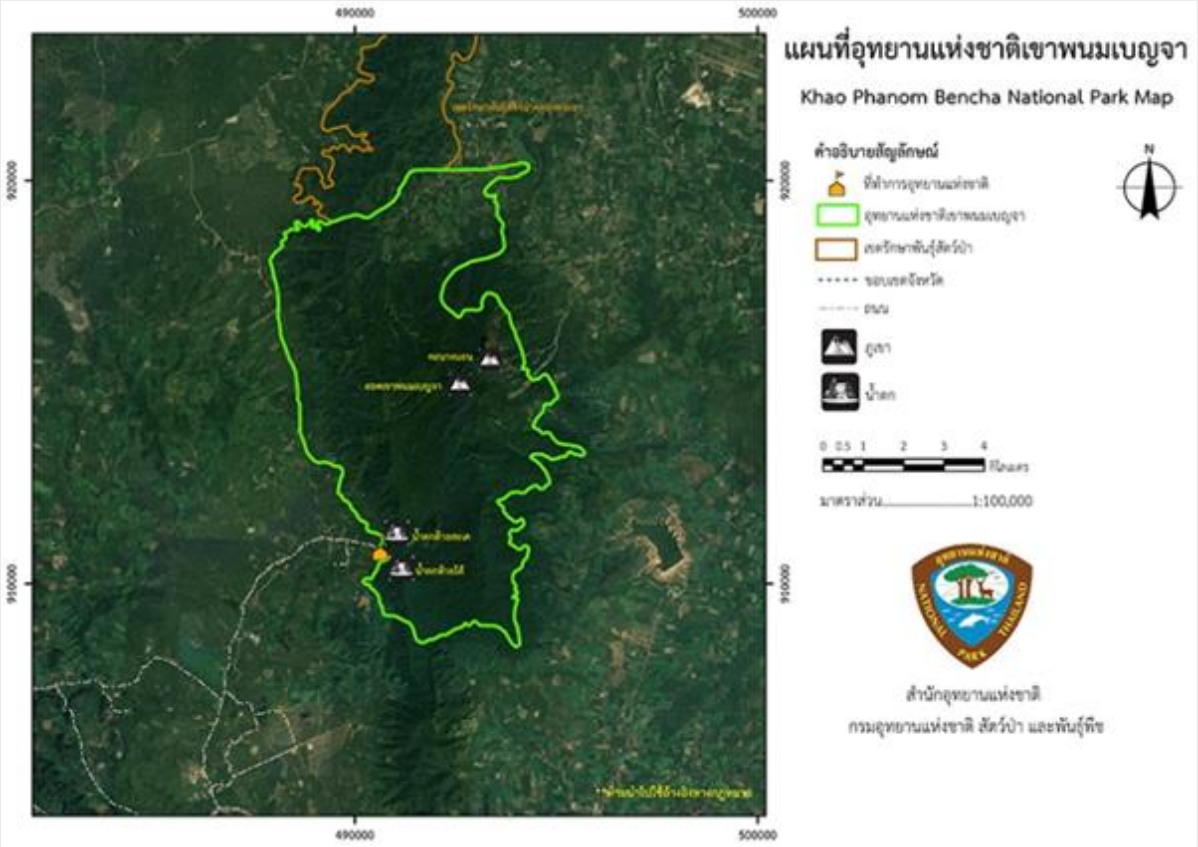
National parks in Krabi province are consisted of inland national parks and marine national parks. In this topic (Terrestrial), we will mention only inland national parks, Khao Phanom Bancha National Park and Than Bok Khorani National Park.

Khao Phanom Bencha National Park

Khao Phanom Bencha National Park is in Khao Phanom and Ao Luek districts, Krabi Province, established on 9 July 1981 with an area of 31,325 rai ~ 50 square kilometers. The park is named after Khao Phanom Bencha which is a mountain at 1,397 meters above sea level. This mountain is the origin of an important source of water used for consumption, namely the Krabi Yai Canal. which flows into the Andaman Sea at Pak Nam Subdistrict, Mueang District, Krabi Province. It is also the origin of many streams such as Khlong Ton, Khlong Krabi Noi, Khlong Paka Sai, Huai Sake, Huai Saran, and Huai Phai. The map of Khao Phanom Bencha National Park is shown in Figure 11.

Phanom Bencha forest is a humid evergreen forest because it rains a lot throughout the year. Therefore, there are many important types of wood, such as teak, takian, Dipterocarpus alatus, Lagerstroemia, Magnolia champaca and Parkia speciosa. At lower elevations, Calamus palms and bamboo are found. National Park authorities of Thailand indicates number of mammal species presence in the park such as leopards, clouded leopards, asiatic black bears, Sumatran serow, mouse deer, dholes, wild boars, white-handed gibbons, stump-tailed macaques. Moreover, there are around 120 bird species recorded from Khao Phanom Bencha National Park, for examples, White-crowned hornbills, barred eagle-owls, fluffy-backed tit-babblers, black-throated babblers, scaly-breasted bulbuls, spectacled spiderhunters, rufous-winged philentomas, red-crowned barbets and grey-and-buff woodpeckers.

Figure 11 Location and boundary of Khao Phanom Bencha National Park



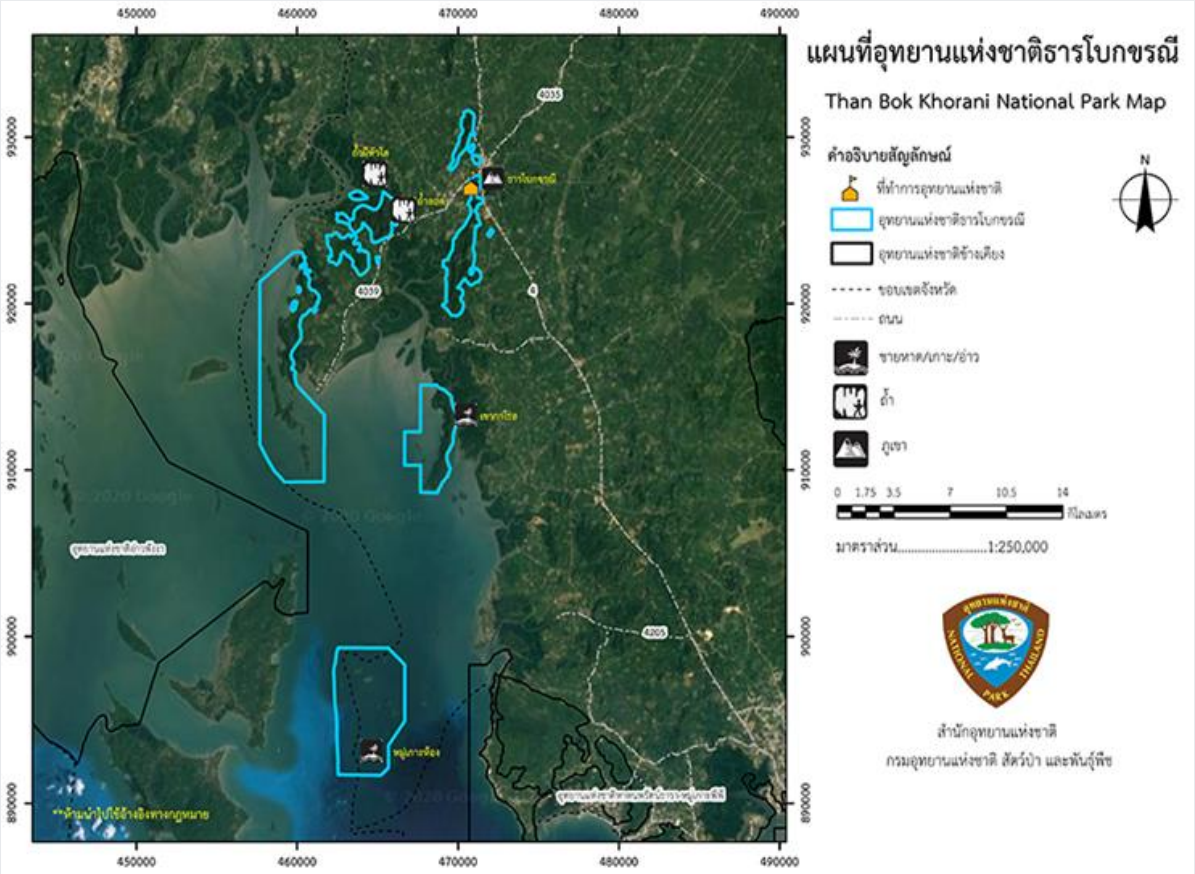
Source: National Parks of Thailand (2015)

Than Bok Khorani National Park

Than Bok Khorani National Park is established on 30 September 1998, with an area of 65,000 rai ~ 104 square kilometers. Different parts are on the mainland in Ao Luek district, along with several archipelagos in Mueang Krabi district: Koh Chong Lat, Koh Ka Rot and an archipelago east of Koh Yai Noi, with among others, Koh Pakbia, Koh Lao Lading and Koh Hong. Location and boundary of Than Bok Khorani National Park is shown in Figure 12.

The landscape of Than Bok Khorani National Park is dominated by a series of limestone mountains, evergreen forests, mangrove forests, and numerous islands. Forests in Than Bok Khorani National Park can be divided into 2 major types, rainforest and mangrove forest. In rainforest, the important trees are, Malacca Teak (*Intsia* sp.), Takian (*Hopea odorata*), Pride of India (*Lagerstroemia speciosa* (L.) Pers.), Thai crape myrtle (*Lagerstroemia floribunda* Jack), and Mango trees (*Mangifera* sp.), etc. Mammal species presence in forest such as wild boars, monkeys, common gibbons, (*Hylobates lar*), fishing cats (*Prionailurus viverrinus*), etc and many bird species are also found. In mangrove forests, the dominant plant species are *Rhizophora mucronata* Poir, *Rhizophora apiculata* Blume, *Avicenni*a sp., Cannonball mangrove (*Xylocarpus granatum* J.Koenig), etc., Animal species are found in mangrove forest such as, small-clawed otter (Aonyx cinerea), Javan mongoose (*Herpestes javanicus*), and many species of snakes and birds.

Figure 12 Location and boundary of Than Bok Khorani National Park



Source: National Parks of Thailand (2015)

2.1.2 Freshwater (F)

The freshwater realm includes all permanent and temporary freshwater bodies as well as saline water bodies that are not directly connected to the oceans (Keith et al., 2020). In Krabi Province, there is subdivided into 3 biomes:

F1: river and streams; rivers and streams, characterized by their linear structure and unidirectional flow, form complex ecosystems influenced by surrounding landscapes and climatic conditions. Productivity generally increases from uplands to lowlands, driven by both allochthonous and autochthonous energy sources, while biotic diversity varies based on factors like flow regimes, seasonal constraints, and anthropogenic nutrient inputs. Trophic webs are complex, with interactions among invertebrates, fish, and larger predators, highlighting the dynamic relationships within these lotic ecosystems. Permanent upland stream (F1.1) is one of the sub biomes where these small rivers or streams in mountainous or hilly areas are characterized by steep gradients and fast flow. They flow all year, increasing in wet periods, in humid tropical and temperate zones. Stones are common along their rapids and pools, turning over and oxygenating the water. The major river of Krabi province is Krabi river.

F2: lake biome; the lakes biome comprises lentic ecosystems characterized by still waters that vary in size, depth, and water regimes, which significantly impact their productivity and diversity. Water dynamics influenced by climate, catchment features, and nutrient availability lead to stratification and varying trophic structures, with larger lakes typically exhibiting more complex food webs. Environmental factors, such as water chemistry and seasonal changes, drive species adaptations and interactions within these ecosystems. Small and large permanent freshwater lakes (F2.1, F2.2) are sub biomes of this ecosystem, for example, Cheow Lan Lake, the most beautiful part of Khao Sok National Park.

F3: artificial fresh waters; the fresh waters consist of human-made structures designed for water management, treatment, and disposal, such as reservoirs, ponds, and aquafarms. These ecosystems typically rely on allochthonous sources for energy and nutrients, resulting in less biological diversity and trophic complexity compared to natural wetlands. However, they can provide critical habitats for various species, including native flora and fauna that may no longer thrive in natural ecosystems, thereby contributing to biodiversity in transformed landscapes. It was divided into F3.1 large reservoirs, F3.3 rice paddies, F3.4 freshwater aquafarms, and F3.5 canals, ditches, and drains. These subsets of terrestrial ecosystems refer to land-used map in Figure 8.

2.1.3 Marine (M)

Marine ecosystems of Krabi province are composed of 3 biomes following the Ecosystem Functional Group (EFG) (Keith et al., 2020).

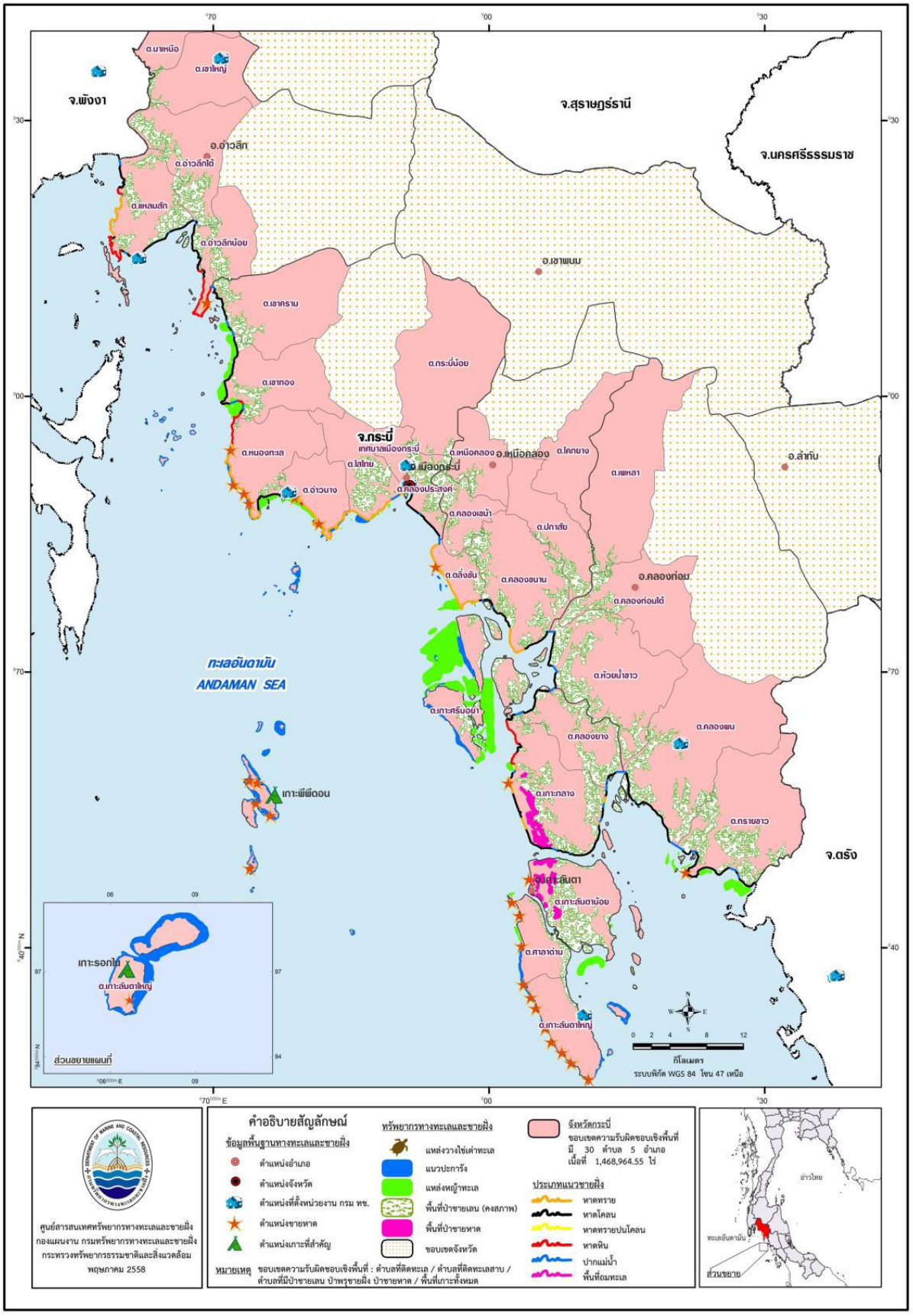
M1: Marine shelf; the marine shelf biome is a dynamic, globally distributed environment shaped by light, nutrient availability, substrate type, and kinetic energy from waves and ice. Productivity and community structure are influenced by feedback loops from habitat-forming organisms, consumer control, and abiotic factors like temperature, salinity, and currents, making it a complex yet essential component of marine ecosystems. It is located in the sea at the west of Krabi Province.

M2: Pelagic ocean waters biome; the pelagic ocean biome, encompassing the vast open-ocean water column, is structured by depth gradients that influence light, nutrients, and carbon availability, resulting in diverse adaptations across zones. Productivity and diversity are highest near the surface, while deeper layers depend on organic fluxes from above, creating a biome shaped by unique vertical and horizontal migrations and specialized adaptations to light scarcity.

M4: Anthropogenic marine biome; Artificial structures in the ocean create unique habitats by providing substrates for sessile organisms and attracting diverse marine life. They enhance local productivity through primary production and nutrient influx, drawing in larger pelagic predators and supporting a complex community structure shaped by both natural and human influences. (IUCN, 2020).

The important marine ecosystems of Krabi province are Seagrass (M1.1), Coral reefs (M1.3) and Anthropogenic marine systems (M4), in which the boundary is shown in Figure 13.

Figure 13 Marine and coastal resources map, Krabi Province



Source: Data from Department of Marine and Coastal Resources (2021)

Marine shelf biome (M1) is distributed between the shoreline and deep sea-floor biomes and is dominated by benthic productivity. It includes ecosystems with biogenic substrates (such as seagrass meadows, kelp forests, oyster beds and coral reefs) and minerogenic substrates, including rocky reefs, sandy bottoms and muddy bottoms.

Seagrass meadows (M1.1)

Krabi Province has a potential area of 5,477.8 ha as a seagrass bed. Seagrass in Krabi province grows well in shallow coastal waters and spreads in many areas, such as in brackish water near river mouths, shallow water with a sandy or muddy bottom, or growth mixed with coral reefs. A total of 12 species of seagrass were found in Krabi province shown in Table 3 and the area is shown in Table 4. The overall status of seagrass in Krabi province is in fair to good condition and shows a trend of increasing in percentage cover. The largest seagrass area is around Koh Sriboya, Koh Ka, Koh Pu, and nearby areas, followed by the areas of Ban Tao Than and Ao Tha Len (Table 4) (Department of Marine and Coastal Resources, 2022; Provincial Office of Natural Resources and Environment Krabi, 2022).

Data in 2023 found that seagrass in Krabi province had a total area of 3,475.8 ha, an increase of 703.84 ha compared to data from 2021, in which the sea had a total area of 2,772.0 ha. Overall, it shows a trend of improvement, especially at Nam Mao Bay, Koh Siboya, Ban Bo Muang-Pak Klong Ka La Sae, and Ban Tao Than-Ao Tha Lane. There is a stable trend in the Ao Nang area (Khlong Muang-Had Noppharat Thara), Ao Railay, Ao Krabi, Lanta Islands, and Koh Dam Hok-Dam Khwan.

Table 3 Species of seagrass found in Krabi Province

Thai name	Scientific Name	Status
หญ้าชะเงาใบมน	*Cymodocea rotundata*	found
หญ้าคาทะเล	*Enhalus acoroides*	found
หญ้าใบพาย	*Halophila beccarii*	frequently found in the province.
หญ้าชะเงาใบฟันเลื่อย	*Cymodocea serrulata*	found
หญ้าเงาใส	*Halophila decipiens*	found
หญ้าเงาใบใหญ่	*Halophila major*	found
หญ้าเงาใบเล็ก	*Halophila minor*	found
หญ้าใบมะกรูด	*Halophila ovalis*	frequently found in the province.
หญ้ากุยช่ายเข็ม	*Halodule pinifolia*	frequently found in the province.
หญ้ากุยช่ายทะเล	*Halodule uninervis*	found
หญ้าต้นหอมทะเล	*Syringodium isoetifolium*	found
หญ้าชะเงาเต่า	*Thalassia hemprichii*	found

Source: Data from Department of Marine and Coastal Resources (2021)

Table 4 Area of seagrass bed in Krabi Province

District	Seagrass	Area (ha)
Klong Tom	เกาะศิลามาก (Koh Sila Mak)	38.90
	บ้านบ่อม่วง (Ban Bo Muang)	79.69
	ปากคลองกะลาเส (Pak Klong Ka La Sae)	320.68
Koh Lanta	เกาะปอ (Koh Po)	4.49
	เกาะแร้ง (Koh Raeng)	16.67
	เกาะลันตาใหญ่	32.54
	ปากคลองลัดบ่อแหน (Pak Klong Lad Bo Nae)	383.07
	อ่าวฝรั่ง (Ao Farang)	44.18
	บ้านทุ่ง (Ban Tung)	31.96
Mueang	ใกล้เกาะนก (near Koh Nok)	1.85
	คลองดินแดง (Khlong Din Daeng)	6.03
	บ้านเขาทองใต้ (Ban Khao Thong Tai)	150.09
	บ้านท่าเลนใต้ (Ban Tha Len Tai)	125.79
	บ้านท่าเลนเหนือ (Ban Tha Len Nua)	100.06
	บ้านแหลมโพธิ์ (Ban Laem Pho)	2.69
	ปากคลองจิหลาด (Pak Klong Jirad)	5.96
	ปากคลองม่วง (Pak Klong Muang)	150.57
	สุสานหอย (Susan Hoi)	16.18
	หาดนพรัตน์ธารา (Hat Noppharat Thara)	131.65
	อ่าวท่าเลน (Ao Tha Lane)	119.96
	อ่าวท่าเลน (Ao Tha Lane)	96.37
	อ่าวน้ำเมา (Ao Nam Mao)	38.83
	อ่าวไร่เลย์ (Ao Railay)	19.68
	เกาะด้ามขวาน (Koh Dam Khwan)	0.26
	เกาะด้ามหอก (Koh Dam Hok)	0.25
Nuakhlong	บ้านคลองริ้ว (Ban Khlong Rua)	0.67
	บ้านแหลมหิน (Ban Laem Hin)	160.74
	เกาะสีมา (Koh Si Ma)	31.74
	เกาะจำ (Koh Jum)	28.05
	เกาะโต๊ะลังตะวันออก (Koh Toh Lung-East)	794.76
	เกาะโต๊ะหลำ (Koh Toh Lum)	29.99
	เกาะปูด้านเหนือ (Koh Pu-North)	199.38
	เกาะปูด้านใต้ (Koh Pu-South)	54.78
	เกาะปูด้านตะวันออก (Koh Pu-East)	57.26
	เกาะปูด้านตะวันตก (Koh Pu-West)	6.49
	เกาะปู (Koh Pu) (ติงไหร)	29.70
	เกาะเล็ก (Koh Lek)	27.69
	เกาะเล็กด้านเหนือ (Koh Lek-North)	32.87
	เกาะศรีบอยาด้านตะวันออก (Koh Siboya-East)	124.59
	เกาะศรีบอยาด้านใต้ (Koh Siboya-South)	177.31
	เกาะศรีบอยาด้านตะวันตก (Koh Siboya-West)	1,803.33

Source: Data from Department of Marine and Coastal Resources (2021)

Photic coral reefs (M1.3)

Pelagic ocean water, ecological realm that includes the entire ocean water column. It consists of the open ocean habitat that begins at the edge of the continental shelf and extends from the surface to the ocean bottom. Coral reefs and seagrass beds are some of the habitats that belong to this ecosystem. Krabi Province has 154 islands with a total area of 262.047 sq. km. It is the province with the second largest number of islands after Phang Nga province. The largest islands are Koh Lanta Yai, Koh Lanta Noi and Koh Pu which have a coastline length of 203.79 km. (Department of Marine and Coastal Resources, 2020).

Most of the coral reefs in Krabi province are scattered on various islands, with only a small number of coral reefs, that can form along the mainland coast. The total area of coral reefs in Krabi province is approximately 2,246 ha. Most of Krabi Province's coral reefs are in the Hat Nopparat Thara National Park - Phi Phi Islands and Mu Koh Lanta National Park. Most of the coral reefs are in good to very good condition, including Koh Por, Koh Rok Nai, Koh Siboya, Koh Ma, Koh Cham Yai, etc. The trend of coral change is stable and shows a tendency to improve.

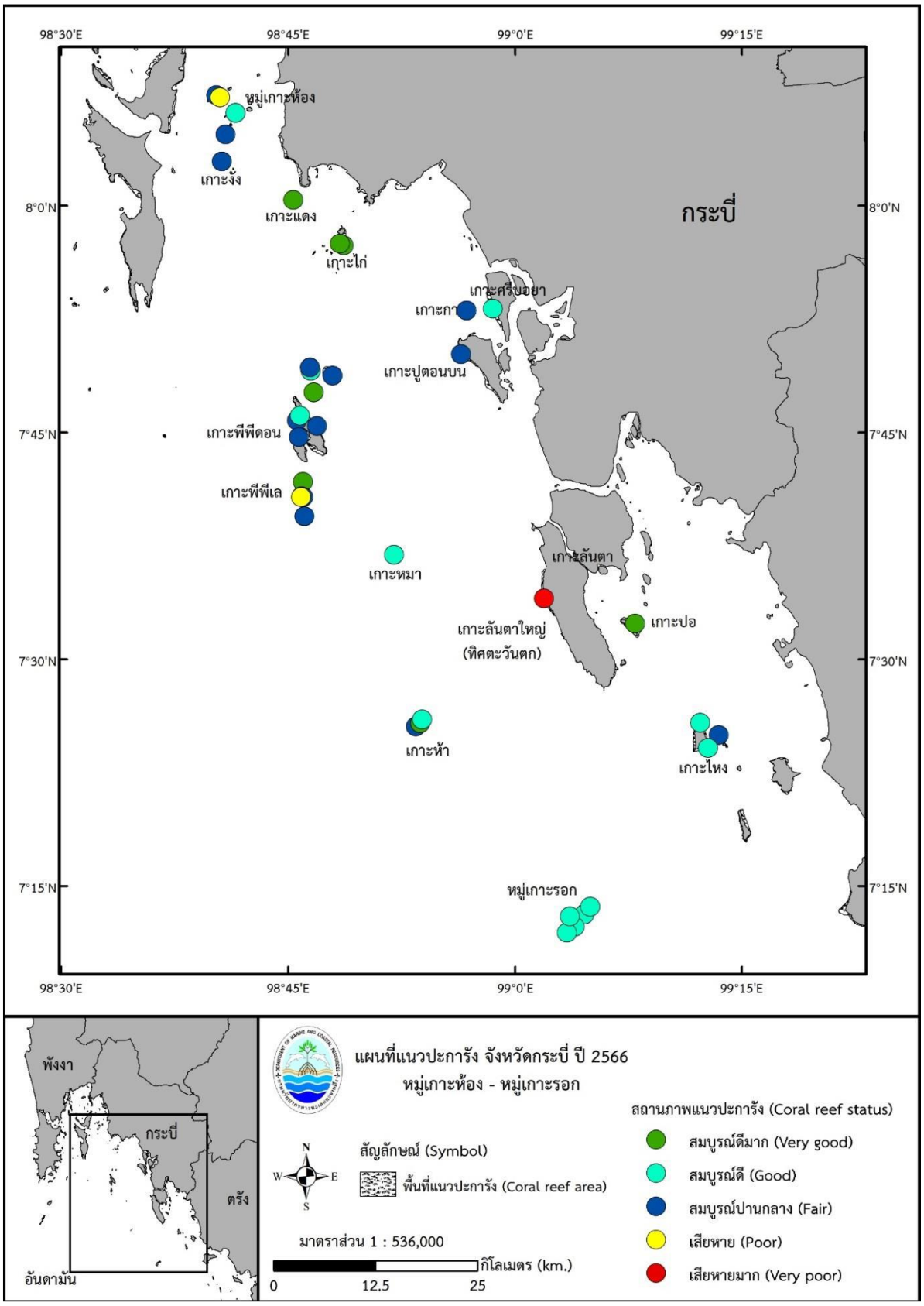
The status of coral reefs (Table 5 and Figure 14) around Koh Ka, Koh Sriboya, Ko Ma, Koh Phi Phi Le, Koh Rok Nok, Laem Son, and Koh Ha is likely to improve while coral reefs around Koh Ngung, Koh Por, Koh Lanta Yai (western side), Koh Huntu, Koh Kamid, Koh Pak Bia, Koh Hong (Ao Lek), Koh Lao Lading, Koh Pahusia, and Koh Pakka, Koh Rok (northern side) and Koh Ngai has a constant trend of change. Moreover, the coral reefs around Koh Pu show a trend of deterioration. The main cause of the deterioration is fishing, particularly garbage from fishing activities that cover the coral reefs, anchoring, increasing sediment, coral bleaching, dumping garbage and releasing of wastewater. The overall area and status of coral reefs at Krabi province is shown in Table 6 and trend of coral reefs in Figure 15 (Department of Marine and Coastal Resources, 2022; Provincial Office of Natural Resources and Environment Krabi, 2022).

Table 5 Coral reef status

Year	Coral reef status (ha)		
	Good	Fair	Poor
2563	598.976	910.30	736.96
2564	1,346.24	628.96	271.04
2565	1,457.12	115.36	673.76

Source: Data from Department of Marine and Coastal Resources (2021-2022)

Figure 14 Coral reef status



Source: Data from Department of Marine and Coastal Resources (2024a)

Table 6 Area and status of coral reef in Krabi Province

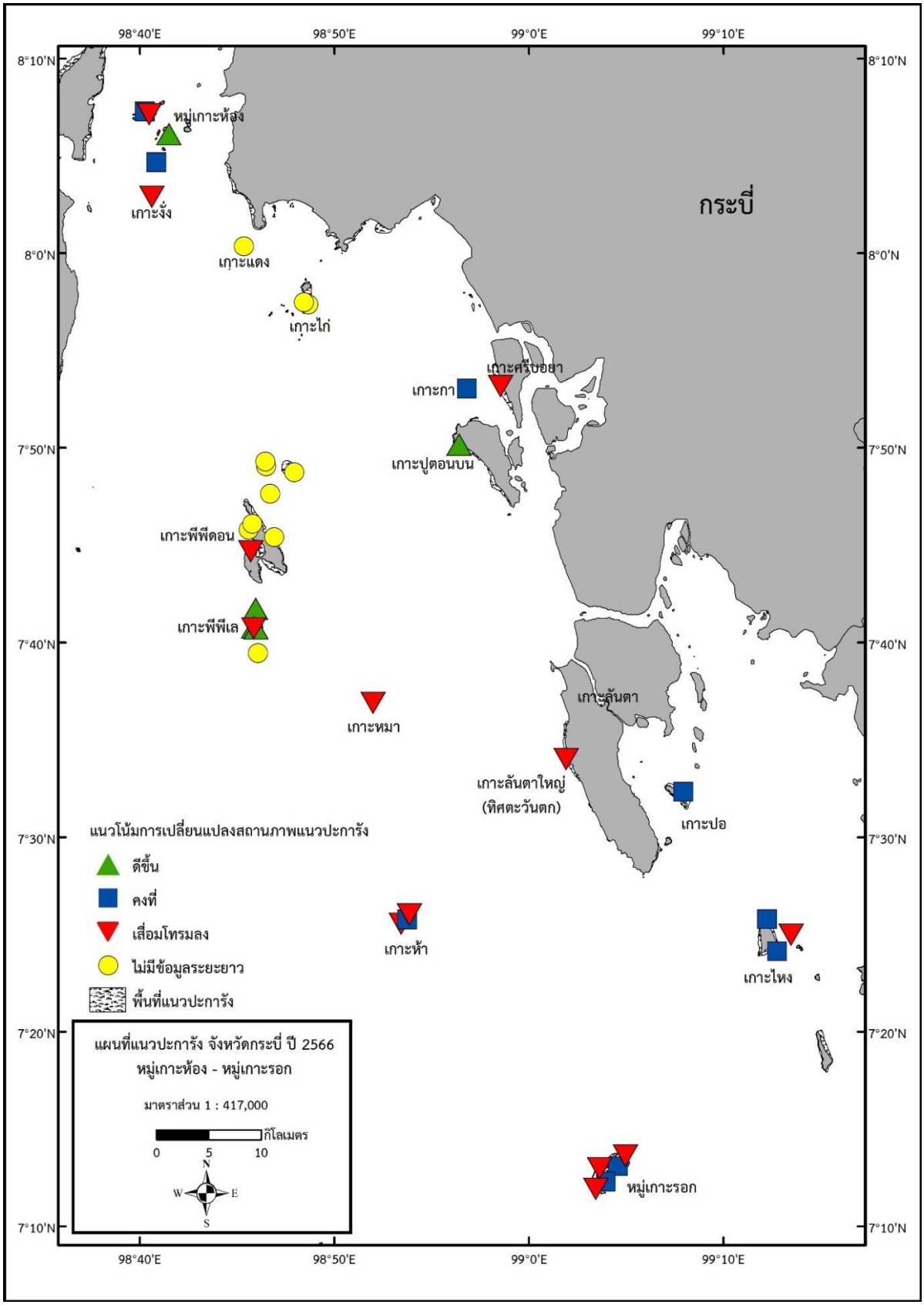
District	Coral reef	Area (ha)	Status
Koh Lanta	กองหินแดง (Hin Daeng Pinnacle)	3.52	Very good
	กองหินม่วง (Hin Muang Pinnacle)	2.56	Very good
	เกาะปอ (Koh Po)	129.44	Poor
	เกาะกลวง (Koh Kluang)	9.6	Fair-Very poor
	เกาะม้า (Koh Ma)	3.68	Very poor
	เกาะรอกนอก (Koh Rok Nok)	78.72	Poor-Very poor
	เกาะรอกใน (Koh Rok Nai)	136.48	Good-Very poor
	เกาะลันตาใหญ่ด้านตะวันตก (Koh Lanta Yai-West)	137.6	Poor-Very poor
	เกาะลันตาใหญ่ด้านใต้	28.8	Poor-Very poor
	เกาะลันตาใหญ่ด้านใต้ (Koh Lanta Yai-South)	2.08	Poor
	เกาะหมา (Koh Ma)	12.32	Fair-Very poor
	เกาะห้าใหญ่ลูกกลาง (Koh Ha Yai-Middle)	2.72	Fair-Very poor
	เกาะห้าใหญ่ลูกตะวันตก (Koh Ha Yai-West)	5.6	Good-Poor
	เกาะห้าใหญ่ลูกตะวันออก (Koh Ha Yai-East)	0.48	Poor
	เกาะห้าใหญ่ลูกเล็ก (Koh Ha Yai-Small)	0.32	Poor
	เกาะไหงด้านตะวันตก (Koh Ngai-West)	60.16	Poor-Very poor
	เกาะไหงด้านตะวันออก (Koh Ngai-East)	57.28	Fair-Very poor
	เกาะไหงด้านใต้ (Koh Ngai-South)	47.68	Poor-Very poor
Mueang Krabi	เกาะกลาง (Koh Klang)	46.56	Poor-Very poor
	เกาะกามิด (Koh Kamid)	3.68	Fair-Very poor
	เกาะค่อม (Koh Khom)	0.16	Good-Fair
	เกาะงั่ง (Koh Ngung)	0.8	Fair-Very Poor
	เกาะจาบัง (Koh Chabang)	0.8	Poor
	เกาะด้ามขวาน (Koh Dam Khwan)	46.4	Fair-Very poor
	เกาะด้ามหอก (Koh Dam Hok)	50.88	Fair-Very poor
	เกาะแดง (Koh Daeng)	1.76	Fair-Very poor
	เกาะบิด๊ะนอก (Koh Bida Nok)	2.4	Fair-Poor
	เกาะบิด๊ะใน (Koh Bida Nai)	0.96	Fair-Poor
	เกาะปากกะ (Koh Pakka)	6.88	Very good-Very poor
	เกาะปาหุเสีย (Koh Pahusia)	2.88	Poor-Very poor
	เกาะผักเบี้ย (Koh Phak Bia) (เหลาบุโล๊ะ)	12.96	Poor-Very poor
	เกาะไผ่ (Koh Mai Phai)	122.4	Fair-Very poor
	บ้านแหลมตง (Laem Tong)	70.08	Poor-Very poor
	อ่าวต้นไทรด้านตะวันตก (Ao Ton Zai West)	17.44	Very good-Very poor
	อ่าวต้นไทรด้านตะวันออก (Ao Ton Zai East)	98.24	Poor-very poor

Table 7 Area and status of coral reef in Krabi Province *(continued)*

District	Coral reef	Area (ha)	Status
	อ่าวลานา (Ao Lana)	29.76	Poor-Very poor
	อ่าวโล๊ะดาลัม (Ao Lo Dalam)	108.64	Very poor
	เกาะพีพีดอนด้านตะวันออก (Koh Phi Phi Don-East)	52.16	Fair-Very poor
	เกาะพีพีเลด้านตะวันตก (Koh Phi Phi Le-West)	17.6	Good-Very Poor
	เกาะพีพีเลด้านตะวันออก (Koh Phi Phi Le-East)	20.32	Very good-Very poor
	เกาะเมย (Koh Moei)	0.96	Fair
	เกาะแม่อุไรตะวันตก (Koh Mae Urai-West)	0.32	Good-Fair
	เกาะแม่อุไรตะวันออก (Koh Mae Urai-East)	0.16	Fair-Poor
	เกาะยะลาฮูตัง (Koh Yala Hutang)	2.72	Good-Poor
	เกาะยาวาซำ (Koh Yawazam)	2.24	Fair-Very poor
	เกาะยาวาบน (Koh Ya Wa Bon)	0.96	Good-Fair
	เกาะยาวาบ๊องเกาะ (Koh Ya Wa Bong Ko)	2.24	Poor-Very Poor
	เกาะยูง (Koh Yung)	16.32	Fair-Very poor
	เกาะเลาเปใต้ (Koh Lao Pe Tai)	0.32	Fair-Poor
	เกาะเลาเปเหนือ (Koh Lao Pe Nuea)	0.64	Poor-Very poor
	เกาะสะยา (กายา) (Koh Saya, Kaya)	5.28	Very good-Fair
	เกาะสะยาตาลิง (ซากา) (Koh Saya Taling)	2.4	Good-Poor
	เกาะห้อง (Koh Hong)	14.72	Fair-Very poor
	เกาะเหลากา (Koh Lao Ka)	2.72	Fair-Poor
	เกาะเหลาเรียม (Koh Laoriam)	0	Fair
	เกาะเหลาลาดิง (Koh Lao Lading)	2.08	Very good-Very Poor
	เกาะฮันตู (Koh Huntu)	1.28	Fair-Poor
	เขาแหลมนาง (Khao Laem Nage)	32.64	Poor-Very poor
	แหลมนาง-อ่าวน้ำเมา (Laem Nang-Ao Nam Mao)	61.28	Fair-Poor
	แหลมป่อง-เกาะกวาง (Laem Pong-Koh Kwang)	64.32	Very Poor
	แหลมโพธิ์ (Laem Pho)	85.92	Fair-Very poor
	แหลมหางนาค-เกาะกวาง (Laem Hang Nak-Koh Kwang)	118.56	Good-Very Poor
Nuakhlong	เกาะกา (Koh Ka)	6.08	Fair-Very poor
	เกาะปูด้านตะวันตก (Koh Pu-West)	163.68	Fair-Very poor
	เกาะปูด้านเหนือ (Koh Pu-North)	17.92	Poor-Very poor
	เกาะโละละ (Koh Lola)	0.8	Fair-Poor
	เกาะศรีบอยา (Koh Siboya)	186.24	Poor-Very poor
	แหลมหิน (Laem Hin)	20.64	Very poor

Source: Data from Department of Marine and Coastal Resources (2021)

Figure 15 **Trend of coral reef status**



Source: Data from Department of Marine and Coastal Resources (2024a)

Pelagic ocean waters (M2)

Pelagic ocean waters (M2) are the largest on earth, comprising the open-ocean water column across all latitudes. This ecological realm includes the entire ocean water column. It consists of the open ocean habitat that begins at the edge of the continental shelf and extends from the surface to the ocean bottom. Coral reefs and seagrass beds are some of the habitats that belong to this ecosystem. Krabi Province has 154 islands with a total area of 262.047 sq. km. It is the province with the second largest number of islands after Phang Nga province. The largest island is Koh Lanta Yai, Koh Lanta Noi and Koh Pu have a coastline length of 203.79 km. (Department of Marine and Coastal Resources, 2021) The main activity carried out in Pelagic ocean waters is fisheries. (Table 7).

Table 8 Production volume and value of important aquatic animal products in Krabi Province

Year	Local/commercial marine fisheries		Marine shrimp farming		Freshwater aquaculture		Brackishwater fish farming	
	Volume (Ton)	Value (Baht)	Volume (Ton)	Value (Baht)	Volume (Ton)	Value (Baht)	Volume (Ton)	Value (Baht)
2017	8,520	596,400,000	10,359	1,998,467,703	248	16,800,000	310	65,100,000
2018	10,600	742,000,000	9,940	1,940,523,341	252	17,506,000	345	23,800,000
2019	12,681	1,141,290,000	11,020	2,247,533,956	235	16,450,000	320	51,200,000
2020	16,843	1,179,010,000	9,854	1,664,553,082	178	12,460,000	285	42,750,000
2021	8,627	780,175,490	11,045	1,654,126,220	235	11,773,000	207	36,888,305

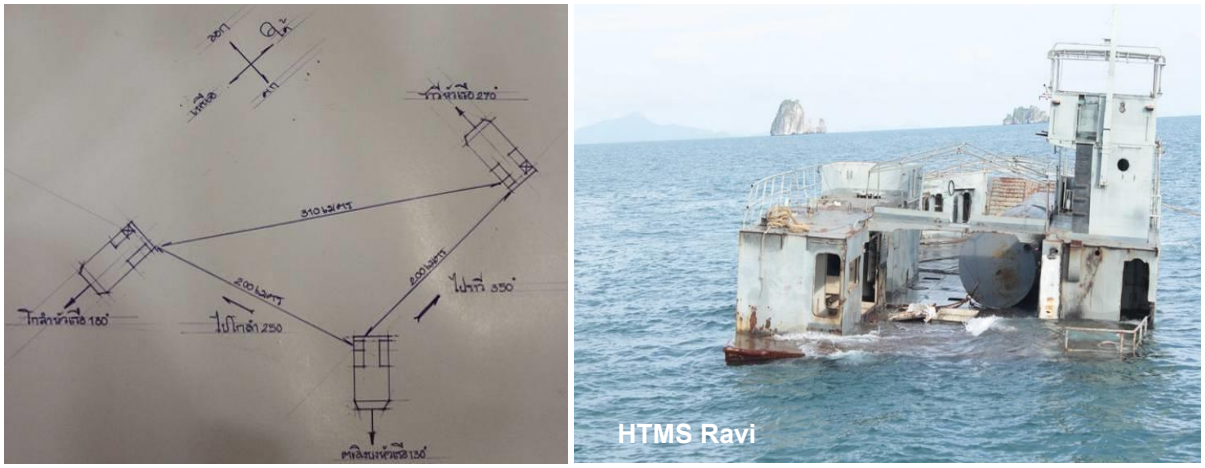
Source: Data from Krabi Provincial Office (2025)

Anthropogenic marine system (M4)

Anthropogenic marine system (M4) is the biome in which humans have constructed, deposited, or dumped artificial structures in the oceans that either confine managed marine organisms or attract marine biota that would not otherwise occupy such locations. It includes shipwrecks and mineral, gas, or energy infrastructure, pipelines, and rubble piles, as well as aquaculture infrastructure.

Krabi province has a project to build the Krabi Underwater Education Park by sinking the His Thai Majesty's Ship (HTMS) Talibong, HTMS Kolam, and HTMS Ravi at Koh Yawasam, Mueang Krabi district (Figure 16). HTMS Klet Kaew sank at Koh Phi Phi Le Island, Mueang Krabi District while HTMS Prap Prapak, HTMS Su Phairin, Tor 15, and Tor 16 sank at Koh Ma, Koh Lanta district to be an artificial coral reef and underwater learning center. The example of anthropogenic marine system is shown in Figure 17.

Figure 16 Underwater layout plan for (HTMS) Talibong, HTMS Kolam, and HTMS Ravi



Source: Department of Marine and Coastal Resources (2015)

Figure 17 Examples of anthropogenic marine systems

Source: Department of Marine and Coastal Resources (2015)

2.1.4 Marine-Terrestrial (MT)

The marine-terrestrial transitional realm is characterized by steep environmental gradients in desiccation, salinity and wave and tide disturbance, occupied by contrasting shoreline ecosystems.

Marine-Terrestrial Ecosystems of Krabi province are composted of 1 biome under IUCN (2020).

MT1: Shoreline biome; The shoreline systems biome, spanning diverse intertidal habitats globally, is shaped by tides, waves, and substrate stability, leading to high biodiversity and unique adaptations to desiccation and disturbance. Productivity and community structure vary with substrate type and exposure, with interactions among species often aiding survival under challenging conditions.

Shoreline system (MT1)

Shoreline systems (MT1) is the biome comprises naturally formed, intertidal abiogenic habitats situated at the interface between land and sea. Within and across ecotypes, biotic communities are strongly structured by tides, waves and particle size, ranging from contiguous rock to fine silts and clays.

Krabi Province has a coastline (Figure 18 and Table 8) length of approximately 206.17 kilometers. According to a survey by the Department of Marine and Coastal Resources in 2023, there is a coastal area with erosion problems of approximately 203.79 kilometers. Divided into:

1) Areas that have not yet been corrected, approximately 2.17 kilometers, classified as:

- Area with severe erosion problems, 1.31 kilometers
- Area with moderate erosion problems, 0.74 kilometers
- Area with minor erosion problems, 0.12 kilometers

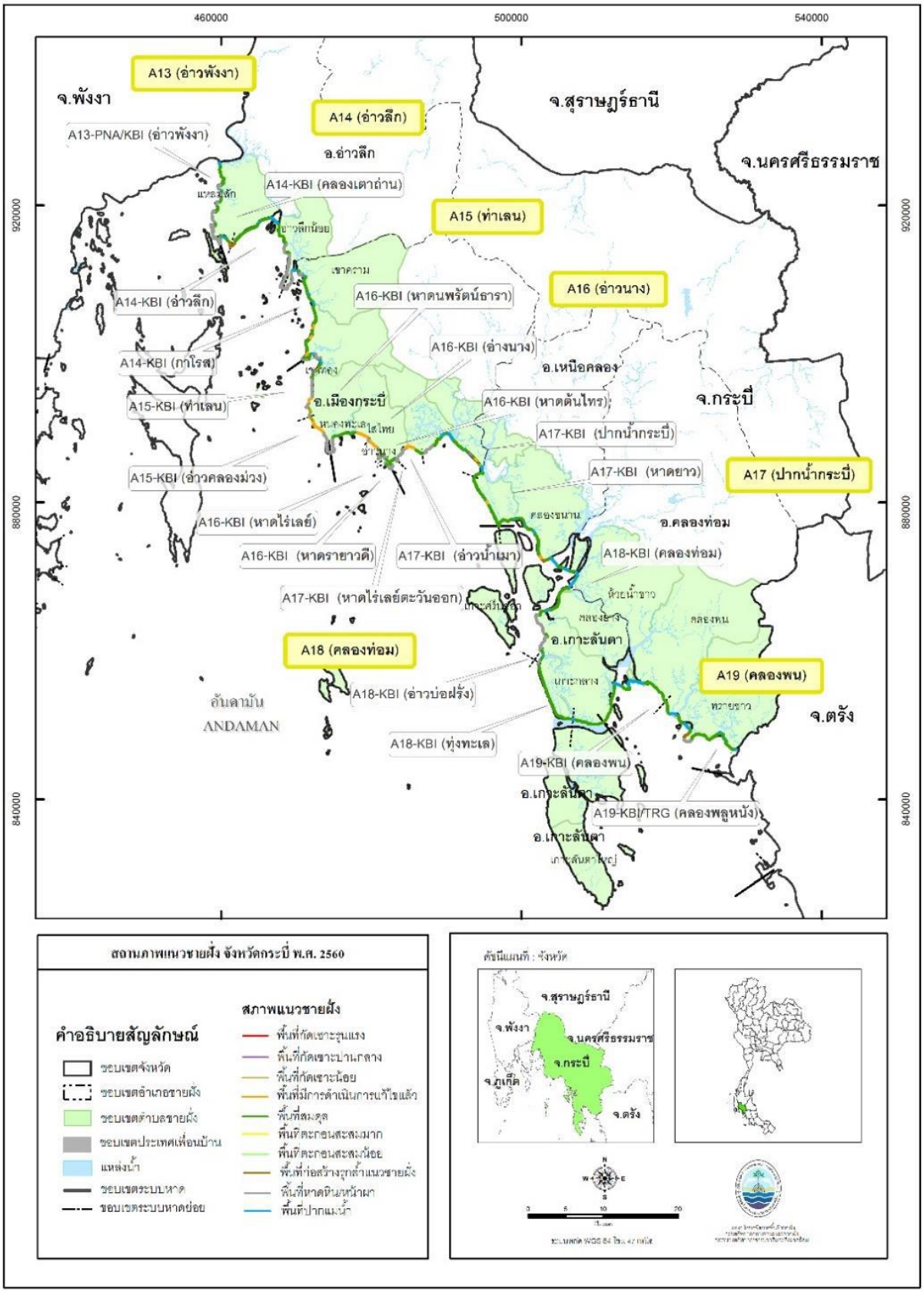
2) Areas with erosion problems that have been corrected, approximately 13.40 kilometers, classified as:

- Area with corrective actions and no erosion, approximately 13.40 kilometers
- Area with corrective actions but still eroding, approximately 0 kilometers

3) Areas that are not eroded (Monitoring) length approximately 188.22 kilometers, classified as:

- Area with sediment accumulation approximately 52.66 kilometers
- Area with beachheads, cliffs approximately 1.25 kilometers
- Balanced area approximately 107.32 kilometers
- Encroachment area approximately 3.97 kilometers
- Other areas (construction areas encroaching on the coastline, rocky beach areas, river mouth areas) approximately 23.02 kilometers

Figure 18 Coastal status in Krabi Province



Source: Department of Marine and Coastal Resources (2023)

Table 9 Physical characteristics of Krabi beaches in 2017

District	Subdistrict	Muddy beach	Muddy-sandy beach	Sandy beach	Sandy-muddy beach	Sandy and rocky beaches	Rocky beach	River mouth/canal mouth
Ao Luek	Laem Sak	8.95		4.82			10.97	1.85
	Ao Luek Noi	3.91					10.82	0.15
Mueang Krabi	Khao Kram	3.89					1.24	0.86
	Khao Thong	10.69					3.91	0.63
	Nongthale	3.03		4.29			11.07	0.06
	Ao Nang	0.34		6.43			7.32	0.1
	Sai Thai			4.24	0.37		2.58	0.78
	Khlong Prasong			3.20				1.70
Nuakhlong	Taling Chan			8.75	2.77			0.66
	Khlong Khanan	8.33		10.32				4.01
Klong Tom	Huai Nam Khao	0.57						1.31
Koh Lanta	Khlong Yang			4.74				0.95
	Koh Klang			14.14	9.62		6.77	3.70
Klong Tom	Khlong Phon			6.70				1.85
	Sai Khao	10.74						2.41

Source: Department of Marine and Coastal Resources (2018)

Beach forest: Thailand has a beach forest area of 47,149.30 rai, distributed in 18 coastal provinces. Krabi Province has the second largest beach forest area after Phang Nga, with an area of 4,406.97 rai. Mostly found in Mueang District, Nuea Khlong District and Koh Lanta District. Most of the beach forest is in the Thung Talay Wildlife Sanctuary, Koh Klang Subdistrict, Koh Lanta District. Beach forest is a forest along the coast that is made of gravel, sand and rocks. The plant species are different from those in areas that are flooded.

Coastal erosion protection structures in Krabi province are shown in Table 9.

Table 10 Coastal erosion protection structures in 2017

District	Subdistrict	Distance	Name	Structure	Efficiency	Impact
Mueang Krabi	Khao Thong	1.03	Ban Khao Thong	VS RE PI	Effective	No impact
		0.36	Ban Tha Len	VS CPI	Effective	No impact
		0.41	Ao Tha Len	VS	Ineffective	Damaged condition
	Nongthale	0.52	Huai Thap Khaek	RE PI	Effective	No impact
		0.51	Koh Kwang Beach	GA RE VS CPI	Effective	No impact
		1.40	Ban Klong Muang	RE GA VS	Ineffective	Damaged condition
	Ao Nang	1.74	Noppharat Thara Beach	GA MS ST	Effective	No impact
		1.41	Ao Nang Beach	VS MS GA ST RE PI	Effective	No impact
	Sai Thai	0.15	Ban Ao Nam Mao	VS	Effective	No impact
		0.48	Ban Ao Nam Mao	PI VS ST	Effective	No impact
		0.94	Ban Laem Pho	RE VS	Effective	No impact
	Khlong Prasong	0.28	Ban Klong Kam	VS	Effective	No impact
		0.22	Laem Kham	BP	Ineffective	No impact
Nuakhlong	Taling Chan	0.24	Ban Had Yao	PI VS CPI	Effective	No impact
	Khlong Khanan	0.29	Ban Laem Kruat	VS	Effective	No impact

Note. BP: Bamboo Fences Prevention, CPI: Concrete pipe laying, GA: Gabion, MS: Mild slope seawall, PI: Pier, RE: Revetment, ST: Stepped Sloping Seawall, VS: Vertical Seawall

Source: Department of Marine and Coastal Resources (2018)

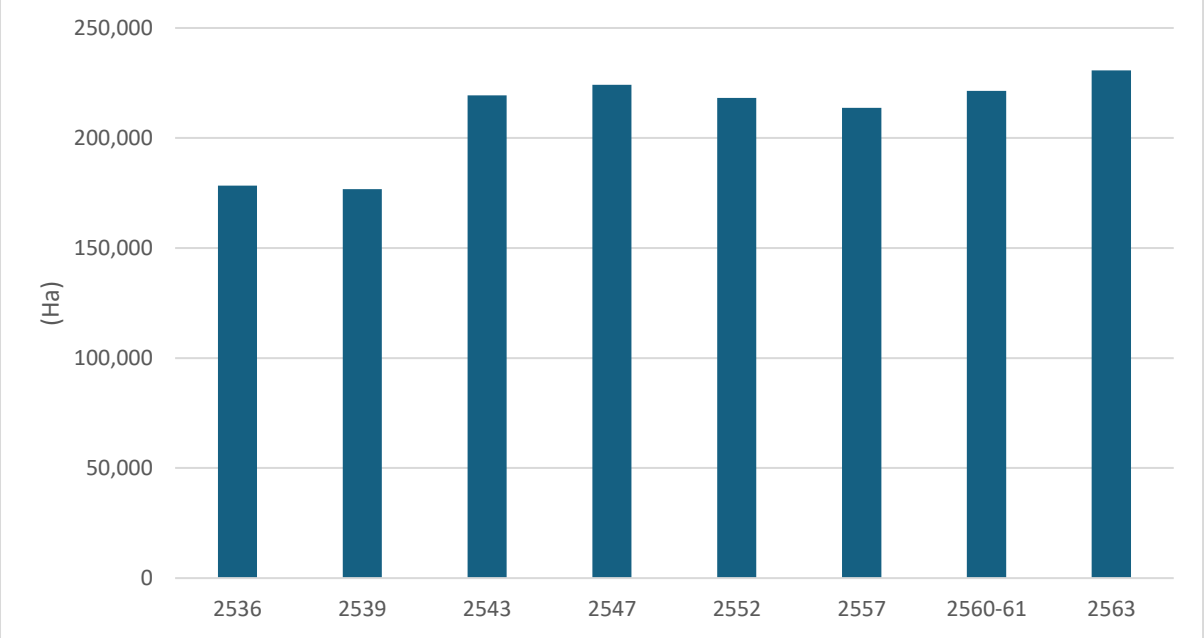
2.1.5 Marine-Freshwater-Terrestrial (MFT)

Marine-Freshwater-Terrestrial (MFT) is associated with regrading depositional shorelines at the interface of terrestrial, freshwater, and marine realms. The relative influences of marine, freshwater, and terrestrial processes vary from strongly fluvial deltas to marine-dominated intertidal forests and terrestrial-dominated coastal saltmarsh (IUCN, 2020). Mangroves are structural engineers and possess traits, including pneumatophores, salt excretion glands, vivipary and propagule buoyancy, that promote survival and recruitment in poorly aerated, saline, mobile and tidally inundated substrates. In this case, Mangrove forest is identified to MFT1.2 Intertidal forests and shrublands.

Brackish water is a mixture of freshwater and seawater which has salinity is between 0.5-30 ppt. Mangroves are confined in brackish water environment and adapt to changing environmental conditions including salinity through physiological and biochemical mechanisms (Kavitha et al., 2010).

Mangrove forests of Krabi province can be found along the coastline around mud flat and river mouth. Krabi Province has a mangrove forest area according to the Cabinet resolution of 328,993.33 ha, and a mangrove forest area of 230,790.77 ha, consisting of 5 districts and 30 sub-districts: Koh Lanta District, Khlong Thom District, Mueang Krabi District, Nuea Khlong District, and Ao Luek District. A total of 31 mangrove plant species were found in Krabi. The total density of trees is 342.91 trees per ha. The most common tree species are in the family Rhizophoraceae. Tall-stilt mangrove has the highest density (166.18 trees per ha), followed by Tagal mangrove (66.02 trees per ha) and Cannonball mangrove (46.83 trees per ha), respectively. The diameter at breast height (DBH) is 12.03 centimeters and the average height (H) is 10.08 meters. Mangrove biomass in Krabi Province was found to have above-ground biomass equal to 28,265.95 kilograms per ha. The amount of carbon stored in biomass is equal to 13.76 tons per ha. (Department of Marine and Coastal Resources, 2024) Changes in areas of mangrove forests is shown in Figure 19.

Figure 19 Changes in areas of mangrove forests



Source: Data from Department of Marine and Coastal Resources (2024b)

2.2 Ecosystem services

2.2.1 Terrestrial Ecosystem Service (T)

Forest ecosystems provide critical and diverse services and values to human society. As primary habitat for a wide range of animal and plant species, forests support biodiversity maintenance and conservation. Forest growth sequesters and stores carbon from the atmosphere, contributing to regulation of the global carbon cycle and climate change mitigation. Moreover, forest produce and conserve soil and stabilize stream flows and water

runoff—preventing land degradation and desertification and reducing the risks of natural disasters such as droughts, floods, and landslides. In addition, forests also serve as sites of aesthetic, recreational, and spiritual value in many cultural and societal contexts, and contribute to poverty eradication and economic development by providing food, fiber, timber, and other forest products for subsistence and income generation (Jenkins & Schaap, 2018). The ecological services of forest of Krabi province are concluded in Table 10.

Table 11 Ecosystem services of terrestrial ecology at Krabi Province

Ecosystem	Ecosystem services		
	Provisioning and cultural	Regulating	Supporting
Tropical forest	Genetic resources, raw materials, food, education, Recreation and tourism, aesthetic, economic	Carbon sequestration and climate regulation, nutrient cycling, erosion control, air purification	Biological diversity, ecological connectivity, nursery and protective habitats for wildlife

Source: Revised from Odum and Barrett (2005)

2.2.2 Freshwater Ecosystem Services (F)

Ecosystem services by river and streams provides in the form of provision, regulating, supporting and cultural service in both environment and human. River ecosystems vary greatly in scale, from headwater streams to vast river deltas, and the relative importance of various types of ecosystem services changes dramatically with spatial and temporal scales (Yeakley, et al., 2016). As it was mentioned in topography, major water resources of Krabi province are rivers and stream (canals) (F1). There are some reservoirs for agriculture and irrigation scattered around the area.

The ecosystem services of rivers and streams at Krabi province is shown in Table 11.

Table 12 Ecosystem services of river and stream ecology at Krabi Province

Ecosystem	Ecosystem services		
	Provisioning and cultural	Regulating	Supporting
River and stream	Genetic resources, raw materials, education, Recreation and tourism, aesthetic	processing nutrients, water use and water supply, hydrological cycle	Biological diversity, ecological connectivity, nursery and protective habitats for fish, aquatic animals and plants

Source: Revised from Odum and Barrett (2005)

2.2.3 Marine Ecosystems Services (M)

Ecosystem services refer to the benefits that ecosystems provide to human society, supporting life and contributing to well-being. These services are typically categorized into four main types:

Provisioning Services: These include tangible products such as food, water, timber, and fiber, which ecosystems produce and humans utilize directly.

Regulating Services: These are natural processes managed by ecosystems, like climate regulation, water purification, disease control, and pollination, that help maintain environmental balance.

Supporting Services: Essential for all other ecosystem services, supporting services include nutrient cycling, soil formation, and primary production, forming the foundation for other ecosystem functions and life on Earth.

Cultural Services: Ecosystems offer recreational, aesthetic, and spiritual benefits, enhancing cultural and emotional well-being for people.

M1 is crucial within Krabi Ecosystem Typology due to its significant biodiversity and ecological productivity. This biome supports various habitats, including seagrass meadows, kelp forests, coral reefs, and shellfish beds, each hosting diverse marine organisms. These habitats contribute extensively to ecosystem services like nutrient cycling, carbon sequestration, and supporting fisheries. M1 are known for moderate-to-high productivity and provide essential resources such as oxygen and nutrients, supporting a range of species, including burrowing organisms and forage predators, which aid in biogeochemical processes.

The ecosystem services of M: Marine Ecosystems of Krabi province is concluded in Table 12.

Marine and coastal resources of Krabi province enrich of many marine ecosystems especially, mangroves, coral reefs, seagrass beds, sandy beach, muddy shore and rocky shore. Coral reefs and seagrass beds are the most important ecosystems in the coastal area, they provide foods and shelters for many marine organisms as feeding ground or nursery ground particularly for the economic important species, particularly in Phangnga and Krabi.

Table 13 Ecosystem services of Marine Ecosystems at Krabi Province

Ecosystem	Ecosystem services		
	Provisioning and cultural	Regulating	Supporting
Seagrass meadows	Fish and shellfish harvesting,raw materials, education, and aesthetic	Nutrient cycling, erosion control, carbon sequestration, water purification	Biological diversity, ecological connectivity, nursery and protective habitats for fish, shellfish and aquatic animals
Photic coral reefs	Genetic resources, raw materials, education, recreation and tourism, aesthetic	Nutrient cycling, water purification	Biological diversity, ecological connectivity, nursery and protective habitats for fish and aquatic animal
Pelagic ocean waters	Fish and shellfish harvesting, genetic resources, raw materials, education, and aesthetic	Nutrient cycling, erosion control, carbon sequestration, water purification	Biological diversity, ecological connectivity, nursery and protective habitats for fish, shellfish and aquatic animals
Anthropogenic marine system	Education, recreation and tourism, aesthetic	Still not clear	Biological diversity, ecological connectivity, nursery and protective habitats for fish, aquatic animals and plants

Source: Revised from Odum and Barrett (2005)

2.2.4 Marine-Terrestrial Ecosystems Services (MT)

MT plays an essential role in supporting diverse ecological communities and environmental functions. Situated at the interface of land and sea, these ecosystems are structured by tides, waves, and sediment composition, ranging from rocky to sandy shores. This biome provides habitats for many species, promoting high biodiversity and productivity. Additionally, organisms here exhibit various adaptations, like burrowing and desiccation resistance, which allow survival under fluctuating conditions.

The ecosystem services of MT: Marine-Terrestrial Ecosystems of Krabi Province is concluded in Table 13.

Table 14 Ecosystem services of Marine-Terrestrial Ecosystems at Krabi Province

Ecosystem	Ecological services		
	Provisioning and cultural	Regulating	Supporting
Shoreline systems	Raw materials, shellfish harvesting, education, recreation and tourism, aesthetic	Nutrient cycling, erosion control, carbon sequestration, water purification, Strom prevention	Biological diversity, ecological connectivity, nursery and protective habitats for fish, shellfish and aquatic animals
Coastal shrublands and grasslands (Beach Forest)	Raw materials, education, recreation and tourism, aesthetic	Nutrient cycling, erosion control, carbon sequestration, water purification	Biological diversity, ecological connectivity, nursery and protective habitats for coastal plant
Anthropogenic shorelines	Education	Nutrient cycling, erosion control, carbon sequestration, water purification	Biological diversity, ecological connectivity, nursery and protective habitats for fish, shellfish and aquatic animals

Source: Revised from Odum and Barrett (2005)

2.2.5 Marine-Freshwater-Terrestrial ecosystem services (MFT)

MFT are highly productive and crucial to biodiversity, especially in intertidal zones where they act as buffers against flooding and coastal erosion. These ecosystems support diverse species adapted to fluctuating salinity and oxygen levels and contribute significantly to nutrient cycling and habitat complexity. They serve as nurseries for fish and other marine life, providing feeding grounds for migratory birds and habitat for invertebrates. Furthermore, MFT ecosystems play a vital role in sequestering carbon, thus helping mitigate climate change impacts. The ecosystem services of MFT: Marine- Freshwater-Terrestrial Ecosystems of Krabi province is concluded in Table 14.

Table 15 Ecosystem services of Marine- Freshwater-Terrestrial Ecosystems at Krabi Province

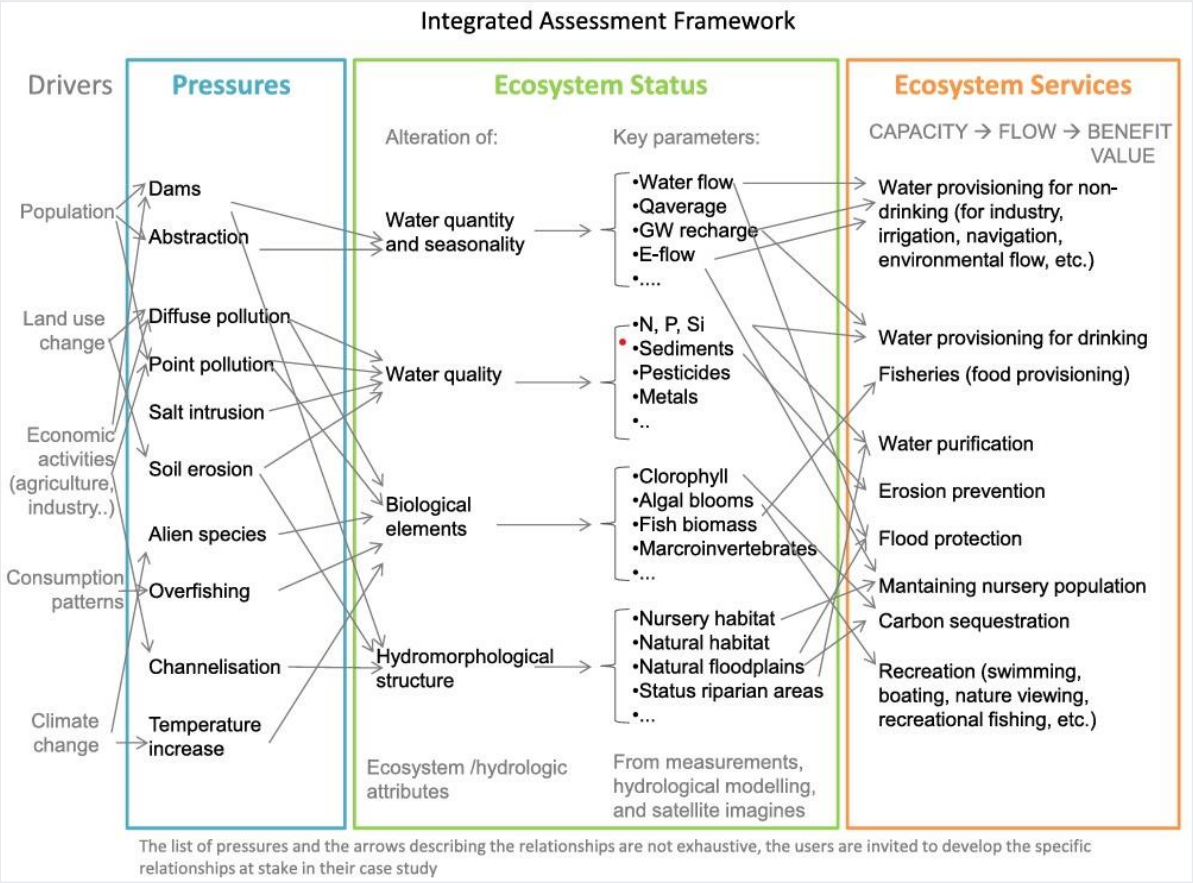
Ecosystem	Ecosystem services		
	Provisioning and cultural	Regulating	Supporting
Intertidal forests and shrublands (Mangrove)	Fish and shellfish harvesting, raw materials, education, and aesthetic	Strom prevention, nutrient cycling, erosion control, carbon sequestration, water purification	Biological diversity, ecological connectivity, nursery and protective habitats for fish, shellfish and wildlife

Source: Revised from Odum and Barrett (2005)

2.2.6 Ecological service of water resource management

Grizzetti et al. (2016) analysed definitions and methods for assessing and valuing ecosystem services for water resource management. The use context of the approach is the study of the relationship between multiple pressures, ecological status and delivery of ecosystem services in water systems. Integrated assessment framework for analysing the links between pressures, ecosystem status and ecosystem services of water resource management is shown in Figure 20.

Figure 20 Integrated assessment framework of water resource management



Source: Grizzetti et al. (2016)

3. Interdependencies of water resources and tourism sector and ecological service assessment

3.1 Assessing the inter-dependencies of the water resource and tourism sector on NC and Ecosystem service

Assessing the inter-dependencies of water resources and ecosystem services involves understanding how water availability, quality, and distribution affect ecosystems and, in turn, how ecosystems regulate and sustain water resources. This requires a holistic approach considering hydrology, ecology, socio-economics, and governance.

Inter-dependencies between water resources and tourism sector and ecosystem services

Provisioning Services (Direct benefits humans get from water)

- Surface water supply for domestic, agriculture, industrial and tourism sector
- Groundwater recharge
- Marine Water quality

Regulating Services (Natural processes that help maintain water systems)

- Wetlands and forests regulate water flow, prevent flooding, and reduce soil erosion
- Mangroves and coastal ecosystems filter pollutants, reducing water contamination

Supporting Services (Underlying ecological functions)

- Water bodies sustain biodiversity and habitats for aquatic and terrestrial species
- Nutrient cycling in rivers and wetlands maintains water quality

Cultural Services (Recreational, aesthetic, and spiritual values)

- Water-related ecosystems attract tourism, recreation, and cultural activities
- Sacred rivers and natural springs have spiritual significance.

3.2 Assessing Interdependencies of Water Resources Sector on NC and Ecological Service

To assess the inter-dependencies of water resources and tourism section in Krabi, Thailand, it's important to consider several factors that influence water availability, quality, and usage. These inter-dependencies typically involve natural systems, human activities, and the infrastructure that supports water use. This included water usage for tourism services at Krabi Province.

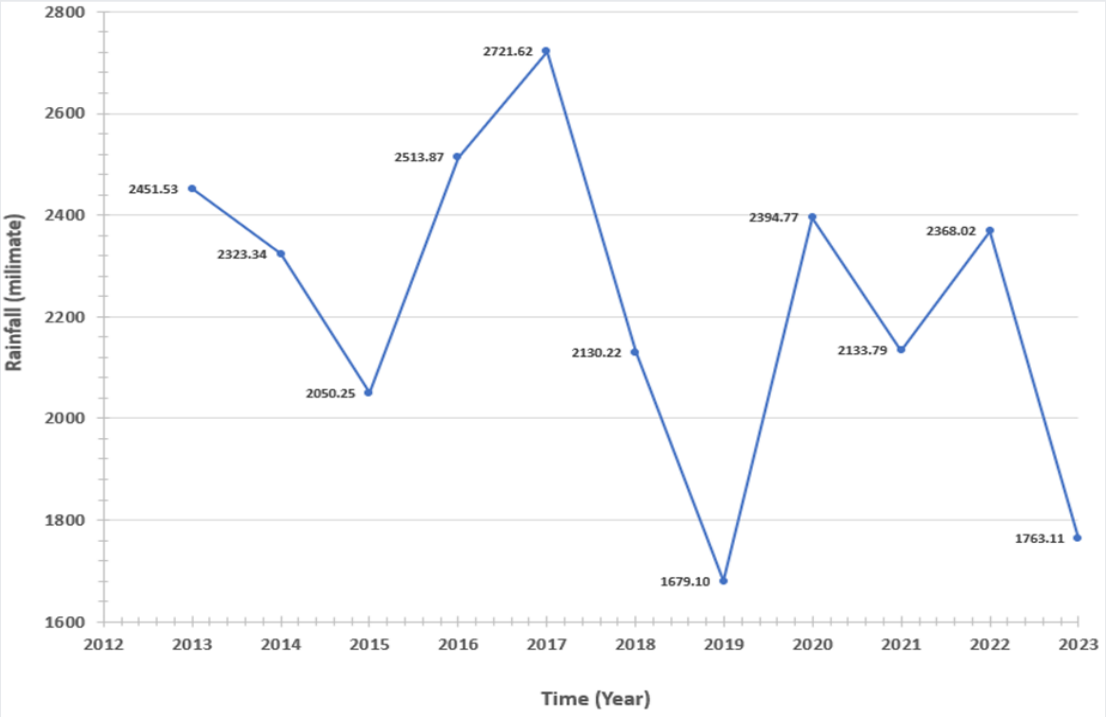
In this study, we used GIS-tool, satellite images from Sentinel-2 MSI: Multispectral Instrument and secondary data from relevant organizations to determine the footprint of water resources.

3.2.1 Hydrological interdependencies

Rainfall and Surface Water

Krabi, like many areas in Thailand, is heavily reliant on seasonal rainfall. The inter-dependencies of water systems here would need to take into account the varying precipitation levels, especially during monsoon and dry seasons. Local rivers and streams, are vital for agriculture and domestic use. In this study, the rain fall and surface water runoff for 10 years in Krabi province were investigated as shown in Figure 21 and 22.

Figure 21 Rainfall at Krabi Province during 2012-2023

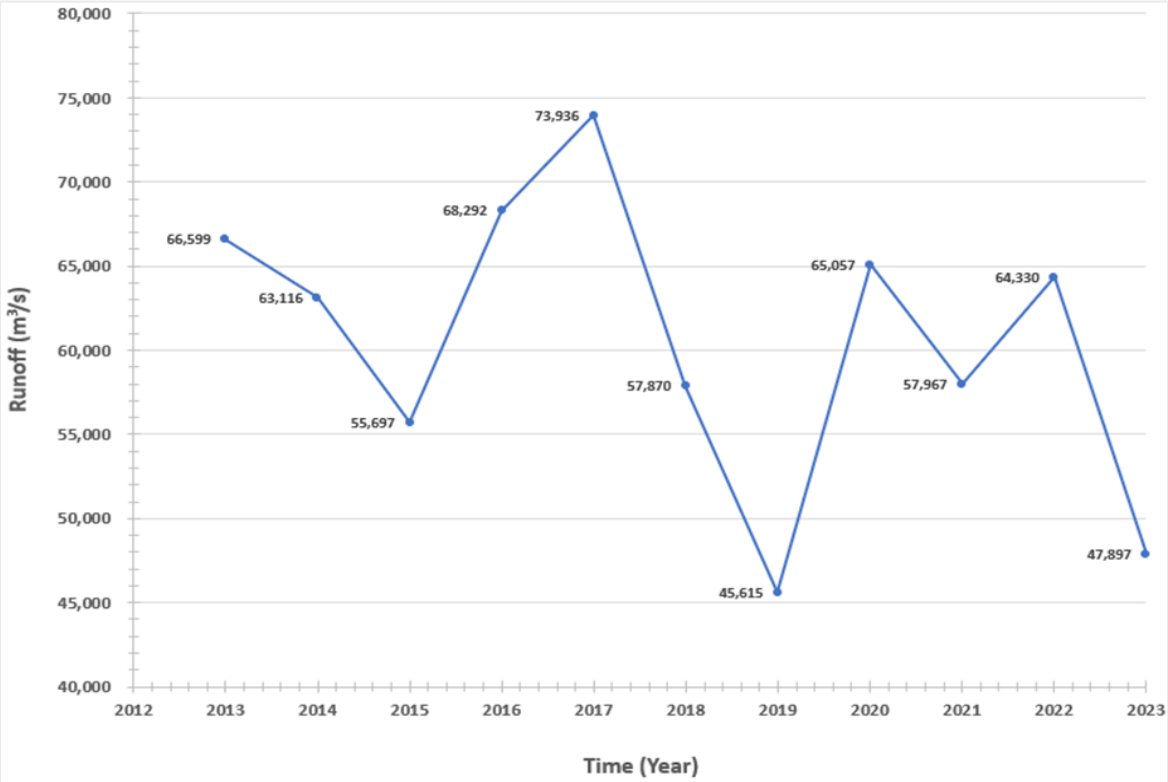


Source: Data provided by Krabi Provincial Water Statistical Office (2024)

For the assessment, the relationship between rainfall and surface water runoff (Figure 23) in Krabi, Thailand, is primarily driven by how much precipitation falls in a given period and the interactions between this water and the region's topography, vegetation, soil, and hydrological systems. For example, during 2016-2017, the higher amount of rainfall, the higher the surface water runoff. During this period, Thailand was bracing itself for La Nina, another weather phenomenon that brought excessive rainfall to Krabi province. For Hydrological Changes, Sangmanee et al., (2011) indicated that annual rainfall may increase by 3% to 20%, with mean annual maximum temperatures rising by 1.6 to 3.8 degrees Celsius. These changes could lead to increased discharge during the southwest monsoon season, while other periods may experience unchanged discharge levels, raising concerns about water supply imbalances. For the report of surface water quality of Krabi by Pollution control department (2024), it indicated that water quality of Krabi province was good in 2023. It is suitable for water consumption with disinfection processes, agriculture and industry. We also developed map of water resources of Krabi province by GIS tool during 2017, 2019, and 2024. In Figure 24, the water area and availability in each year is not

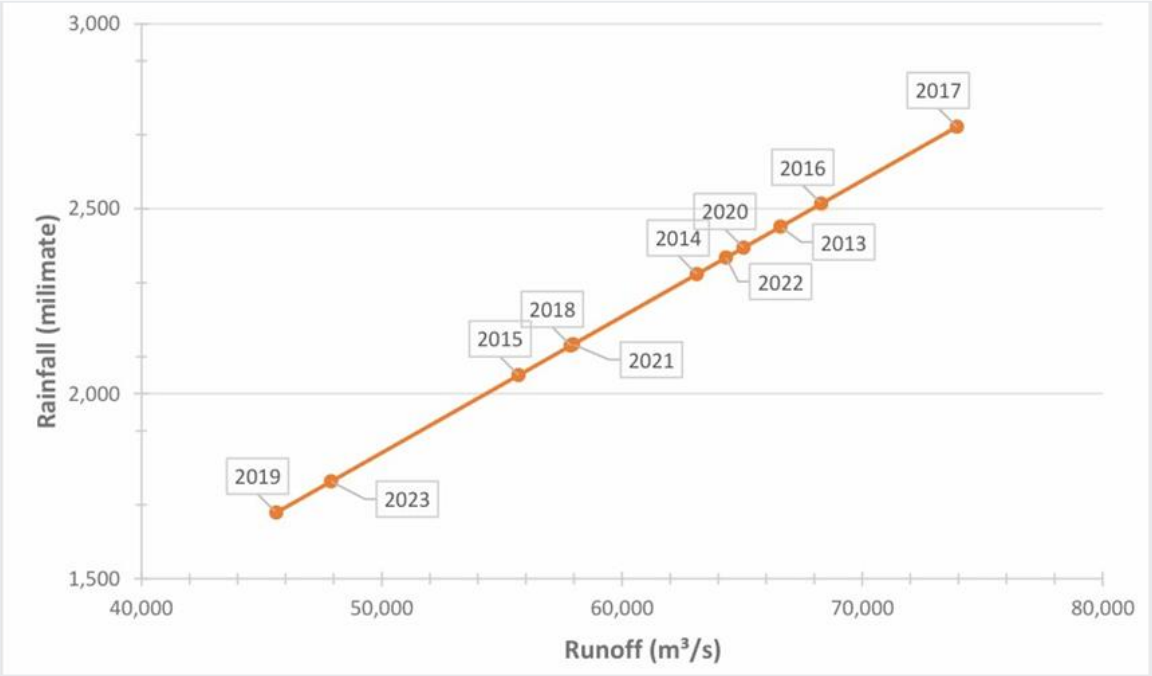
significantly different. It majorly depends on rain fall amount. For surface water quality, Pollution Control Department (2024) indicated that surface water quality in all southern parts of the Thailand was good in 2023.

Figure 22 Runoff water at Krabi Province during 2012-2023



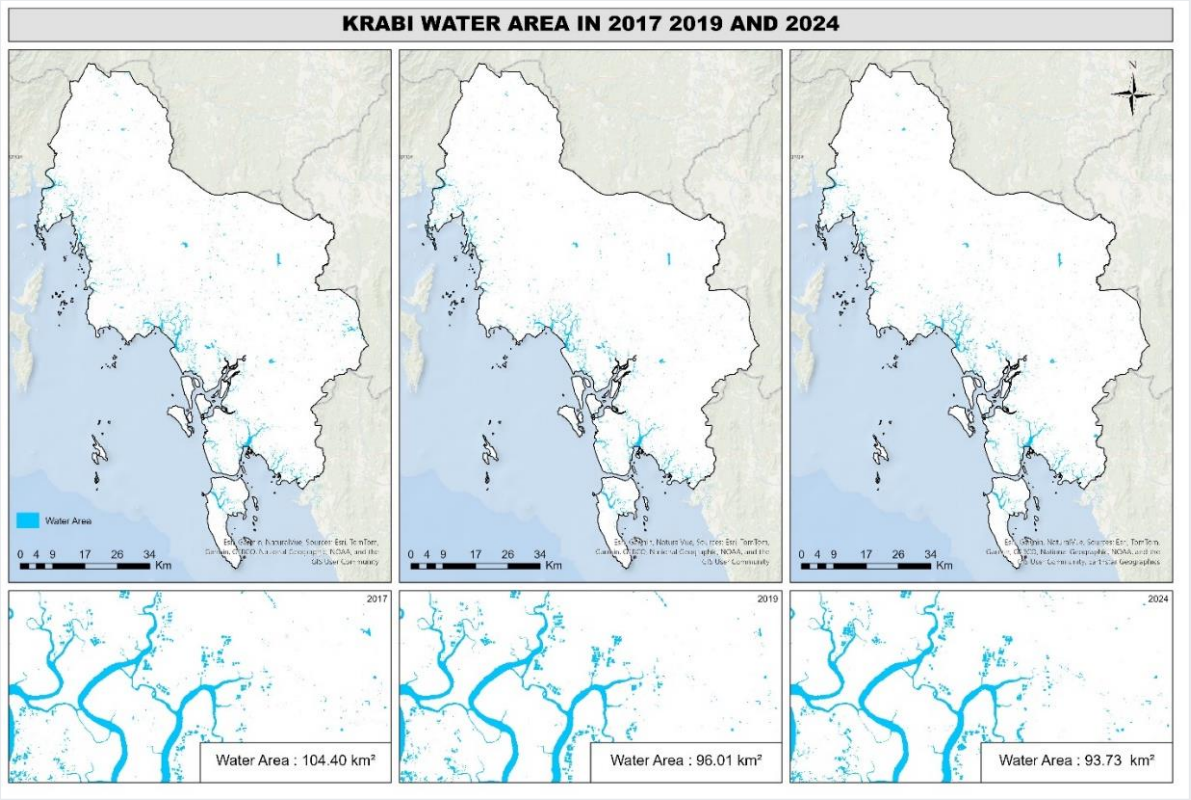
Source: Data provided by Krabi Provincial Water Statistical Office (2024)

Figure 23 The relationship between rainfall and surface water runoff at Krabi Province for since 2013-2023



Source: Data provided by Krabi Provincial Water Statistical Office (2024)

Figure 24 **Water resources at Krabi Province**



Source: Created by the authors using spatial data obtained from GISTDA (2024a)

Groundwater Resources

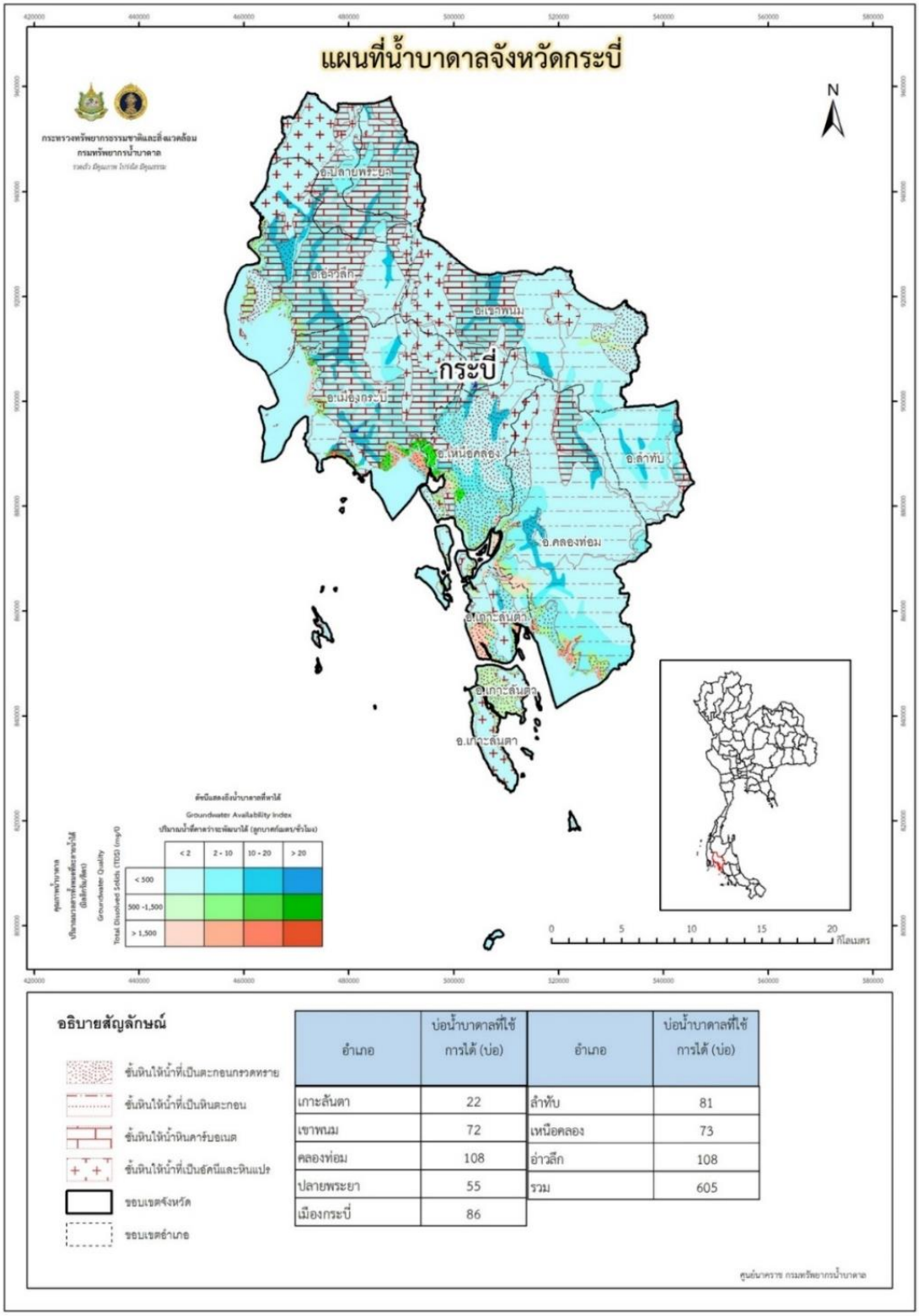
Groundwater serves as a vital water source in Krabi, especially during dry periods. The groundwater map of Krabi Province, Thailand shown in Figure 25. The data provided by the Bureau of Groundwater Resource Region 6 (2021). The overall, the groundwater availability index is 2-10 cubic meters per hour, and water quality index, most total dissolved solid is less than 500 mg/L except the areas where are closed to the coastal and islands. The rapid growth in tourism has led to increased water demand, resulting in over-extraction of groundwater resources. This overuse has caused seawater intrusion into freshwater aquifers, compromising water quality. For instance, on Koh Phi Phi Don, the limited freshwater sources are insufficient for the growing number of visitors, leading to water shortages (Newman, et.al., 2024). Figure 25 also indicates that most groundwater quality in Krabi province is in good condition (blue color).

Marine Water Quality

Marine water quality is essential for ecological service because it is maintaining healthy ecosystems, supporting biodiversity, and sustaining human activities such as fishing and tourism. Ecological services provided by marine environments include water filtration, carbon sequestration, and habitat provision for marine life. However, pollution, climate change, and over-extraction of resources are degrading water quality and threatening these services. For the report of marine water quality of Krabi by Pollution control department, it indicated that marine water quality of Krabi province including in islands was good in 2024 as shown in Figure 26 A “good” Marine

Water Quality Index (MWQI) generally means a score that falls within the mid-to-high range of the index scale, signifying that the marine water quality is considered healthy and suitable for most aquatic life, with minimal pollution levels.

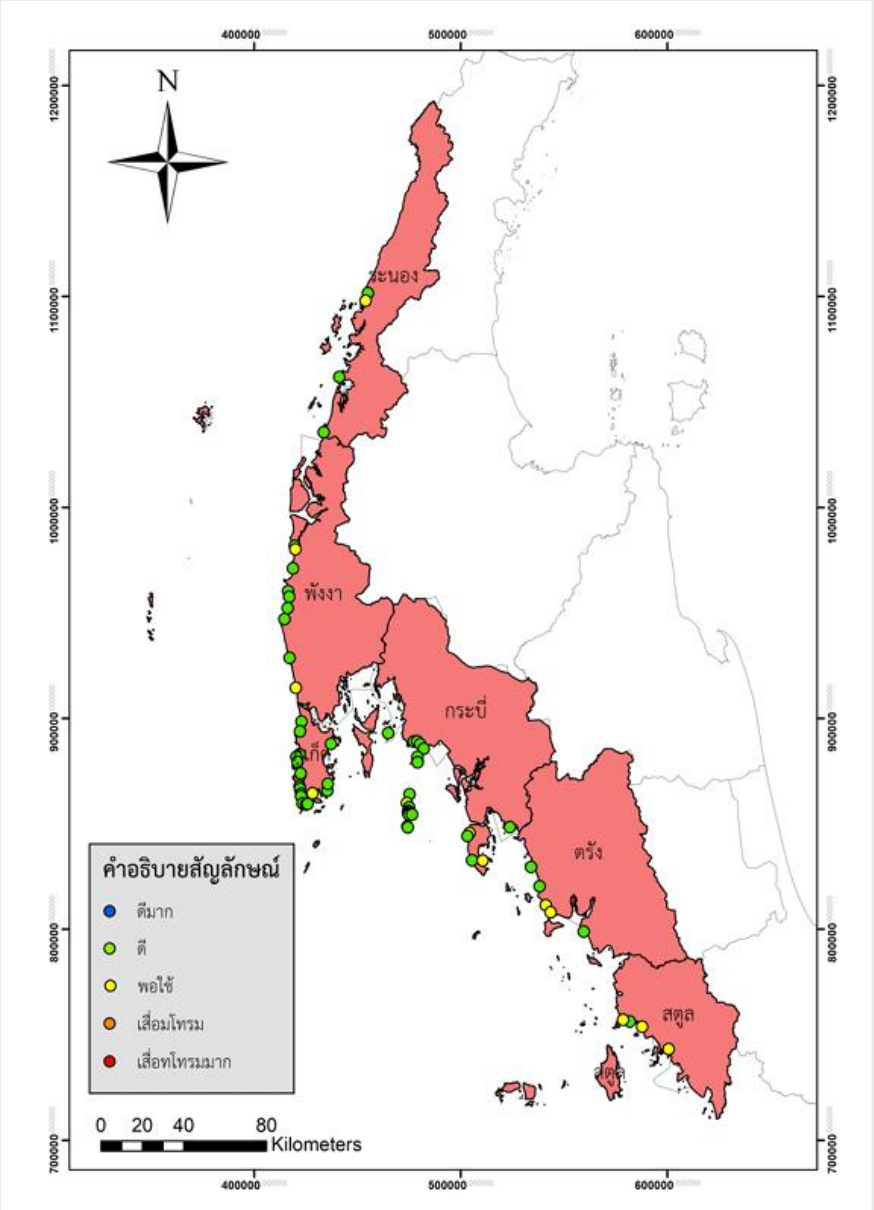
Figure 25 Groundwater Map at Krabi Province



อำเภอ	บ่อน้ำบาดาลที่ใช้การได้ (บ่อ)	อำเภอ	บ่อน้ำบาดาลที่ใช้การได้ (บ่อ)
เกาะลันตา	22	ลำทับ	81
เขาพนม	72	เหนือคลอง	73
คลองท่อม	108	อ่าวลึก	108
ปลายพระยา	55	รวม	605
เมืองกระบี่	86		

Source: Bureau of Groundwater Resource Region 6 (2021)

Figure 26 **Marine Water Quality index of Krabi Province**



Source: Data provided by Pollution Control Department (2022)

Water pollution in Krabi Province, Thailand, stems from several interrelated sources, primarily driven by tourism, inadequate infrastructure, and agricultural practices.

Mass Tourism and Inadequate Waste Management

Krabi Province experiences considerable environmental pressure associated with tourism activities. Figure 27 illustrates the spatial distribution of hotels and accommodation establishments in relation to the Marine Water Quality Index (MWQI) in 2023 across the 24 monitoring stations in krabi. Most monitoring stations were classified as having good marine water quality. However, the Ao Nang station was classified as fair. This station is located in an area with a high density of tourism-related accommodation, exceeding 25 hotels and

accommodation establishments per square kilometer (purple area in Figure 27), suggesting a spatial association between tourism intensity and relatively lower marine water quality.

Presently, Krabi province have generated 180,550.9 tons of waste, an average of 494.66 tons per day (Office of Natural Resources and Environmental Policy and Planning (ONEP), 2024). The data from Pollution Control Department (2024) indicated that only one location (green area in Figure 28) was properly disposed of, 29 locations were improperly disposed of, and no transfer stations. Figure 28 illustrates the spatial distribution of municipal solid waste disposal sites. The map shows that several monitoring stations with poor to very poor Surface Water Quality Index (WQI) and Marine Water Quality Index (MWQI) values are situated in close proximity to waste disposal sites, indicating a spatial association between waste disposal areas and degraded water quality.

Moreover, some wastewater is released into the sea without proper treatment as nonpoint source pollution. The absence of a comprehensive wastewater management system exacerbates this issue, leading to contamination of surface, marine and groundwater resources. These is one of more possible water pollution sources, tourist pier at Krabi province (Figure 29).

Agricultural Runoff

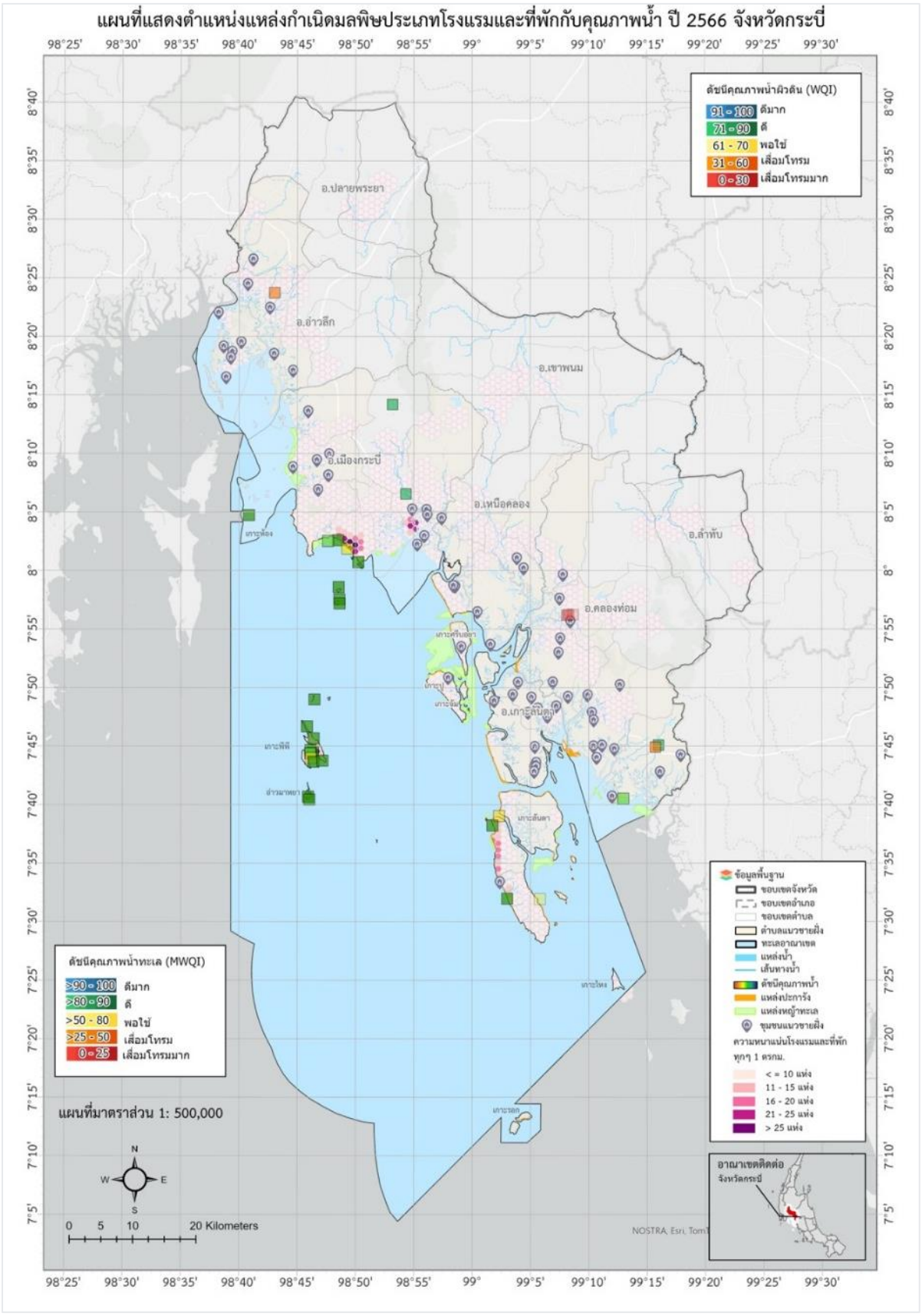
Agricultural activities in Krabi also contribute to water pollution through the runoff of fertilizers and pesticides. Excessive use of nitrogen-based fertilizers leads to nitrate leaching into groundwater, causing contamination. Pesticides can also seep into water sources, posing risks to both human health and aquatic ecosystems. Moreover, aquaculture, for examples, shrimp farms possibly release nutrient-rich wastewater containing nitrogen and phosphorus into nearby rivers and coastal areas. These nutrients can lead to eutrophication, which depletes oxygen in the water and harms aquatic life. In Figure 30, it shows the aquaculture areas where may be responsible for water pollution at Krabi province.

Industrial and Domestic Wastewater

Across Thailand, including Krabi, untreated domestic sewage and industrial effluents are significant contributors to water pollution. The palm oil and para rubber industries play a significant economic role in Krabi Province, Thailand, but also bring complex environmental and social challenges. The province has processing mills and refining facilities, making it a hub for both cultivation and processing. However, these industries may cause high water to use and chemical runoff leading to water quality issues. In Figure 31 spatial distribution of oil palm and para rubber industries at Krabi Province.

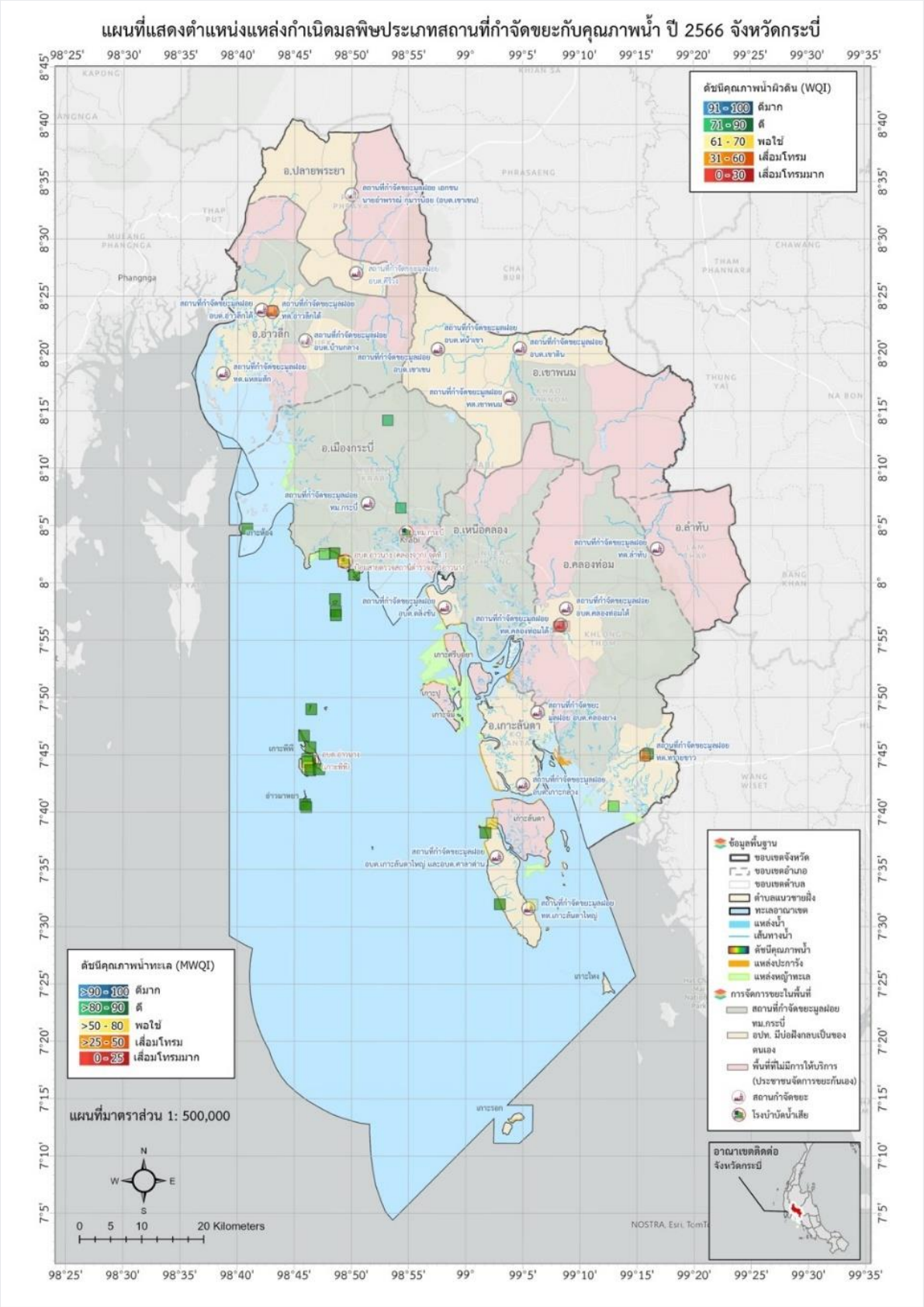
In addition, the Pollution Control Department (2024) reports that only 18% of residential wastewater undergoes effective treatment. This lack of adequate wastewater management infrastructure leads to the discharge of pollutants into rivers and coastal waters, affecting water quality and marine life. Figure 32 shows the possible water pollution sources from domestic areas at Krabi province and also Figure 33 shows market located at Krabi Province.

Figure 27 Spatial distribution of hotels and communities (Gray points) at Krabi province, Thailand



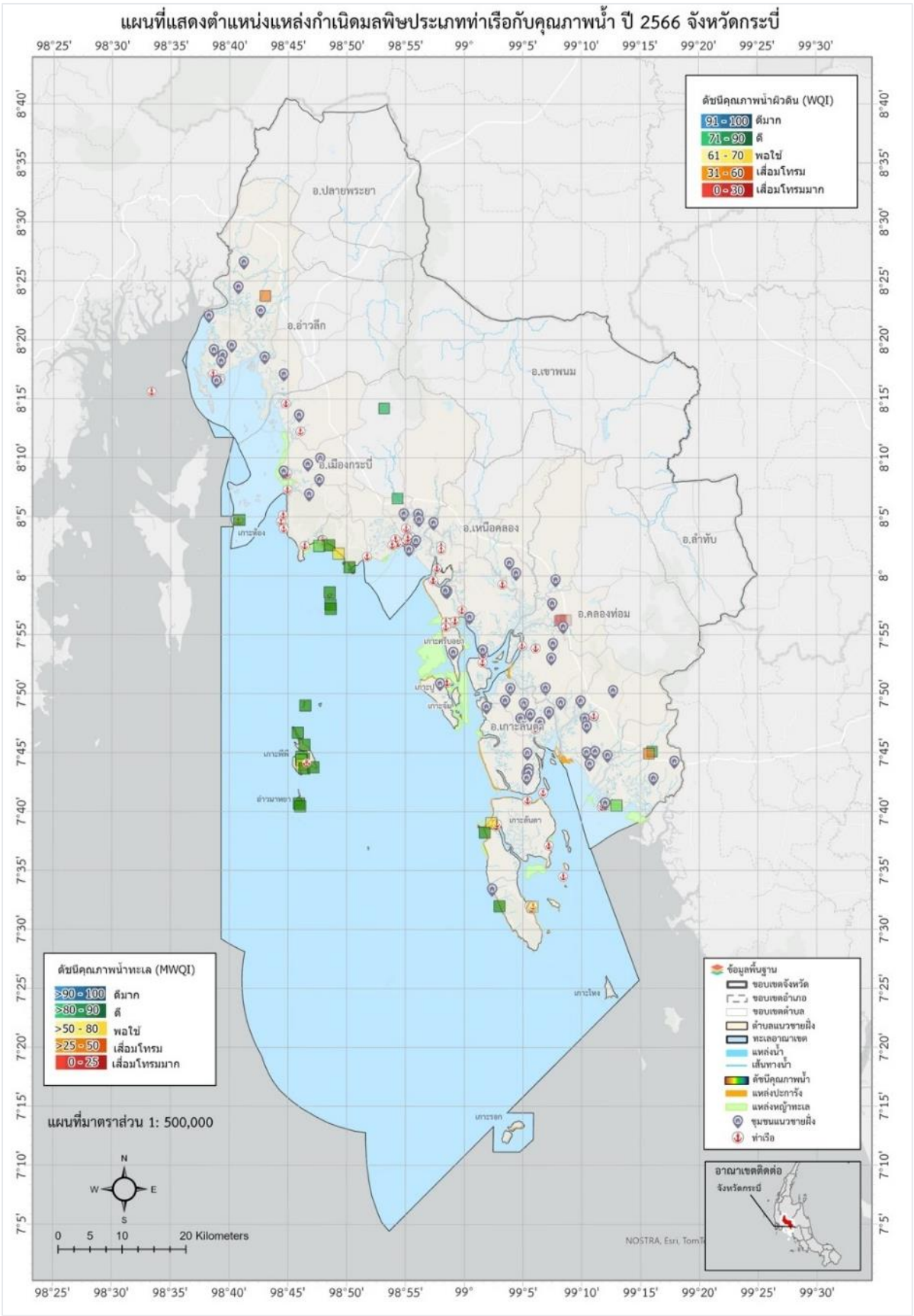
Source: Analysis by TDRI as of 2024

Figure 28 Spatial distribution of landfills at Krabi Provinces, Thailand



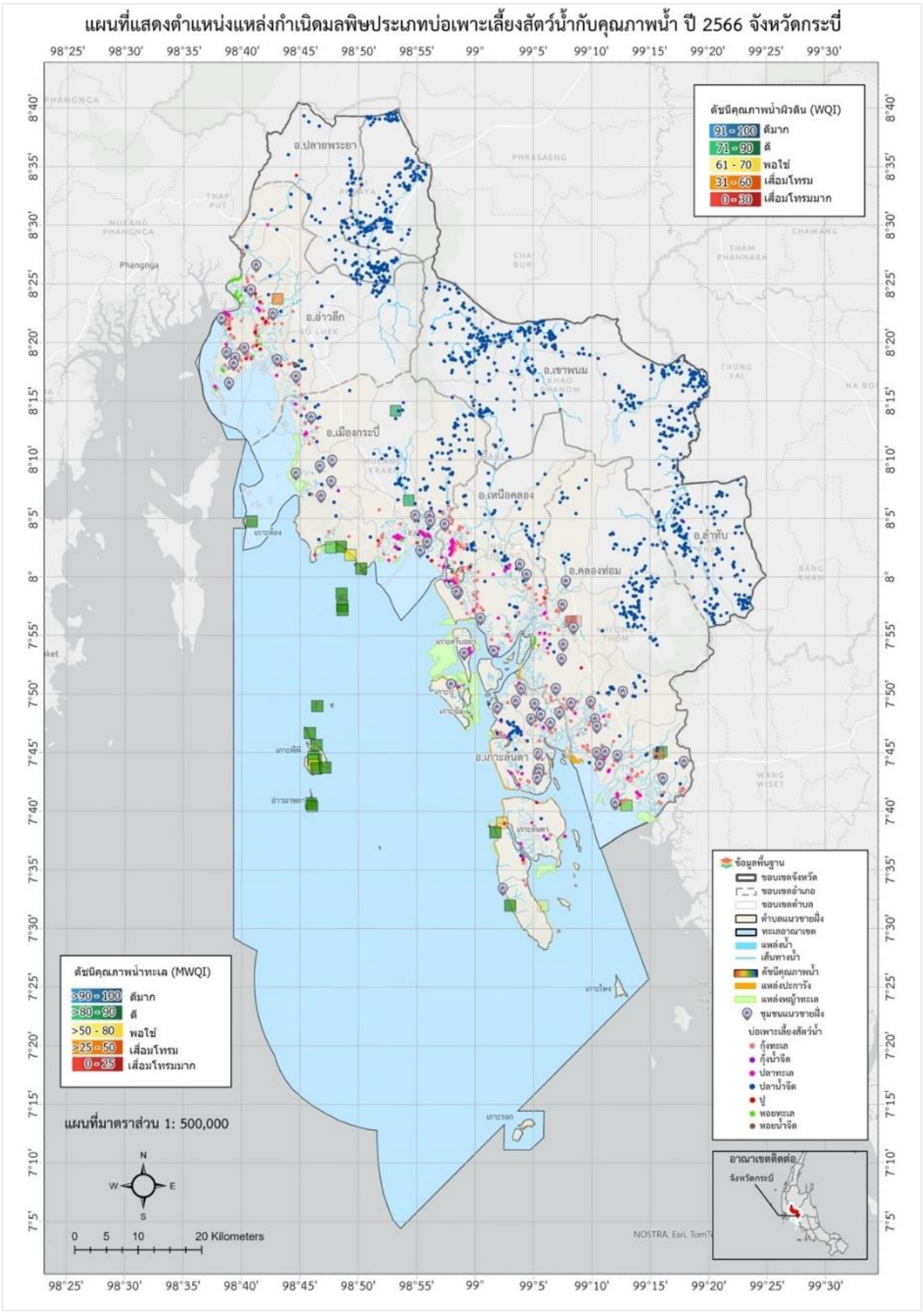
Source: Analysis by TDRI as of 2024

Figure 29 Tourist piers at Krabi Province



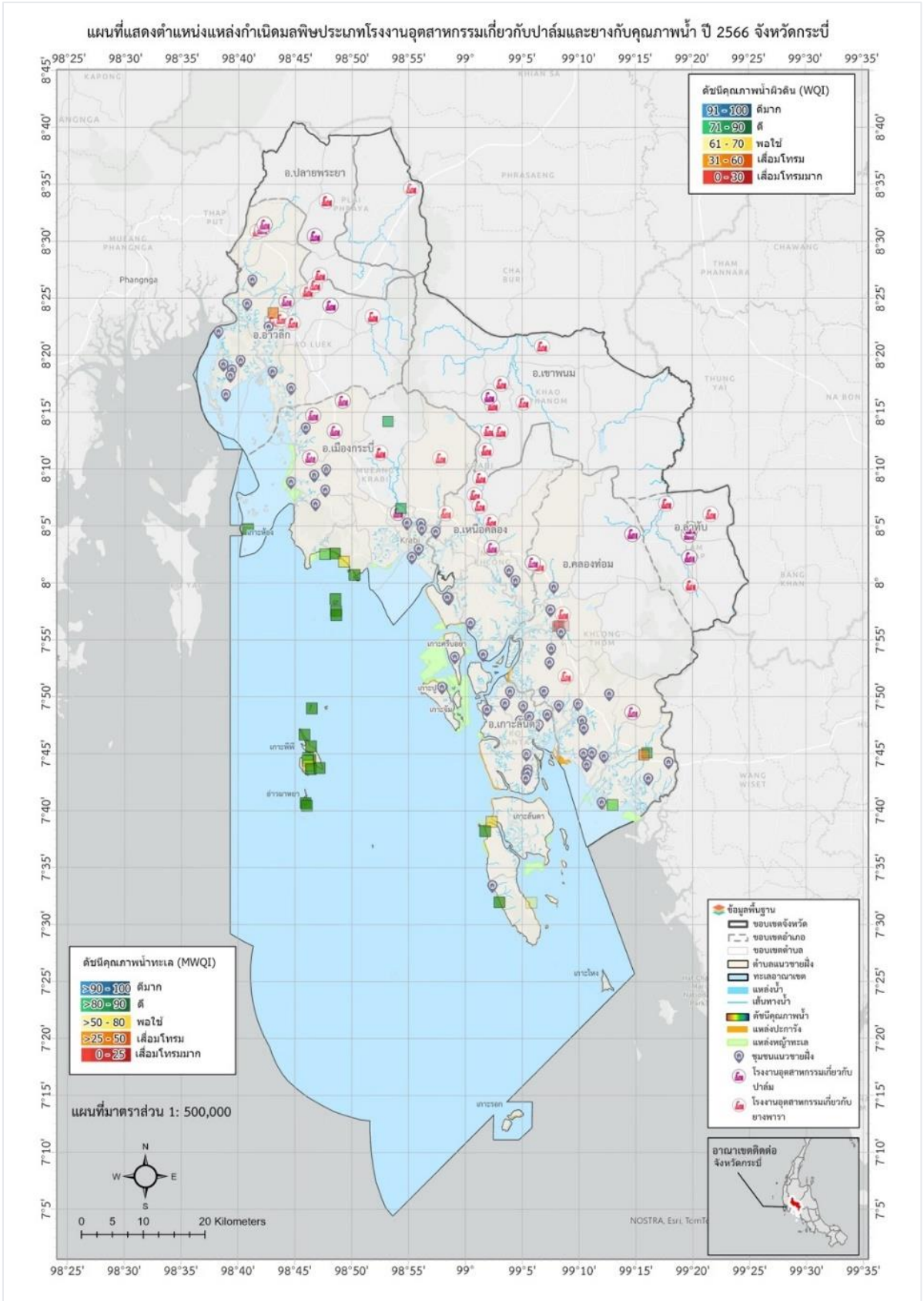
Source: Analysis by TDRI as of 2024

Figure 30 Spatial distribution of aquaculture at Krabi Province



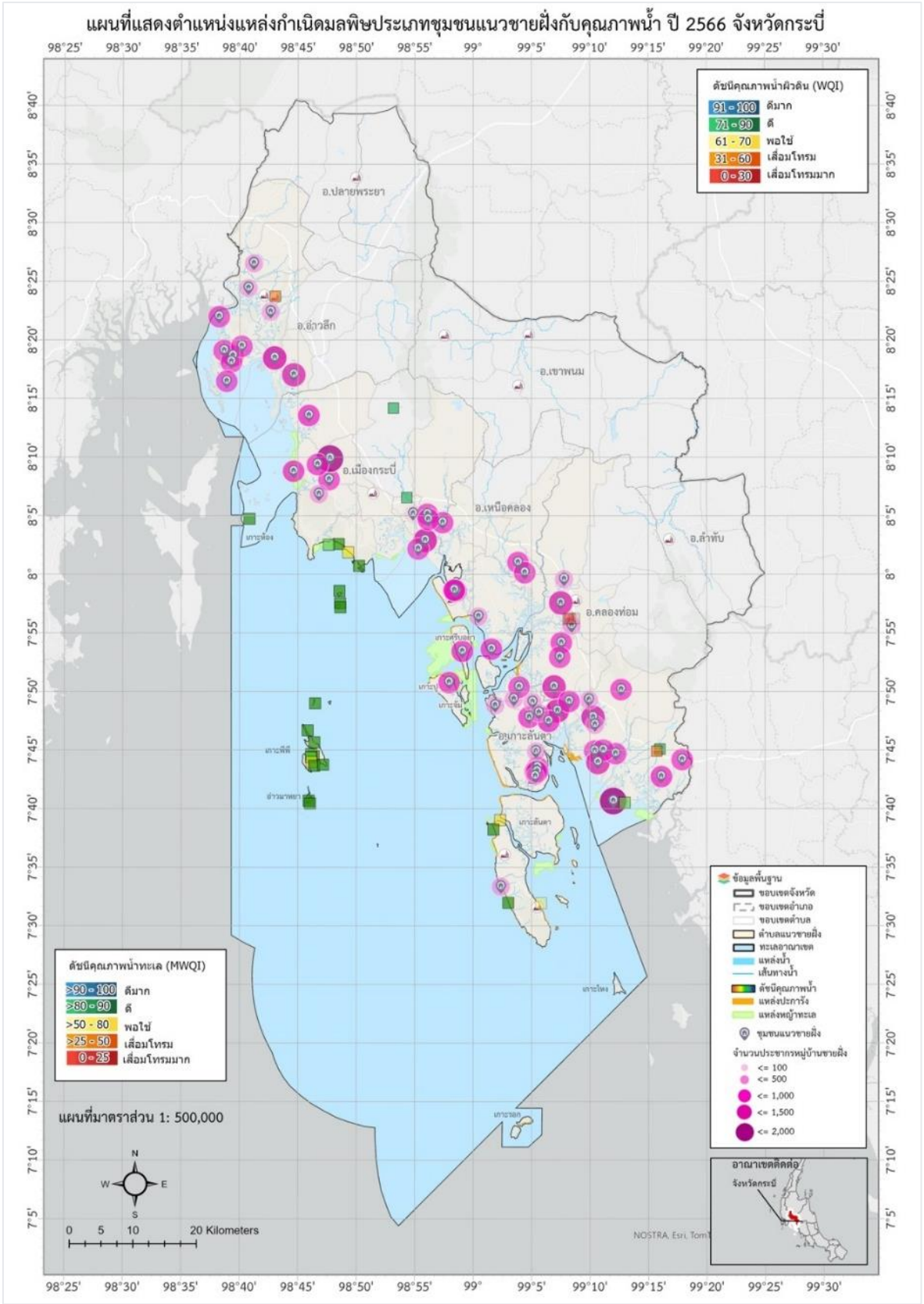
Source: Analysis by TDRI as of 2024

Figure 31 Spatial distribution of oil palm and para rubber industries at Krabi Province



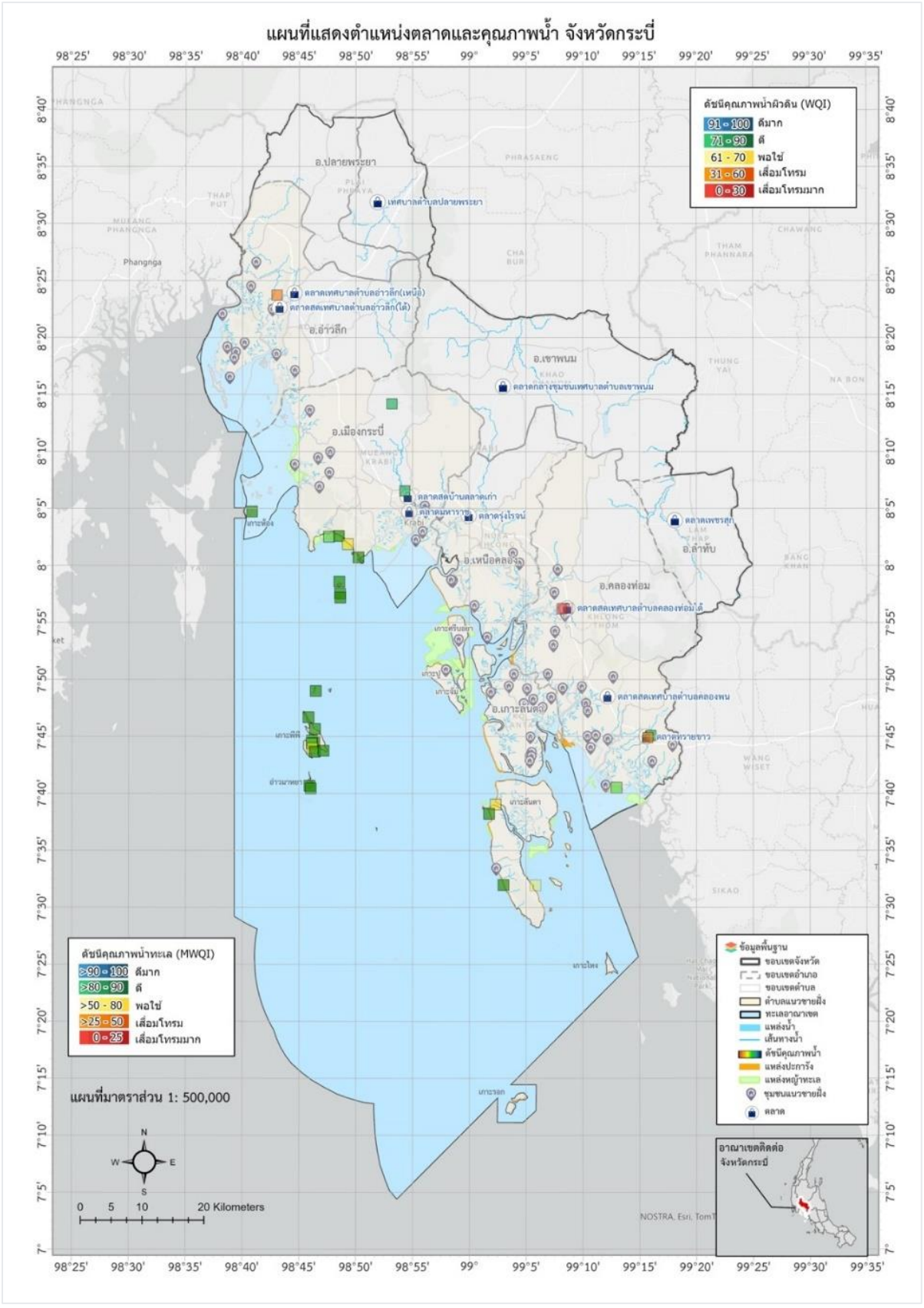
Source: Analysis by TDRI as of 2024

Figure 32 Water pollution sources from domestic areas at Krabi Province



Source: Analysis by TDRI as of 2024

Figure 33 Spatial distribution of markets at Krabi Province

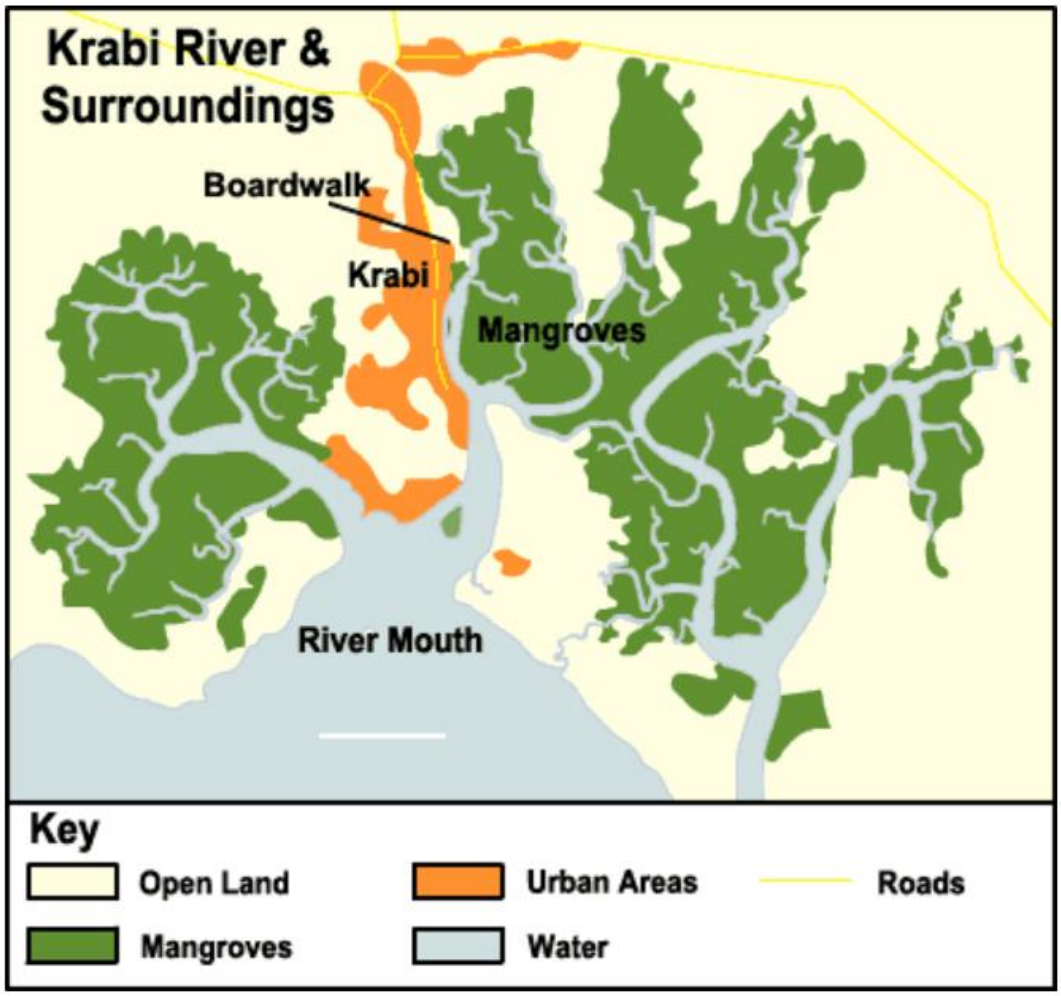


Source: Analysis by TDRI as of 2024

3.2.2 Ecological Interdependencies

Krabi province's ecosystems are closely linked to its water resources and tourism section is The Khlong Krabi Yai watershed or Krabi estuary (Figure 34) supports wetlands recognized as Ramsar sites, which are critical for maintaining biodiversity and ecological balance. From the Information Sheet on Ramsar Wetlands (RIS) indicated that Krabi Estuary is located in Muang District, Krabi province on the southern part of Thailand approximately 176 Km. and 814 Km. from Phuket and Bangkok respectively. Krabi Estuary is included with mangrove forest with a high predominance of Rizophora spp., mud flats, rocky mountain with evergreen forest mollusk fossil and sea grass bed. Even though during the past the area was under logging, some large plant still exists. At last 19 species of mangrove species are found, some of them are Large-leaf mangrove (*Rhizophora mucronata*), Small-leaf mangrove (*R. apiculata*), *Ceriops* spp., *Xylocarpus* spp, *Lummitzera* spp mangrove date palm (*Phoenix paludosa*), seagrass such as *Cymodocea serruleta*, *Halophila ovalis*, *Cymodocea rotundata*, *Syringodium isoetifolium*. (Scott A. Derek, 1989 and National Inventory of Natural Wetland, 2000). This area has much recreational potential owing to its proximity to the town of Krabi. It is perhaps the most easily accessible area of species-rich mangrove for birdwatcher and naturalists in Thailand.

Figure 34 Krabi Estuary



Source: Thaibirding (2019)

Because this area is under Ramsar Site, Krabi estuary is now under forest conservation. Mangrove forest area is under functional jurisdiction of the Royal Forest Department. The relationship between water resources and ecological inter-dependencies is fundamental to sustaining ecosystems, biodiversity, and human societies. Water resource sector plays a critical role in supporting ecological processes, while ecosystems, in turn, influence the availability, quality, and distribution of water. This relationship is dynamic and can be affected by natural and human-induced changes. For tourism sector, the interaction between tourism and ecological interdependencies can be both positive and negative, affecting water resources, biodiversity, and ecosystem services. From the assessment of water demand to maintain the downstream ecosystem in Krabi Province by Royal Irrigation Department (2018a) is equal to 617.56 million cubic meters/year.

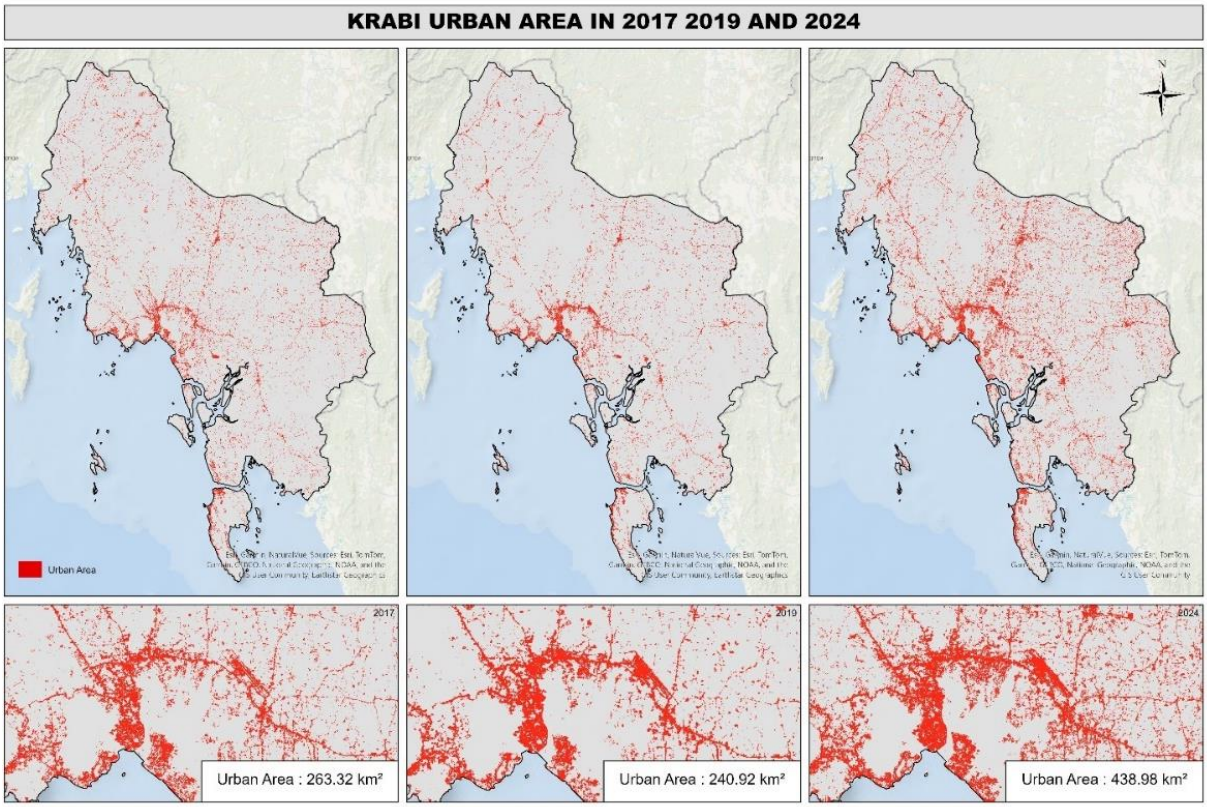
3.2.3 Socioeconomic Interdependencies

Based on national and provincial development plans for the province, major economic and social sectors were identified as:

- Agriculture & Water Use: Irrigation is a major water consumer; shortages affect food production and economies. Para rubber and oil palm are the major crop of Krabi province, other crops of the province include coconut, fruit trees, coffee, and paddy rice. Water demand for agriculture was estimated from agricultural areas in the rainy and dry seasons, both in irrigated areas and non-irrigated areas, with water usage rates for cultivation per rai. The data of Royal Irrigation Department (2018b) indicated water demand for agriculture of Krabi province was equal to 2,421.60 million cubic meters/year and water demand for agriculture will increase to 2,450.17, 2,452.01 and 2,452.01 million cubic meters/year in 5, 10 and 20 years respectively. The water demands for agriculture during the next 20 years are not significantly different.
- Energy Production: Senpong and Wiwattanadate (2022) revealed that Electricity load forecast indicated that peak load demand in the Krabi province had continuously increasing from 35 MW in 2000, up to 159 MW in 2019, and tends to increase up to 320 MW in 2037. Krabi province's energy demand, driven by tourism and economic growth. However, there is no hydropower plant at Krabi province, therefore, there is no water demand for energy production.
- Industry: The industries of Krabi province are rubber & palm oil processing: factories process raw materials for domestic use and export. Seafood processing has facilities for drying, freezing, and packaging seafood. Then, some cement and construction material industries operate in the region. Industrial water demand was 13.48 million cubic meters/year and will increase to 14.16, 14.83 and 16.18 million cubic meters/year in 5, 10 and 20 years respectively (Royal Irrigation Department, 2018b).
- Urbanization and Tourism: Growing populations increase demand for drinking water, sanitation, and wastewater treatment. We analyzed the urbanization as shown in Figure 35 The urban area has significantly increased between 2017 (263.32 km^2) and 2024 (438.96 km^2) especially in areas near coastal area and national parks. The urbanization and tourism affected water resources as water consumption demand. Tourism increases water consumption in hotels, resorts, swimming pools, golf courses, and recreational activities, often straining local water supplies. Recently, tourism operators in Krabi province are requesting

long-term water supply investment as the southern province lacks sufficient reservoirs and efficient management to deal with a future that could feature longer droughts The data of Royal Irrigation Department (2018) indicated the demand for water for consumption is 25.70 million cubic meters/year and will increase to 30.51, 36.18 and 50.90 million cubic meters/year in 5, 10 and 20 years, respectively.

Figure 35 The urbanization map of 2017, 2019, 2024



Source: Created by the authors using spatial data obtained from GISTDA (2024b)

3.2.4 Ecological Footprint of Water resources

Water resources in Krabi are crucial for tourism, local communities, and ecosystems. However, tourism and urbanization have increased water consumption, pollution, and ecosystem degradation. For the water use and demand for tourism, Krabi Provincial Statistical Office (2024) forecasted the tourist between 2025-2029 as show in Table 15 The water use calculated by using 50 liters (0.05 m^3) of water for drinking and using per person per day. This volume is the volume of water that is sufficient for basic human needs. The average day of tourist staying at Krabi province was 3 days.

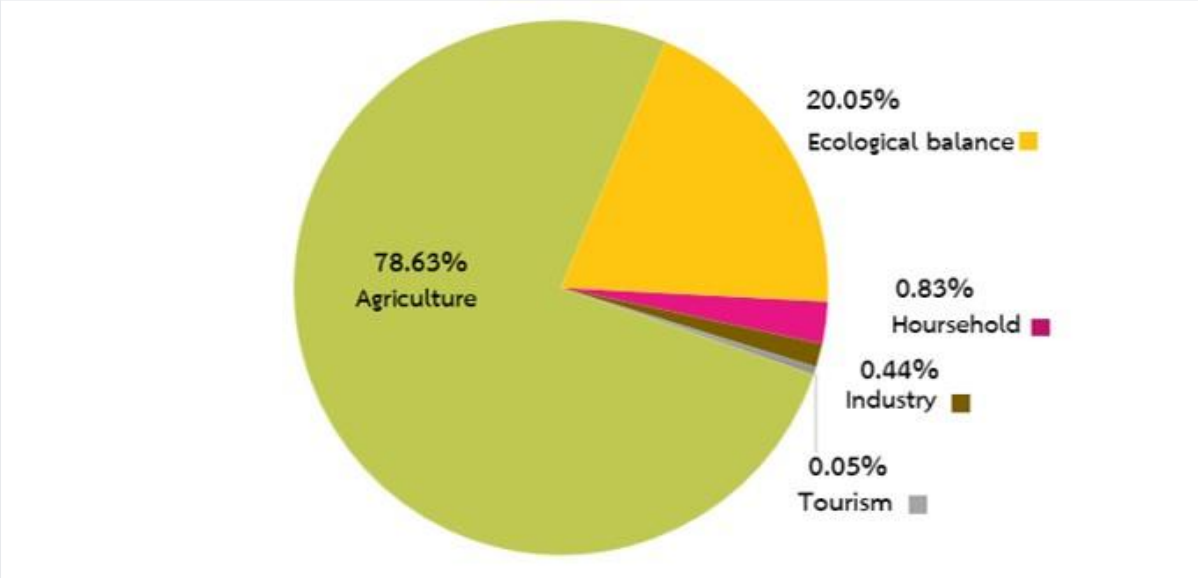
Table 16 Amount of Tourist and estimated water used at Krabi Province

Year	Tourist (person)	Estimated Water use (million cubic meter)
2025	9,337,968	1.401
2026	11,636,865	1.746
2027	13,950,676	2.092
2028	16,283,323	2.442
2029	18,636,654	2.795

Source: Krabi Provincial Statistical Office (2024)

The ecological footprint of water resources is contributed by water used in each activity in Krabi province as shown in Figure 36.

Figure 36 Ecological footprint of water resources at Krabi Province, Thailand



Source: Royal Irrigation Department (2018a)

Risks and impacts of alternative development for water resources

Water resources play a crucial role in the success of Alternative Development (AD) projects. The key risk factors associated with water resources in Alternative Development are:

1) Water Availability Risks (A):

- Seasonal Water Variability – Fluctuations in rainfall and water availability can impact crop yields of Krabi province as we shown in hydrological dependencies.
- Drought Risk – Prolonged dry periods may limit the viability of alternative crops.
- Over-extraction – Excessive water use can deplete local water sources, affecting sustainability.

2) Water Quality Risks (Q):

- Water Pollution – Industrial, agricultural, or human waste can contaminate water sources. As we mention earlier, surface water and marine water quality of Krabi province are in good condition.
- Salinity Issues – High salt levels in water can degrade soil quality and reduce crop growth.

3) Water Infrastructure Risks (I):

- Inefficient Irrigation Systems – Poor irrigation technology can lead to water waste and inefficiencies.
- Lack of Water Storage Facilities – Absence of reservoirs or tanks can limit water supply during dry periods.
- Dam or Canal Failures – Structural weaknesses in water distribution infrastructure can disrupt AD projects.

4) Institutional & Governance Risks (G):

- Weak Water Management Policies – Lack of regulations on water usage can lead to misallocation or scarcity.
- Conflicts Over Water Rights – Competing demands from different users (farmers, industry, and households) may cause disputes.
- Corruption & Mismanagement – Poor governance can result in inefficient distribution or unfair access.

5) Climate Change & Environmental Risks (C):

- Changing Rainfall Patterns – Unpredictable precipitation can impact water supply.
- Desertification & Land Degradation – Reduced water availability can accelerate soil degradation.
- Flood Risks – Extreme weather events may lead to excessive water supply, damaging crops and infrastructure.

In this study, we use five main categories of risk related to water resources in Table 16.

Then, we assume the following scores for the water resource risks based on a hypothetical AD project of Krabi province using water resources expert, environmentalist, scientist and economist to evaluate the score of risk. As shown in table 17.

Table 17 **Risk categories, risk factors and weighting**

Risk Category	Risk Factor	Weight (%)
Water Availability Risks (30%)	Seasonal Water Variability	15%
	Drought Risk	15%
Water Quality Risks (20%)	Water Pollution	10%
	Salinity Issues	5%
Water Infrastructure Risks (20%)	Inefficient Irrigation Systems	10%
	Lack of Water Storage Facilities	10%
Governance & Institutional Risks (20%)	Weak Water Management Policies	10%
	Conflicts Over Water Rights	5%
	Corruption & Mismanagement	5%
Climate Change & Environmental Risks (10%)	Changing Rainfall Patterns	5%
	Flood Risks	5%

Table 18 **Risk factor score**

Risk Factor	Score (0-5)
Seasonal Water Variability	4
Drought Risk	3
Water Pollution	2
Salinity Issues	1
Inefficient Irrigation Systems	3
Lack of Water Storage Facilities	2
Weak Water Management Policies	4
Conflicts Over Water Rights	2
Corruption & Mismanagement	3
Changing Rainfall Patterns	4
Flood Risks	2

The we calculated risk score for water resource of Krabi province as:

$$Water\ Risk\ Score = (W_1 \times A) + (W_2 \times Q) + (W_3 \times I) + (W_4 \times G) + (W_5 \times C)$$

Where:

- $W_1, W_2, \ldots, W_5$ are the weights for each risk category.
- A, Q, I, G, C are the scores for each risk factor.

Total Water Risk Score =1.05+0.25+0.50+0.65+0.30 = **2.75**

Total water resource risk score:

- 0.0 – 1.5 → Low Risk: Water-related risks are manageable with little chance of significant disruptions.
- 1.6 – 3.0 → Moderate Risk: Water-related risks are present but can be managed with interventions.
- 3.1 – 4.5 → High Risk: Water-related risks are substantial and require strong mitigation measures.
- 4.6 – 5.0 → Very High Risk: Water-related risks are very severe, threatening the sustainability of the project.

In conclusion, water resource section of Karbi province is in moderate risk. The water resource can be managed in some factors especially water availability and water quality. However, some factors we cannot control include climate factors. The impacts of climate change on water resources assessment clearly are the changes of streamflow volume.

3.3 Assessing Interdependencies of Tourism sector on NC and Ecological Service

Assessing the interdependencies of the tourism sector on natural capital and ecosystem services is crucial for sustainable development, environmental conservation, and economic resilience. The relationship between ecological service and tourism sector is shown in Table 18.

Table 19 The relationship between ecological services and tourism

Ecological Service	Functions	Link to Tourism
Provisioning	Fresh water, food	Tourist facilities require water and food sourced from the local environment.
Regulating	Climate regulation, air quality, water purification	Clean air and water are vital for health-based and ecotourism.
Supporting	Biodiversity, soil formation	Biodiversity drives wildlife tourism; soil stability supports landscapes.
Cultural	Recreation, aesthetics, spiritual value	The core of most tourism activities—especially nature-based tourism.

Krabi boasts a wide range of ecosystems:

- Marine ecosystems: Coral reefs, seagrass beds, and coastal waters. The map of spatial distribution of coral reefs and seagrass is in chapter 5.

- Forests: Tropical rainforests and mangroves. The map of the forest is in chapter 2. Some forests are located in national parks for examples, Than Bok Khorani National Park is, with an area of 104 square kilometres (40 sq mi). This national park is located on the mainland in Ao Luek district, along with several archipelagos in Mueang Krabi district: Ko Chong Lat, Ko Ka Rot and an archipelago east of Ko Yai Noi, with among others, Ko Pakbia, Ko Lao Lading and Ko Hong. Moreover, Khao Phanom Bencha National Park is in Khao Phanom and Ao Luek districts, established on 9 July 1981 with an area of 50 square kilometres (19 sq mi)
- Caves and karst landscapes,
- National parks: Ao Phang Nga, Than Bok Khorani, and Hat Noppharat Thara–Mu Ko Phi Phi

These ecosystems form the natural capital that sustains both the environment and tourism-based livelihoods. The ecosystem services supporting Tourism in Krabi province is shown in Table 19.

Table 20 Ecological service of Krabi Province and tourism sector

Ecosystem Service Type	Krabi Natural Resources	Tourism Link
Cultural	Scenic beaches, diving reefs, traditional knowledge	Major draw for international tourists
Provisioning	Seafood, fresh water	Supports hospitality sector
Regulating	Mangroves protecting against coastal erosion	Helps maintain beautiful beaches and tourist safety
Supporting	Coral reefs & forests sustaining biodiversity	Vital for snorkeling, diving, and ecotourism

The trend of tourist at Krabi province from Krabi Provincial Statistical Office. (2024) indicates that in between 2025-2029, tourists increase around 2 million tourists per year. The estimated tourist is shown in Table 20.

Table 21 The estimated tourist of Krabi Province, Thailand

Year	Tourist (person)
2025	9,337,968
2026	11,636,865
2027	13,950,676
2028	16,283,323
2029	18,636,654

3.3.1 Ecological footprint of tourism sector at Krabi province

While the ecological footprint of tourism in Krabi Province are limited, available studies provide insights into the environmental impacts associated with various tourism-related activities. Nantavisit et al. (2023) indicated that the carbon footprint, one of the ecological footprint, of tourism activities in Krabi Province, focusing on marine tourism. The findings revealed the following contributions to greenhouse gas emissions:

1) Transportation = 36.25%

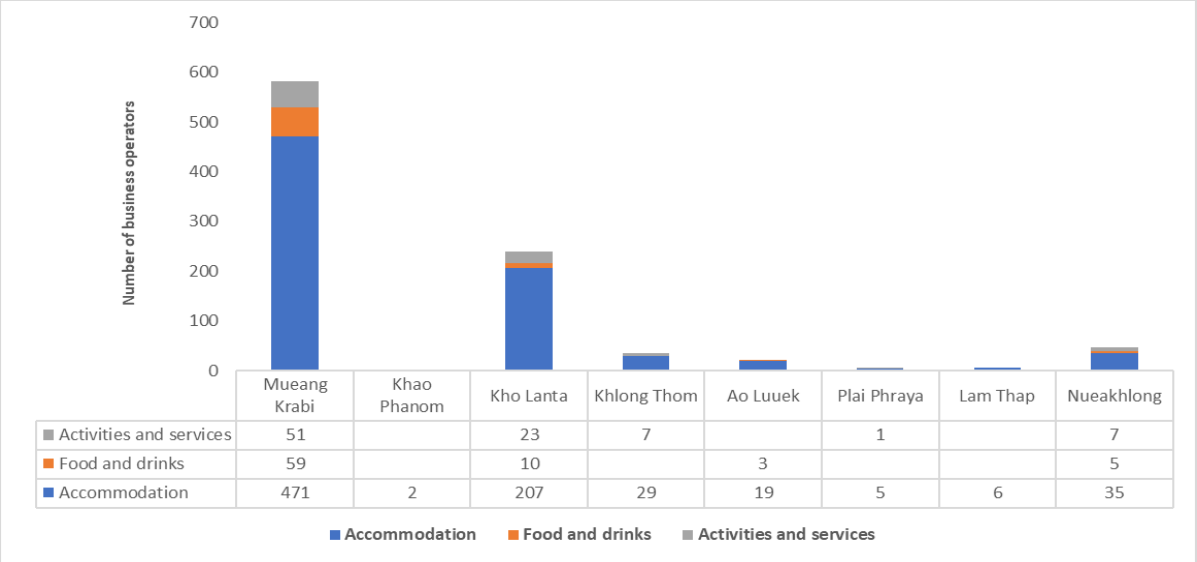
2) Waste = 22.91%

3) Food & beverage = 21.56%

4) Accommodation = 19.28%

Our study also determines ecological footprint following the major environmental impact contributions as shown in Figure 37.

Figure 37 Ecological footprint of sub provinces at Krabi Province



Source: National Statistical Office (2020)

Impacts of tourism on environments at Krabi province

Tourism in Krabi Province, Thailand, is a major economic driver, but it also exerts significant pressure on the environment. According to the literature reviews, the key environmental impacts of tourism in Krabi include:

1) Marine and Coastal Degradation

- Coral reef destruction from boat anchors, snorkeling, and diving.
- Oil leaks and fuel spills from speedboats pollute the sea.
- Over-tourism at popular sites like Maya Bay has caused severe reef bleaching and ecosystem collapse.
- Construction of coastal resorts contributes to beach erosion.

2) Solid Waste Accumulation

- Rapid influx of tourists results in massive amounts of garbage, especially plastic waste.
- Tourist islands such as Phi Phi Island generate 30–40 tons of waste per day during peak season, much of which is improperly managed.

- Littering by tourists is common in both urban and natural areas.

3) Water Resource Depletion and Pollution

- High water demand from hotels and resorts leads to overuse of freshwater, especially on islands with limited supply.
- Untreated wastewater from accommodations and restaurants is often discharged directly into the sea or rivers, contributing to eutrophication and health risks.

4) Habitat Destruction and Land Conversion

- Development of resorts, roads, and tourism infrastructure leads to the clearing of mangroves, forests, and wetlands.
- Disruption of wildlife corridors and nesting areas for species like sea turtles and birds.

5) Air and Noise Pollution

- Increase in transportation (boats, tuk-tuks, buses) leads to air pollution from fuel combustion.
- Popular beaches and tourist sites suffer from noise pollution, disturbing both wildlife and local communities.

Risks of alternative development for tourism sector

Our study estimates risk of alternative development for tourism sector in 5 categories as environmental risk, socio-policy risk, health and safety risk, economic risk and infrastructure risk as show the assessment at Table 21

1) Environmental Risks, for example, natural disasters, landslides & flooding: common during monsoon season due to hilly terrain and heavy rainfall, earthquakes: assam lies in a seismically active zone. Forest Fires: possible during dry seasons in wildlife sanctuaries, promote off-season travel safety measures, build resilient infrastructure, Early warning systems and community awareness, biodiversity disruption, wildlife disturbance: unregulated tourism can affect animal behavior, deforestation for development.

2) Socio-Political Risks, for examples, local conflicts & ethnic tensions, Krabi Anglong has a history of inter-ethnic tensions and demands for autonomy, occasional protests or bandh (strikes) could disrupt travel plans, government coordination for security, real-time travel advisories, educate tourists on cultural sensitivity, community displacement: tourism-related development can displace indigenous communities or marginalize them economically.

3) Health & Safety Risks, for example, medical infrastructure, limited healthcare facilities in remote areas, risk of waterborne diseases or insect-borne diseases (malaria, dengue), safety standards, lack of safety protocols in adventure activities (e.g., trekking, waterfall visits), inadequate tourist signage or emergency access routes.

4) Economic Risks, for example, overdependence on tourism, seasonal tourism can make the local economy vulnerable to shocks (e.g., pandemics, political instability), price inflation, tourist influx may raise the cost of living for locals.

5) Infrastructure Risks, for example, poor transport connectivity, road conditions, and digital access, limited hospitality infrastructure in rural parts.

Figure 38 Risk assessment of tourism sector at Krabi Province

Risk Category	Likelihood	Impact	Overall Risk
Environmental	High	High	High
Socio-political	Medium	High	Medium-High
Health & Safety	Medium	Medium	Medium
Economic	Medium	Medium	Medium
Infrastructure	High	Medium	Medium-High

In chapter 3, we conclude that inter-dependencies of water resource and tourism sector on ecological services related to natural capital cost.

3.4 Key Findings on Tourism–Ecosystem Service Interdependencies

The assessment highlights several key interdependencies between the tourism sector, natural capital, and ecosystem services in Krabi Province.

First, tourism activities in Krabi strongly depend on marine ecosystem services. Coral reefs and seagrass beds support marine biodiversity and provide attractive environments for recreational activities such as snorkeling and diving. (Department of Marine and Coastal Resources [DMCR], 2022) These ecosystems also contribute to the aesthetic value of coastal landscapes, which is a major factor attracting international tourists to Krabi.

Second, freshwater resources play an important role in supporting tourism infrastructure. Hotels, resorts, restaurants, and other tourism facilities require significant amounts of freshwater for daily operations. As the number of tourists increases, water demand also increases, placing pressure on local water resources. (Department of Water Resources, 2022; Provincial Waterworks Authority, 2022).

Third, coastal ecosystems such as mangrove forests and shoreline systems provide regulating ecosystem services that support tourism sustainability. Mangroves help reduce coastal erosion, filter pollutants, and maintain water quality, which contributes to maintaining attractive coastal environments for tourism activities. (DMCR, 2022)

At the same time, tourism development may create environmental pressures on ecosystems. Increased tourist activities can result in higher wastewater generation, marine pollution, and physical disturbances to coral reefs and coastal ecosystems. Without proper management, these pressures may degrade ecosystem health and reduce the quality of ecosystem services. (Pollution Control Department, 2024; Office of Natural Resources and Environmental Policy and Planning [ONEP], 2025)

Therefore, maintaining ecosystem integrity is essential to ensure the long-term sustainability of the tourism sector in Krabi Province.

Policy Implications

The findings of this assessment indicate that the tourism sector in Krabi is closely linked with ecosystem services and natural capital. Sustainable tourism development therefore requires integrating ecosystem conservation into tourism planning and water resource management policies. (ONEP, 2025) Protecting coral reefs, mangrove forests, and maintaining water quality will not only support biodiversity but also ensure the long-term viability of the tourism economy in the province.

Method for Assessing Tourism Dependency on Ecosystem Services

The interdependency assessment between the tourism sector, water resources, and ecosystem services in Krabi Province was conducted using an ecosystem services dependency and impact assessment framework. This approach evaluates how economic sectors rely on ecosystem services and how sectoral activities may affect ecosystem conditions. The assessment was carried out by identifying relevant ecosystem services, mapping sectoral activities, and qualitatively scoring the level of dependency and potential environmental impacts (low, medium, or high). The assessment approach was adapted from the Capitals Protocol framework for integrated capitals assessment. While the original framework provides a comprehensive methodology for evaluating impacts and dependencies across multiple capitals, this study modified the approach to focus specifically on the interdependencies between tourism, water resources, and ecosystem services (Capitals Coalition, 2025).

The table 21 presents the interdependencies between the tourism sector, water resources, and ecosystem services in Krabi Province. It highlights how tourism activities rely on various natural ecosystems and environmental resources, including marine ecosystems, coastal ecosystems, and freshwater resources. The assessment indicates that marine ecosystems such as coral reefs and seagrass beds play a crucial role in supporting tourism activities, including diving, snorkeling, and other marine recreational activities, which are key attractions in Krabi Province. In addition, coastal ecosystems such as beaches and mangrove forests contribute to tourism by providing scenic landscapes, recreational opportunities, and ecotourism experiences. However, tourism development and the increasing number of visitors can also exert pressure on these ecosystems. Activities such as coastal infrastructure development, marine recreation, and tourism-related pollution may lead to coral reef degradation, habitat disturbance, and environmental pollution. Therefore, maintaining healthy ecosystems is essential for sustaining tourism development and preserving the natural attractiveness of Krabi Province.

This table describes the role of ecosystems in supporting and maintaining the balance of water resources in Krabi Province. Various ecosystems, including forests, mangrove forests, and wetlands, play important roles in regulating hydrological processes, filtering pollutants, and maintaining water quality. For instance, forest ecosystems contribute to watershed regulation by controlling runoff and maintaining the natural water cycle. Mangrove ecosystems help trap sediments and pollutants before they reach coastal waters, thereby improving coastal water quality. In addition, marine ecosystems such as seagrass beds contribute to sediment stabilization and help maintain water clarity in coastal areas. The degradation of these ecosystems could significantly affect the quality and availability of water resources. Such changes may have negative consequences not only for

environmental systems but also for economic sectors that depend on water resources, including tourism. As show in Table 22

Table 22 Interdependency Matrix: Tourism – Water Resources – Ecosystem Services

Sector	Dependent on	Ecosystem / Resource	Ecosystem Services Provided	Tourism / Sector Use	Impact / Pressure	Dependency Level
Tourism	Marine ecosystem	Coral reefs	Recreation, biodiversity habitat	Diving, snorkeling, marine tourism	Coral damage from anchors, diving pressure	Very High
Tourism	Coastal ecosystem	Beaches	Cultural & recreational services	Beach tourism, sightseeing	Coastal development and erosion	High
Tourism	Marine ecosystem	Seagrass beds	Fish habitat, biodiversity support	Marine tourism and boating	Sediment disturbance, pollution	High
Tourism	Coastal ecosystem	Mangrove forest	Coastal protection, ecotourism	Mangrove tours, kayaking	Habitat disturbance and waste	Medium
Tourism	Freshwater resources	Rivers, canals, groundwater	Water supply	Hotels, restaurants, tourism facilities	Increased water consumption	High

Table 23 Water Resources Dependency on Ecosystem Services

Tourism Activity	Water Resource Impact	Evidence from Assessment	Impact Level
Hotels and resorts	High water consumption	Tourism increases water demand especially during high season (Dec–Feb)	High
Restaurants and tourism services	Wastewater discharge	Wastewater generation ~132,015 m^3/day but treatment only 5.22%	High
Marine tourism	Water pollution	Waste discharge and sewage affect coastal water quality	Medium–High
Tourist activities	Solid waste entering water bodies	Waste generation increases with tourist numbers	Medium

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