

POLICIES AND MARKET INCENTIVES IN SUPPORT OF NATURAL CAPITAL



COMPONENT 1

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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Executive summary

This report assesses the interdependencies between tourism, water resources, natural capital (NC), and ecosystem services (ESS) in Thailand, with a focus on Krabi Province as a pilot area. The objective of the assessment is to understand how natural capital and ecosystem services support economic activities, particularly tourism and water resource security, and how environmental changes and human activities influence ecosystem conditions and the sustainability of development.

Thailand possesses diverse terrestrial, freshwater, coastal, and marine ecosystems, including forests, river basins, wetlands, mangrove forests, seagrass beds, coral reefs, and coastal ecosystems. These ecosystems represent important natural capital assets that provide essential ecosystem services, including water regulation, water supply, biodiversity conservation, climate regulation, coastal protection, recreation, and cultural values. These services support key economic sectors such as tourism, agriculture, fisheries, and coastal economies, while contributing to national development and human well-being. Within this national context, Krabi Province represents an important pilot area due to its high dependence on natural capital and ecosystem services.

The assessment indicates that tourism in Krabi is highly dependent on several ecosystem services. These services include cultural ecosystem services that support recreation and nature-based experiences, regulating services such as coastal protection and water quality maintenance, and provisioning services including freshwater and natural resources that support tourism operations and local livelihoods. 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. In addition, healthy forests, wetlands, rivers, and coastal ecosystems regulate hydrological processes, maintain water quantity and quality, and support long-term water security. Changes in ecosystem conditions may therefore influence both tourism sustainability and water resource availability.

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 planning, water resource management, and policy development can help ensure that economic growth does not compromise ecosystem sustainability in the long term.

1 Introduction

1.1 Background and National Context: Tourism, Water Resources, and Natural Capital in Thailand

Thailand covers an area of approximately **513,000 square kilometres** and has a population of around **67 million people**, making it one of the most geographically and demographically significant countries in mainland Southeast Asia (National Statistical Office, 2020). The country is endowed with diverse **terrestrial** and **marine ecosystems**, including **forests, river basins, wetlands, mangrove forests, seagrass beds, coral reefs, and coastal ecosystems** that provide essential ecosystem services and support rich biodiversity. **Forests** cover approximately **32% of the country's total land area**, representing a critical component of Thailand's natural capital and contributing to biodiversity conservation, climate regulation, watershed protection, and rural livelihoods (Royal Forest Department, 2019). Thailand also has an extensive **coastline** of approximately **3,150 kilometres**, encompassing valuable coastal and marine ecosystems that support ecological functions and economic activities, including fisheries and tourism (Department of Marine and Coastal Resources, 2020). These diverse natural assets form the foundation of Thailand's economic development and human well-being.

Thailand is characterized by diverse physical landscapes, comprising mountain ranges, plateaus, floodplains, river basins, and extensive coastal areas. These geographical features have given rise to a wide variety of terrestrial, freshwater, coastal, and marine ecosystems that form the country's natural capital. Administratively, Thailand is commonly divided into six regions: the North, Northeast, Central, East, West, and South (Figure 1). Hydrologically, the country is organized into 22 major river basins (Figure 1), which provide the foundation for water resources management and support a wide range of ecosystem services.

The northern region is dominated by mountainous landscapes and contains the largest proportion of Thailand's forest resources, serving as the country's principal watershed area and an important source of freshwater. The northeastern region is characterized primarily by the Khorat Plateau, where water availability is relatively limited and ecosystems support rain-fed agriculture, livestock production, and inland fisheries. The central region consists largely of fertile floodplains within the Chao Phraya River Basin and serves as Thailand's principal rice-producing area. The eastern and western regions contain a mixture of forested mountains, agricultural landscapes, and coastal environments that support diverse economic activities. Southern Thailand is distinguished by its mountainous terrain and coastlines along both the Gulf of Thailand and the Andaman Sea. The region supports a diverse range of terrestrial and marine ecosystems, including tropical forests, mangrove forests, seagrass meadows, coral reefs, estuaries, islands, sandy beaches, and coastal wetlands. These ecosystems provide a wide range of ecosystem services that support agriculture, particularly rubber and oil palm plantations, fruit orchards, fisheries, aquaculture, and nature-based tourism. The high environmental quality of coastal ecosystems and marine waters is a key factor supporting Thailand's tourism industry, while economic activities on land, including agriculture, urban development, and infrastructure expansion, can influence water quality and ecosystem conditions in downstream freshwater and coastal environments.

North

Chiang rai
Mae hong son
Phayao
Chiang mai
Lampang
Nan
Lamphun
Phrae
Uttaradit
Tak
Sukhothai
Phitsanulok
Kamphaeng phet
Phichit
Phetchaburi
Nakhon sawan
Uthairathani
Chai nat
Singburi
Suphanburi
Kanchanaburi
Rachaburi
Phetchaburi
Prachuap khiri khan
Chum phon
Ranong
Surat thani
Phangnga
Krabi
Thammarat
Phuket
Trang
Phatthalung
Satun
Songkhla
Pattani
Yala
Narathiwat

north East

Buang Kan
Nonghai
Loei
Udonthani
Sakonkakhon
Nakhon phanom
Nonglua
Jompho
Khon kean
Kalasin
Mudomhan
Mahasarakham
Roi et
Amnatcharoen
Ubon ratchathani
Buri ram
Surin
Srisaket
Chai yaphum
Nakhon ratchasima

Central

Ayuthaya
Nakhon
Pathom
Bangkok
Samut prakan
Samut sakhon
Nakhon si Thammaraj
Chachoengsao
Prachinburi
Sra kao
Chon buri
Chanthaburi
Rayong
Trat

East

South

THAILAND

- 01 สระบุรี
- 02 โขงเหือ
- 03 โขงตะวันออกเฉียงเหนือ
- 04 ซี
- 05 มูล
- 06 ปิง
- 07 วัง
- 08 ยม
- 09 น่าน
- 10 เจ้าพระยา
- 11 สะเมกกรัง
- 12 ป่าสัก
- 13 ทำจีน
- 14 แม่กลอง
- 15 บางปะกง
- 16 โตนเลสาบ
- 17 ชายฝั่งทะเลตะวันออก
- 18 เพชรบุรี - ประจวบคีรีขันธ
- 19 ภาคใต้ฝั่งตะวันออกตอนบน
- 20 ทะเลสาบสงขลา
- 21 ภาคใต้ฝั่งตะวันออกตอนล่าง
- 22 ภาคใต้ฝั่งตะวันตก

2

Thailand's tropical monsoon climate, combined with its diverse topography and ecosystem types, has resulted in exceptionally high levels of biological diversity. The country contains numerous nationally and internationally important conservation areas, including several **wetlands** designated under the Ramsar Convention. Examples include the **Krabi Estuary Wetland in Krabi Province**, the Laem Son National Park–Kraburi Estuary–Kapoe Estuary Wetland in Ranong Province, and the Hat Chao Mai National Park–Libong Archipelago Wildlife Reserve–Trang River Estuary Wetland in Trang Province. These internationally recognized wetlands provide critical habitats for wildlife, support fisheries and coastal livelihoods, regulate hydrological processes, and contribute significantly to biodiversity conservation and sustainable economic development.

The diversity of Thailand's ecosystems demonstrates the close interrelationship between natural capital, water resources, and economic activities. Healthy terrestrial, freshwater, coastal, and marine ecosystems provide provisioning, regulating, supporting, and cultural ecosystem services that underpin agriculture, fisheries, tourism, and other sectors of the national economy. At the same time, increasing pressures from land-use change, urbanization, resource exploitation, and climate change highlight the importance of integrated natural capital management and sustainable resource planning. These ecosystems collectively provide a wide range of provisioning, regulating, supporting, and cultural ecosystem services that underpin Thailand's economy and society.

Thailand's natural capital provides a wide range of **ecosystem services** that support economic activities and human well-being. Forest ecosystems contribute to water regulation, soil conservation, carbon storage, and biodiversity protection, while freshwater ecosystems provide essential water resources for domestic consumption, agriculture, industry, and tourism. Coastal and marine ecosystems support fisheries, coastal protection, recreation, and tourism activities. These interconnected ecosystems underpin livelihoods, food security, and economic development, while also highlighting the dependence of society and the economy on healthy and resilient natural systems.

Natural resources and ecosystem services are fundamental to Thailand's economic development and social well-being, particularly in sectors such as tourism, agriculture, fisheries, and coastal economies. **Tourism** is one of the country's major economic drivers and depends heavily on the quality of natural landscapes, biodiversity, and healthy terrestrial and marine ecosystems. Prior to the COVID-19 pandemic, Thailand welcomed approximately **40 million international tourist arrivals in 2019**, highlighting the significant contribution of natural and cultural assets to the national economy (Ministry of Tourism and Sports, 2020). Likewise, reliable **water resources** are essential for agricultural production, industrial activities, domestic consumption, hydropower generation, and tourism operations. Sustainable fisheries and coastal livelihoods also depend on the continued health of freshwater, coastal, and marine ecosystems. Tourism and water resources therefore represent two sectors with particularly strong dependencies on natural capital, making them highly sensitive to changes in ecosystem conditions and the continued provision of ecosystem services.

Despite the significant benefits provided by Thailand's natural capital, ecosystems are increasingly affected by multiple environmental and socio-economic pressures. Land-use change, agricultural expansion, urbanization,

infrastructure development, pollution, and increasing demand for land and water resources have altered ecosystem conditions in many parts of the country. Climate change further intensifies these pressures through changing rainfall patterns, rising temperatures, sea-level rise, and more frequent extreme weather events, affecting both terrestrial and aquatic ecosystems. These cumulative pressures may reduce biodiversity, degrade ecosystem functions, diminish water availability and quality, and weaken the resilience of natural systems that support economic activities and human well-being. Consequently, these pressures increasingly affect ecosystem conditions and the capacity of ecosystems to continue providing essential ecosystem services, highlighting the need for integrated approaches that consider the relationships between natural capital, ecosystem services, and economic development.

Recognizing these interdependencies, Thailand has promoted the development of **Natural Capital Accounting (NCA)** based on the **United Nations System of Environmental-Economic Accounting (UN-SEEA)** framework. NCA provides a systematic approach for measuring and monitoring changes in natural capital and ecosystem services and linking environmental information with economic decision-making. By integrating environmental and economic data, NCA can support evidence-based policy formulation, sustainable resource management, and improved planning for balancing economic development with the conservation of natural ecosystems. This provides the foundation for assessing the **interdependencies** between **tourism, water resources, and natural capital** presented in the following sections.

1.2 Assessment Scope: Inter-dependencies of Tourism and Water Resources

Thailand comprises seven types of **ecosystems** in accordance with the **Convention on Biological Diversity (CBD)** guidelines: forest ecosystems, mountain ecosystems, dry and sub-humid lands ecosystems, inland waters ecosystems, agricultural ecosystems, marine and coastal ecosystems, and island ecosystems (Office of Natural Resources and Environmental Policy and Planning [ONEP], 2020). These ecosystems generate a broad range of ecosystem services that support productive sectors, sustain ecological processes, and contribute to national development. Among the sectors closely linked to this natural capital, tourism and water resources are selected for this assessment because both depend extensively on healthy ecosystems while also influencing ecosystem conditions through human activities and resource use.

This assessment examines the interdependencies between natural capital, ecosystem services, tourism, and water resources at the national level. The assessment recognizes that ecosystem assets provide multiple ecosystem services that simultaneously support tourism activities, water security, economic productivity, and societal well-being. Conversely, tourism development and water resource utilization may alter ecosystem conditions through land-use change, increasing demand for natural resources, infrastructure development, pollution, and other anthropogenic pressures. These reciprocal relationships demonstrate that ecosystem services are both fundamental inputs to economic activities and outcomes that depend on the condition and resilience of natural capital.

The assessment adopts an integrated perspective that recognizes water resources as a key linkage between ecosystem health and tourism sustainability. Healthy forests, wetlands, rivers, coastal ecosystems, and other natural systems regulate hydrological processes, maintain water quantity and quality, support biodiversity, and provide recreational and aesthetic values that contribute to tourism. At the same time, sustainable tourism depends on reliable water resources and healthy ecosystems, while the management and utilization of water resources influence the environmental quality upon which tourism activities rely. Understanding these interactions is therefore essential for evaluating how changes in ecosystem conditions may affect both water security and tourism sustainability.

Accordingly, the assessment considers two complementary dimensions. First, it evaluates the contribution of natural capital and ecosystem services to tourism and water resources by identifying the ecosystem services that support economic activities, environmental quality, and societal benefits. Second, it examines how tourism development and water resource utilization may influence ecosystem assets, ecosystem conditions, and the continued supply of ecosystem services. Assessing these reciprocal relationships provides a comprehensive understanding of the interactions between natural capital and sectoral development and establishes the analytical foundation for the subsequent assessment of ecosystem services and interdependencies presented in this report.

Building on this analytical framework, the assessment is organized into two main components. Chapter 3 establishes the ecological baseline by identifying the ecosystem types and ecosystem services that constitute the natural capital of Krabi Province. Based on this baseline, Chapter 4 examines the interdependencies between water resources, the tourism sector, natural capital, and ecosystem services through assessments of ecological interactions, hydrological and socioeconomic linkages, and ecological footprints. Together, these analyses provide the evidence base for identifying opportunities to strengthen the integration of natural capital into sectoral planning and decision-making.

1.2.1 Tourism Inter-dependencies

Tourism is one of Thailand's major economic sectors and depends heavily on natural capital and the ecosystem services provided by healthy ecosystems. Forest, freshwater, coastal, and marine ecosystems support a wide range of tourism activities by providing attractive landscapes, rich biodiversity, recreational opportunities, and high environmental quality. Beaches, mangrove forests, seagrass beds, and coral reefs are particularly important for coastal and marine tourism, while forests and freshwater ecosystems support nature-based tourism and help maintain the environmental conditions that visitors expect.

Tourism benefits from a broad range of ecosystem services. Cultural ecosystem services contribute directly to recreation, aesthetic enjoyment, and nature-based experiences that attract visitors. Regulating and supporting services, including climate regulation, coastal protection, biodiversity conservation, water regulation, and water quality maintenance, help sustain the environmental conditions required for tourism. Provisioning services, such as freshwater, fisheries, and other natural resources, also support tourism operations and local livelihoods, particularly in destinations where tourism is closely linked with natural resources use.

At the same time, tourism development increases demand for land, freshwater, energy, infrastructure, and waste management services. The expansion of tourism facilities and growing visitor numbers may lead to land-use change, habitat disturbance, higher resource consumption, and increased pollution. In many destinations, tourism also competes with local communities and other economic sectors for freshwater resources, placing additional pressure on water-related ecosystems. If these pressures are not effectively managed, they may reduce ecosystem resilience and weaken the capacity of ecosystems to continue providing the services on which tourism depends.

This assessment therefore examines both the dependence of tourism on ecosystem services and the pressures that tourism activities place on natural capital. The assessment considers how changes in ecosystem conditions may affect tourism sustainability and how tourism development may influence ecosystem assets and the continued provision of ecosystem services. The findings provide a basis for identifying opportunities to strengthen sustainable tourism development while maintaining the natural capital that supports the sector.

1.2.2 Water Resources Inter-dependencies

Water resources are a fundamental component of Thailand's natural capital and support the country's ecosystems, economy, and society. Freshwater ecosystems, including rivers, streams, wetlands, lakes, and watersheds, provide essential ecosystem services such as water supply, hydrological regulation, water purification, nutrient cycling, and habitat provision. These services support domestic water use, agriculture, industry, tourism, and maintain ecosystems, highlighting the importance of healthy ecosystems for maintaining water security and sustainable development.

The condition of water resources depends on the integrity of terrestrial, freshwater, and coastal ecosystems. Forests regulate hydrological processes, reduce soil erosion, and help maintain water quantity and quality. Wetlands improve water quality, retain nutrients, reduce flood risks, and provide important habitats for biodiversity, while coastal ecosystems, including mangrove forests and estuarine areas, contribute to ecological connectivity, pollutant filtration, and the health of connected freshwater and marine environments. Together, these ecosystem services support reliable water resources while maintaining the environmental quality required for many economic activities, including tourism.

Water resources are increasingly affected by land-use change, urban expansion, agricultural development, infrastructure development, pollution, resource extraction, and climate variability. These pressures may alter hydrological processes, degrade ecosystem condition, reduce water availability and quality, and weaken the capacity of ecosystems to continue providing essential water-related services. Changes in water resources can also affect sectors that rely heavily on healthy ecosystems, particularly tourism, where environmental quality and reliable freshwater supplies are important for destination sustainability.

This assessment therefore examines both the dependence of water resources on healthy ecosystems and the effects of human activities on ecosystem assets and ecosystem services. It considers how changes in ecosystem condition influence water security and how pressures on natural capital may affect the long-term provision of

water-related ecosystem services. The findings provide a basis for strengthening integrated water resource management, ecosystem conservation, and sustainable development.

1.3 Pilot Site Selection: Krabi Province as a National Policy Model

The national assessment presented in the previous section establishes the conceptual framework for understanding the interdependencies between tourism, water resources, natural capital, and ecosystem services. To translate this framework into practical application, Krabi Province was selected as the project's pilot area. The pilot assessment provides an opportunity to examine these interdependencies under real-world conditions and to demonstrate how ecosystem information can support planning and policy decisions.

Krabi was selected because it represents one of Thailand's most important tourism destinations and contains a wide range of terrestrial, freshwater, coastal, and marine ecosystems. The province supports internationally recognized tourism assets while also providing essential ecosystem services that sustain local communities, economic activities, biodiversity, and water resources. At the same time, continued tourism growth, expanding infrastructure, changing land use, and increasing demand for freshwater place growing pressure on natural capital. This combination of high dependence on ecosystem services and increasing pressure on ecosystem assets makes Krabi an appropriate pilot area for assessing the interactions between economic development and ecosystem sustainability.

The assessment uses spatial analysis to examine how ecosystem assets, ecosystem services, tourism activities, and water resources are distributed across the province and where potential risks may arise from changes in ecosystem condition. Geographic Information System (GIS) analysis provides a practical means of identifying areas where ecosystem services are critical to tourism and water resources, areas exposed to multiple development pressures, and locations where conservation and management interventions are likely to generate the greatest benefits. This spatial perspective strengthens the understanding of ecosystem interdependencies beyond what can be obtained from sectoral information alone.

Although the assessment is undertaken in Krabi Province, its purpose extends beyond the provincial level. The analytical approach, assessment methodology, and lessons generated from the pilot are intended to support the development of a policy framework that can be adapted for application in other provinces with similar environmental and socio-economic characteristics. By demonstrating how ecosystem information can be integrated with tourism and water resource assessments, the pilot provides practical evidence to support national policy development, strategic planning, and future investment decisions that strengthen the sustainable management of Thailand's natural capital.

1.4 Linkage between Natural Capital Accounts and Policy Development

This assessment supports the integration of Natural Capital (NC) information into national policy, planning, regulatory, and budgeting processes in line with Output 1.2 of the project. It examines the inter-dependencies between the tourism sector, water resources, natural capital, and ecosystem services to provide information that can support more informed decision-making.

Krabi Province was selected as the project's pilot area because of its strong dependence on tourism, diverse natural ecosystems, and the important role of water resources in supporting economic activities. The assessment of the pilot area provides practical information on the relationships between natural capital and key economic sectors. The lessons learned are intended to support the wider application of Natural Capital (NC) information in policy and planning processes at the national level.

The information generated through this assessment can support government agencies in considering natural capital alongside economic and social priorities. It can also contribute to future planning, resource management, and investment decisions by providing information on the benefits that ecosystems provide and the potential effects of changes in natural capital on key economic sectors.

2. Environmental Existing Condition of Krabi Province, Thailand

2.1 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:

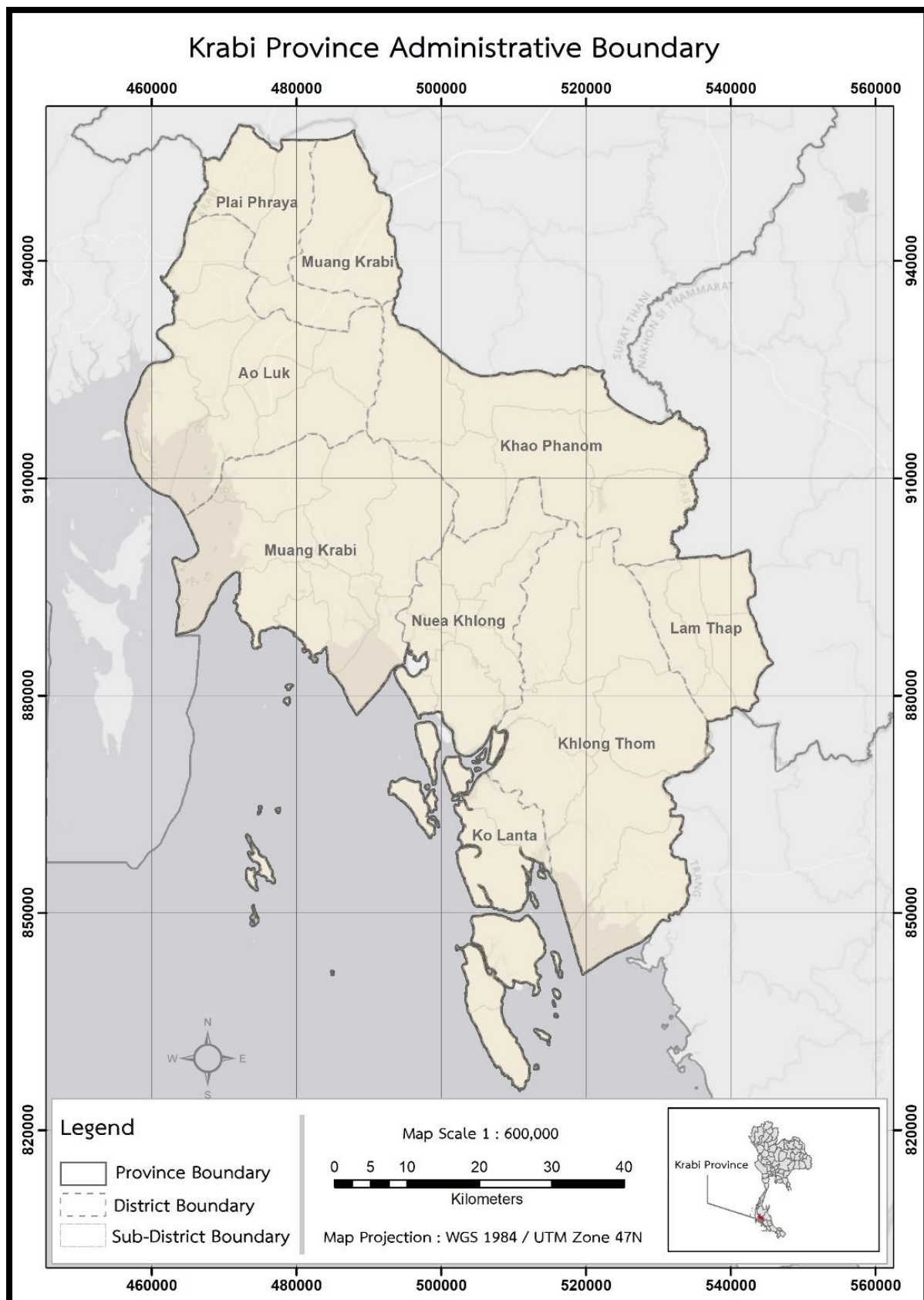
- Northern Krabi: Phang Nga Province and Surat Thani Province
- Southern Krabi: Trang Province and Andaman Sea
- Eastern Krabi: Nakhon Si Thammarat Province. and Trang Province
- Western Krabi: Phang Nga Province. and Andaman Sea

2.2 Administrative classification and population of Krabi province

Krabi is administratively divided into 8 Amphoes (Districts) (Figure 2): 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.

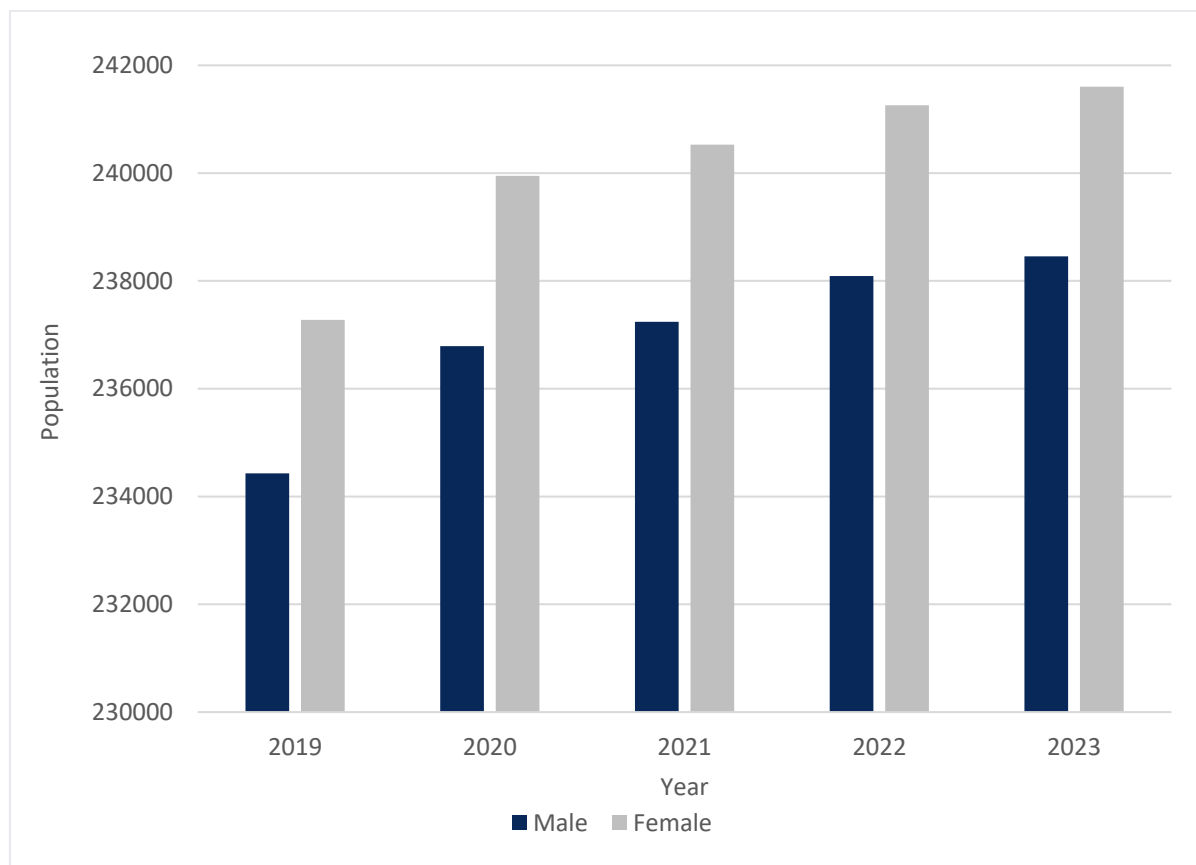
For population, Krabi data was reported at 480,057 Persons in 2023. This records an increase from the previous number of 471,705 Person for 2019 even though there was the COVID-19 pandemic, also known as the coronavirus pandemic as show in Figure 3.

Figure 2 Administrative classification of Krabi province



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

Figure 3 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.

2.3 Topography

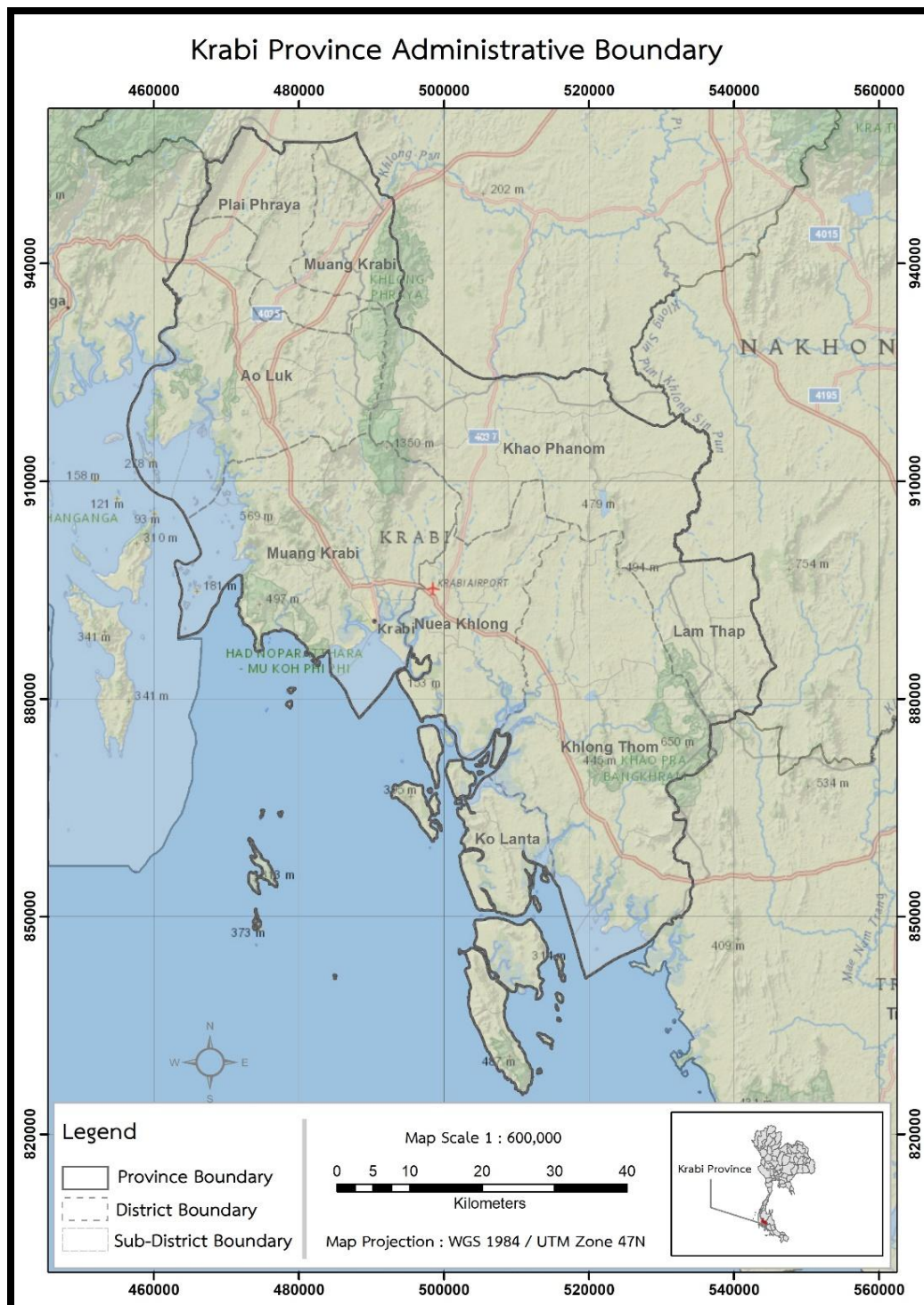
Krabi's landscape can be divided into four types.

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 4 Topographical map of Krabi Province, Thailand

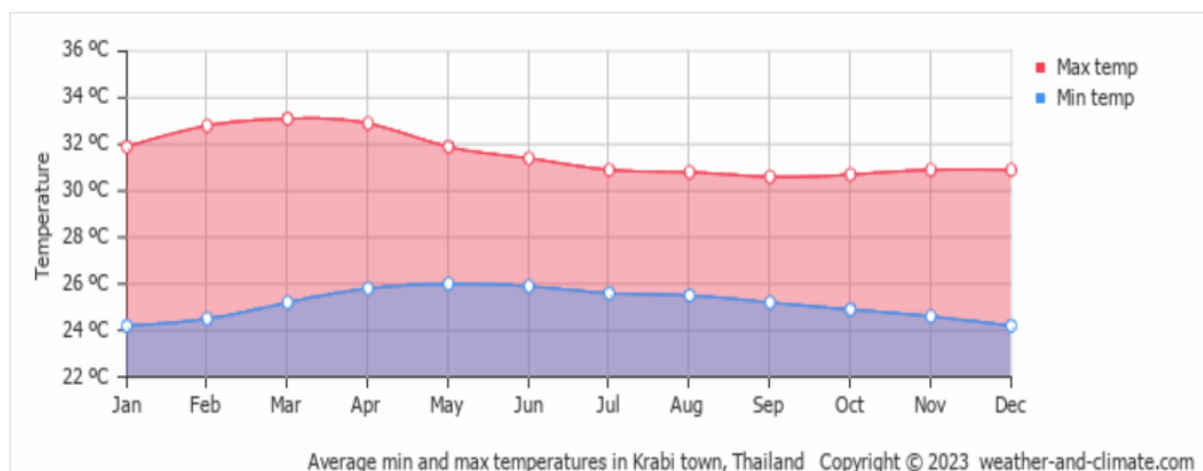


Source: Created by the authors using spatial data obtained from GISTDA (2022a).

2.4 Climate

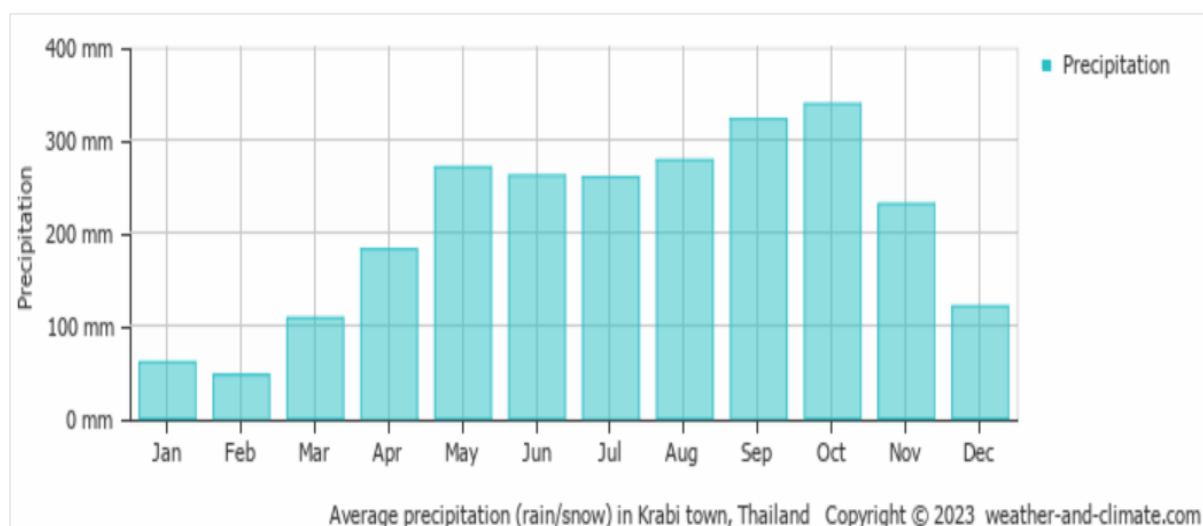
Since Krabi is located in tropical zone, so the climate is hot all year round, with a rainy season due to the southwest monsoon, which starts from May to October, and a dry season from December to March. The temperature is high throughout the year, in fact, average highs never drop below 31 °C (88 °F). 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 5). 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 6). 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 5 Average temperature of Krabi Province, Thailand



Source: Weather and Climate (2023)

Figure 6 Average precipitation of Krabi Province, Thailand



Source: Weather and Climate (2023)

2.5 Soil and land use

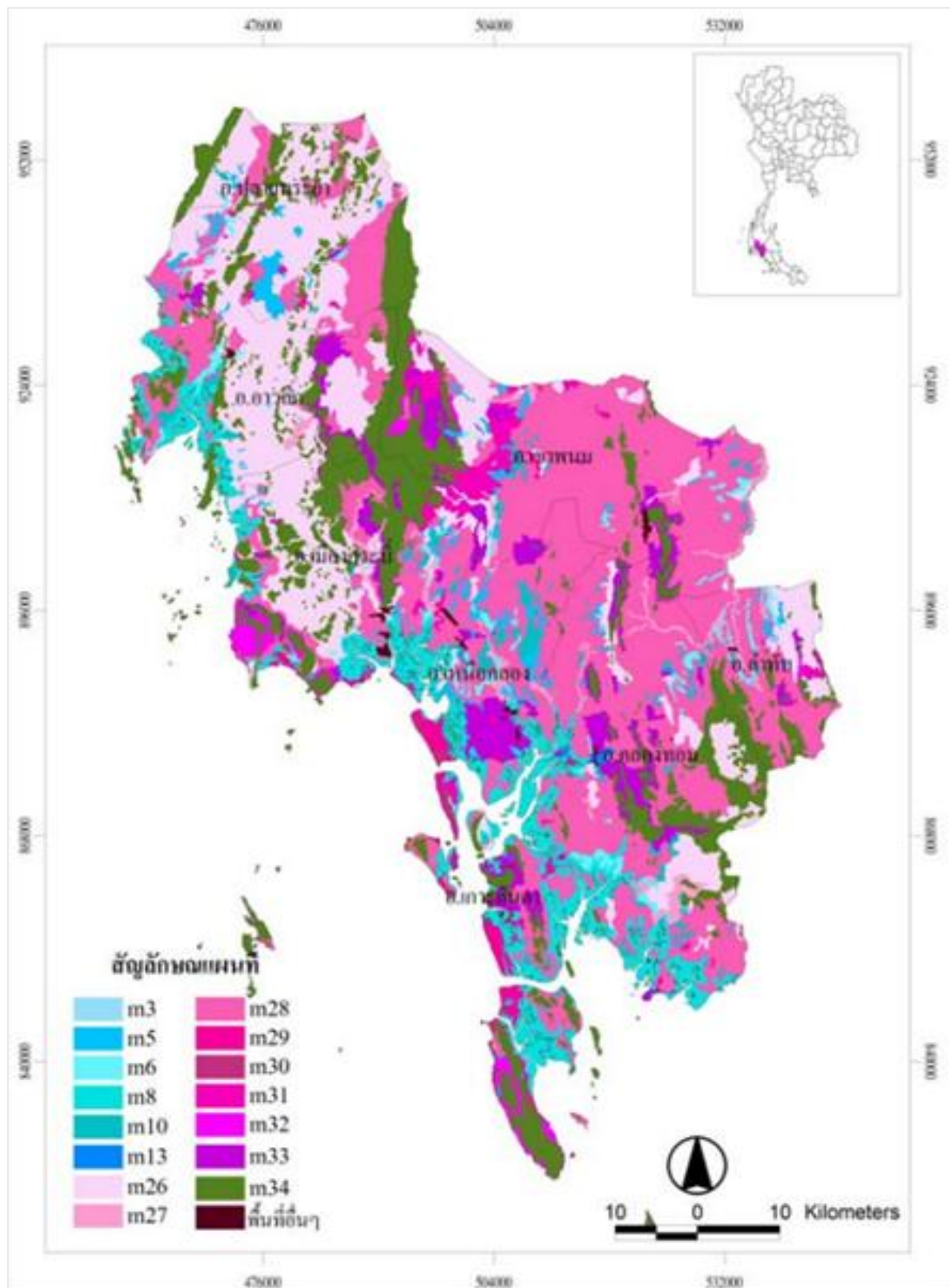
Krabi province soil can be divided into 15 groups based on soil characteristics and properties of soil as show in Table 1 and Figure 7. Most soil is loam soil and suitable for agriculture.

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 7 Soil series map of Krabi Province, Thailand

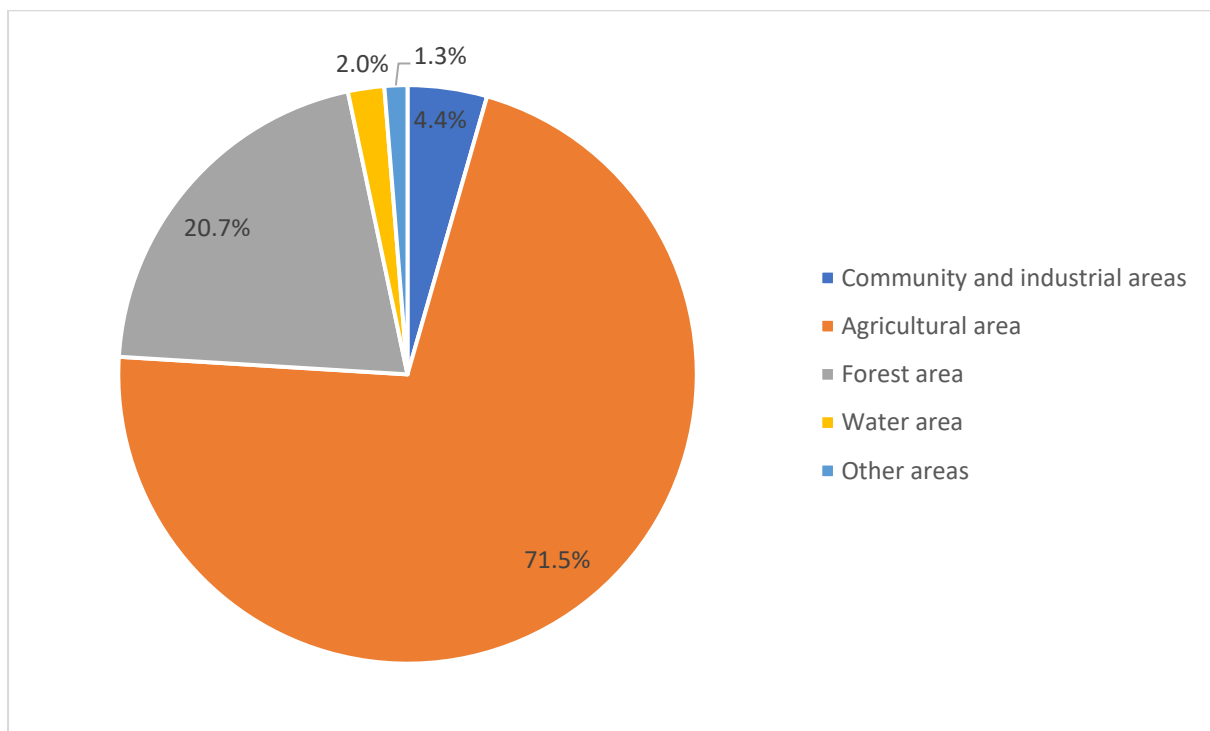


Source: Land Development Department (2007)

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 8 and map in Figure 9. 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.

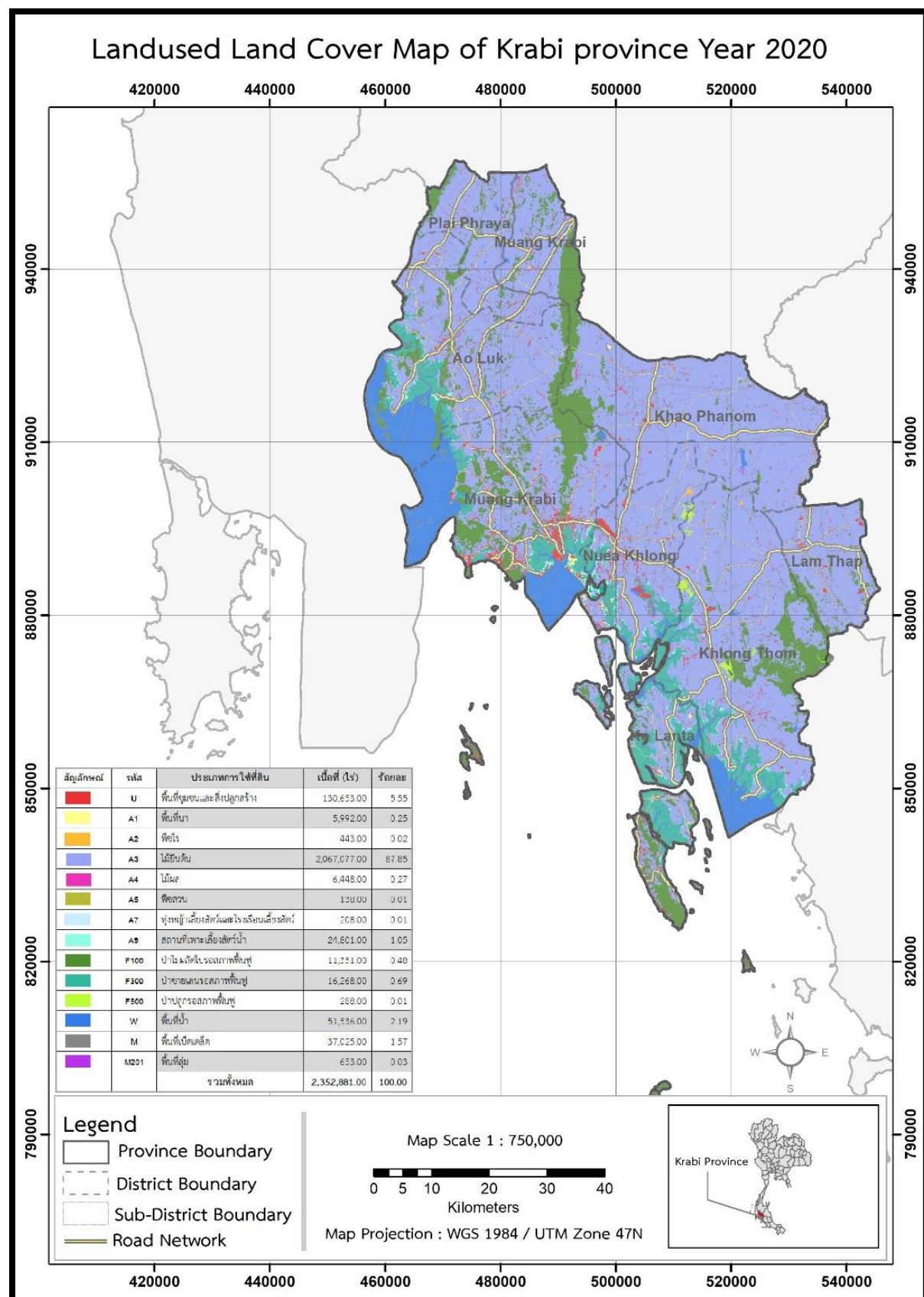
Forest areas are mostly in national parks (tropical forest » 12%) and mangrove (» 7%) along the coastal area, and etc. Community and industrial area can be classified as residential area (3.01%), commercial area and downtown (0.31), industrial area (0.2%), road (0.32%) and resort and hotel (0.08%) and 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 8 Land use of Krabi Province in 2022



Source: Land Development Department (2020)

Figure 9 Land Use of Krabi Province, Thailand



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

3. Ecosystem types and Ecosystem services of Krabi province

3.1 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.

3.1.1 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

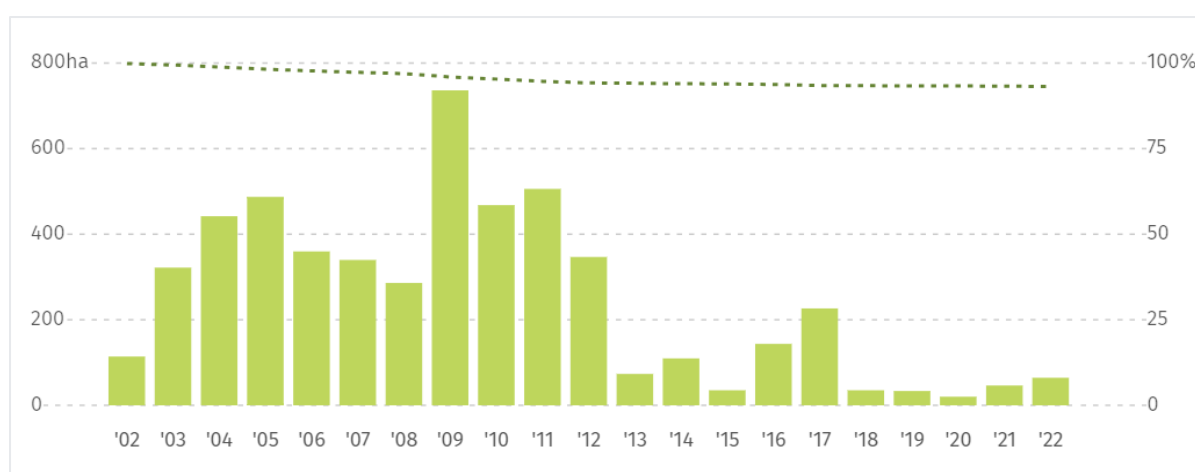
T4: Grassland: The savannas and grasslands biome is characterized by a continuous layer of grasses that supports moderate to high primary productivity, influenced by seasonal water cycles. Herbivory and fire are key factors regulating coexistence between grasses and woody plants, shaping the ecosystem's 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 9.

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 10.

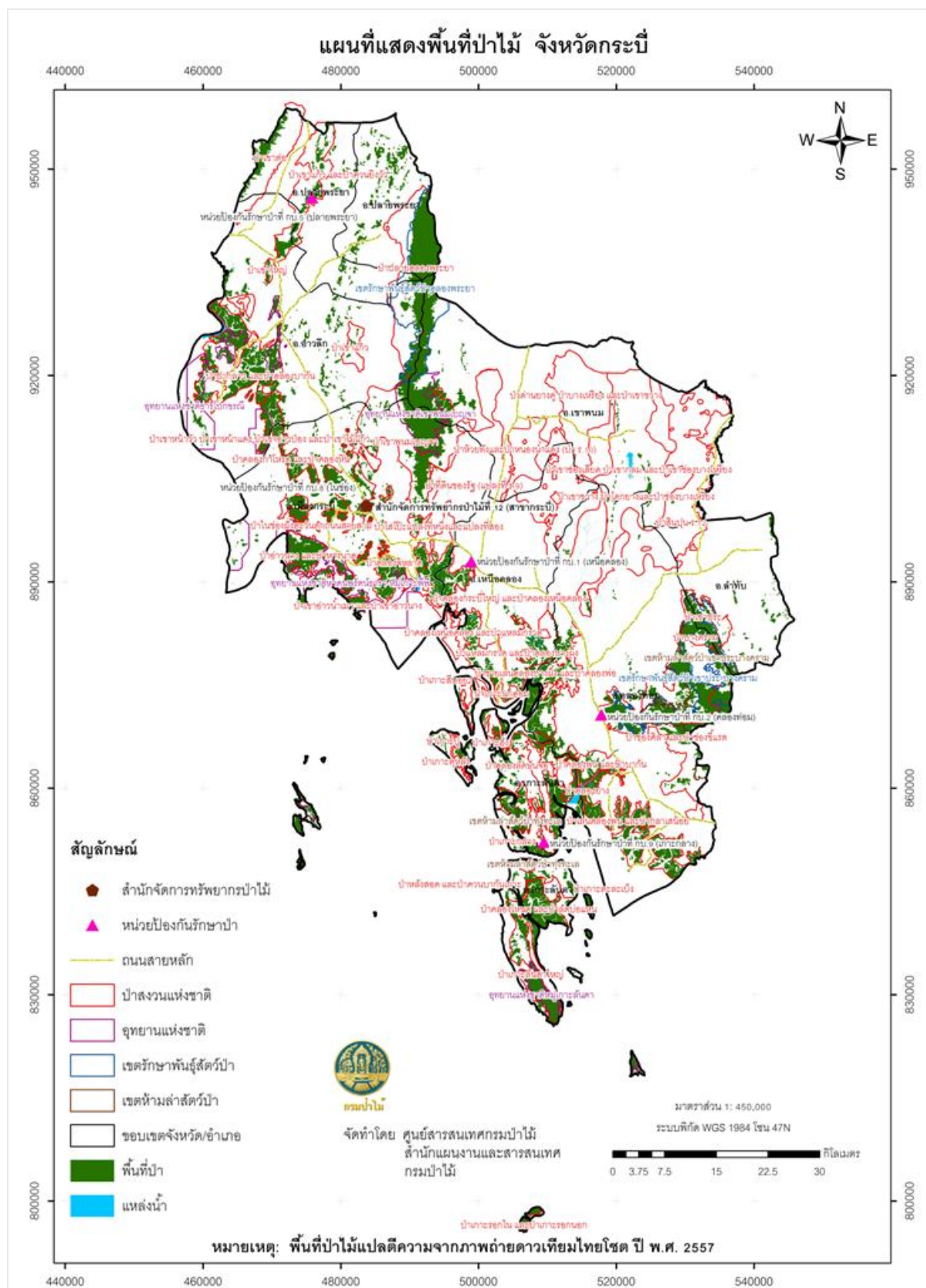
Figure 10 Krabi-forest area loss during 2002-2022



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 11.

Figure 11 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 *Areaceae*; 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

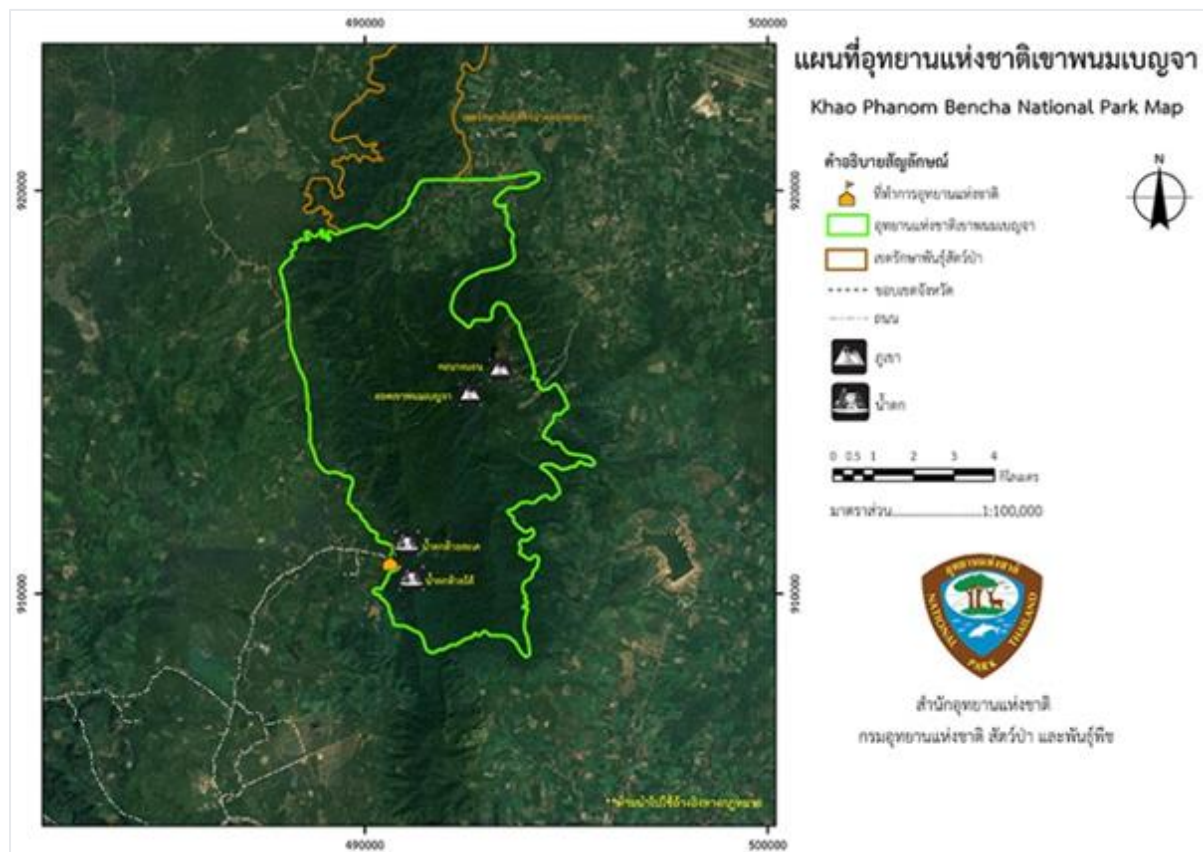
National parks in Krabi province are consisted of inland national parks and marine national parks. In this topic (Terrestrial), we will mention only inland national parks, Khao Phanom Bencha National Park and Than Bok Khorani National Park.

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 12.

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 12 Location and boundary of Khao Phanom Bencha National Park



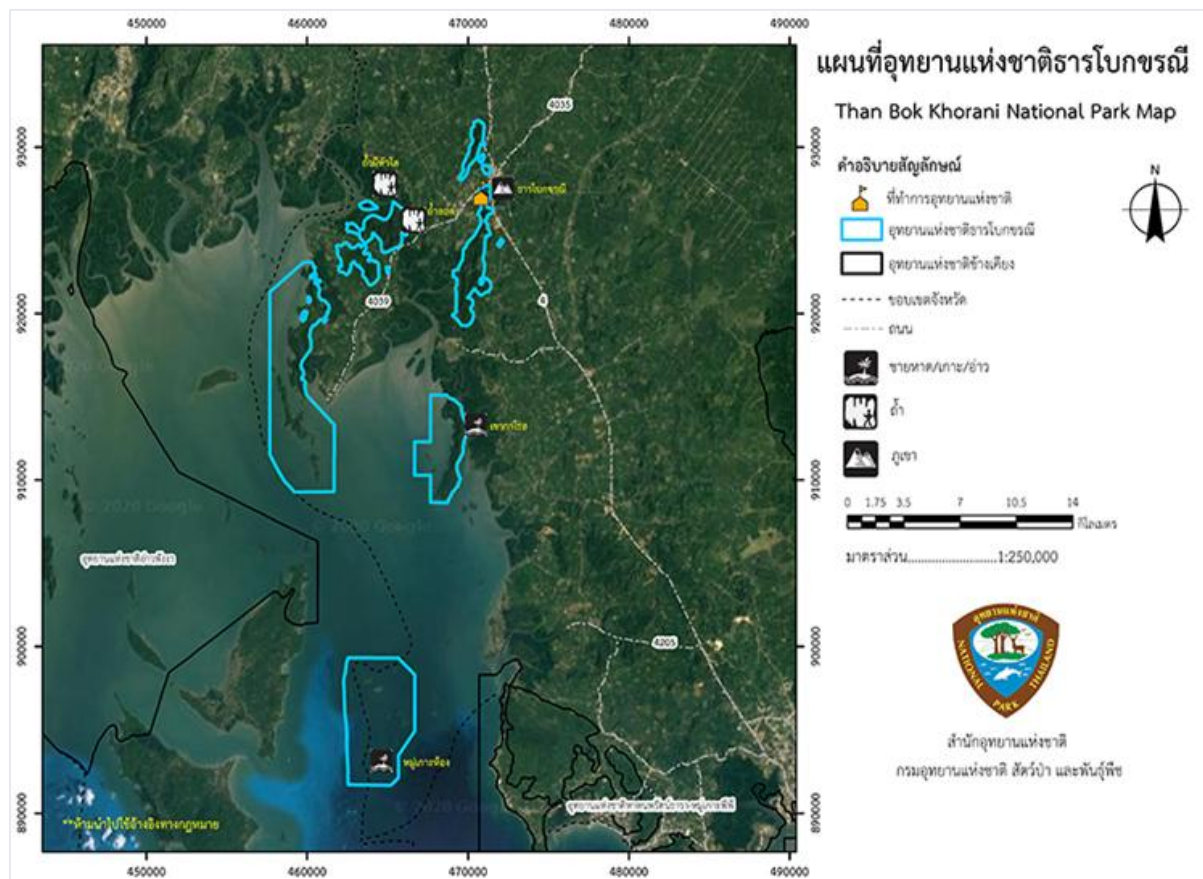
Source: National Parks of Thailand (2015)

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, *Avicennia* 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 13 Location and boundary of Than Bok Khorani National Park



Source: National Parks of Thailand (2015)

3.1.2 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.

3.1.3 Marine (M)

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

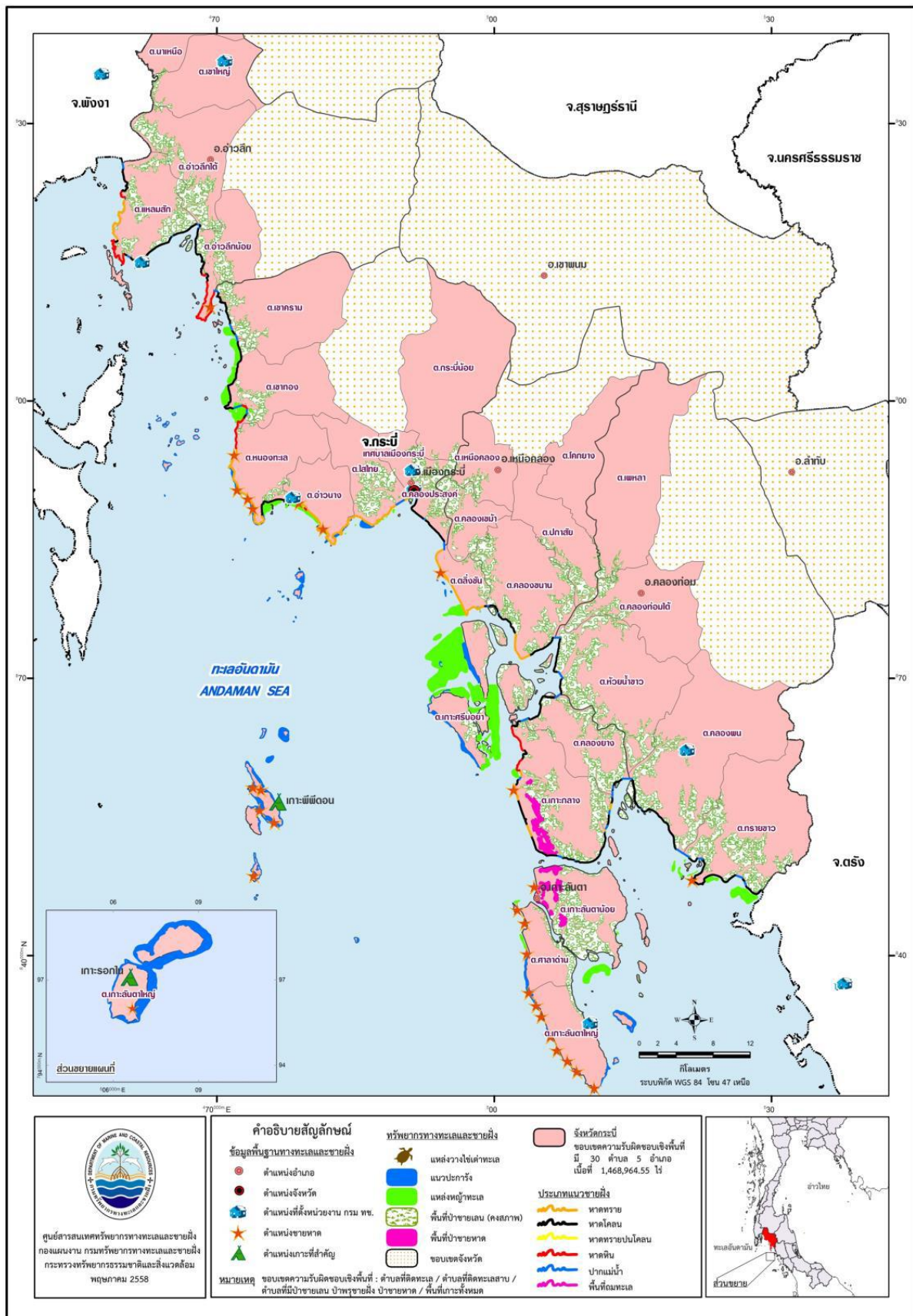
M1: Marine shelf; the marine shelf biome is a dynamic, globally distributed environment shaped by light, nutrient availability, substrate type, and kinetic energy from waves and ice. Productivity and community structure are influenced by feedback loops from habitat-forming organisms, consumer control, 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 14.

Figure 14 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 (Klong 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	<i>Cymodocea rotundata</i>	found
หญ้าคาทะเล	<i>Enhalus acoroides</i>	found
หญ้าใบพาย	<i>Halophila beccarii</i>	frequently found in the province.
หญ้าชะเงาใบฟันเลื่อย	<i>Cymodocea serrulata</i>	found
หญ้าเงาใบ	<i>Halophila decipiens</i>	found
หญ้าเงาใบใหญ่	<i>Halophila major</i>	found
หญ้าเงาใบเล็ก	<i>Halophila minor</i>	found
หญ้าใบมะกรูด	<i>Halophila ovalis</i>	frequently found in the province.
หญ้ากุยช่ายเข็ม	<i>Halodule pinifolia</i>	frequently found in the province.
หญ้ากุยช่ายทะเล	<i>Halodule uninervis</i>	found
หญ้าต้นหอมทะเล	<i>Syringodium isoetifolium</i>	found
หญ้าชะเงาเต่า	<i>Thalassia hemprichii</i>	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
	ปากคลองลัดบ่อแห่น (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 (Khleng Din Daeng)	6.03
	บ้านเขาทองใต้ (Ban Khao Thong Tai)	150.09
	บ้านท่าเลนใต้ (Ban Tha Len Tai)	125.79
	บ้านท่าเลนเหนือ (Ban Tha Len Nuea)	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
Nuakhleng	บ้านคลองร้ว (Ban Khleng Rua)	0.67
	บ้านแหลมหิน (Ban Laem Hin)	160.74
	เกาะสีมา (Koh Si Ma)	31.74
	เกาะจ่า (Koh Jum)	28.05
	เกาะโต๊ะลังตะวันออก (Koh Toh Lung-East)	794.76
	เกาะโต๊ะหล้า (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) (ติงไทร)	29.70
	เกาะเล็ก (Koh Lek)	27.69
	เกาะเล็กด้านเหนือ (Koh Lek-North)	32.87
	เกาะศรีบอยาตะวันออก (Koh Siboya-East)	124.59
	เกาะศรีบอยาใต้ (Koh Siboya-South)	177.31
	เกาะศรีบอยาตะวันตก (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.

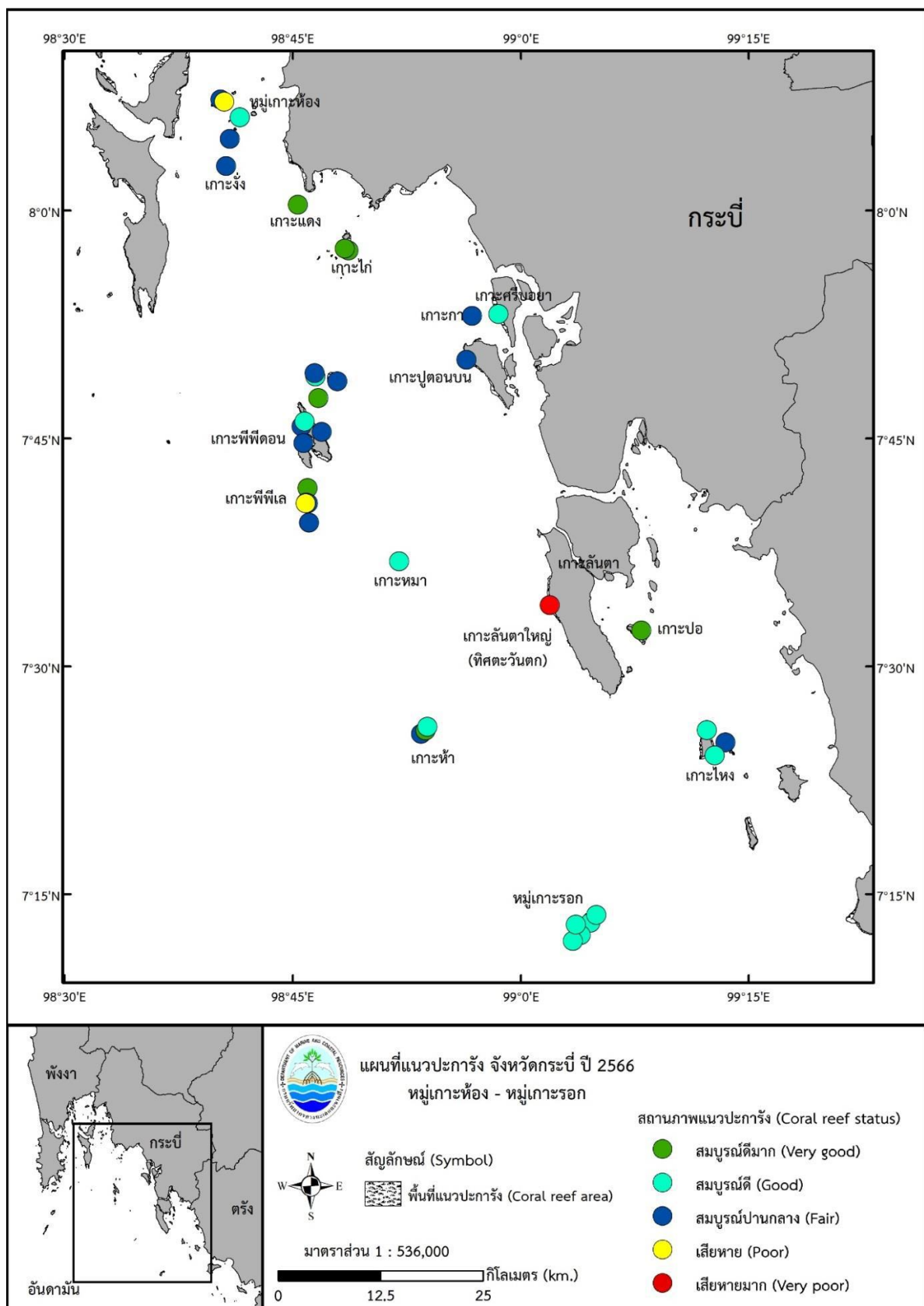
The status of coral reefs (Table 5 and Figure 15) around Koh Ka, Koh Sriboya, Ko Ma, Koh Phi Phi Le, Koh Rok Nok, Laem Son, and Koh Ha is likely to improve while coral reefs around Koh Ngung, Koh Por, Koh Lanta Yai (western side), Koh Huntu, Koh Kamid, Koh Pak Bia, Koh Hong (Ao Lek), Koh Lao Lading, 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 16 (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 15 Coral reef status



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

Table 6 Area and status of coral reef in Krabi Province

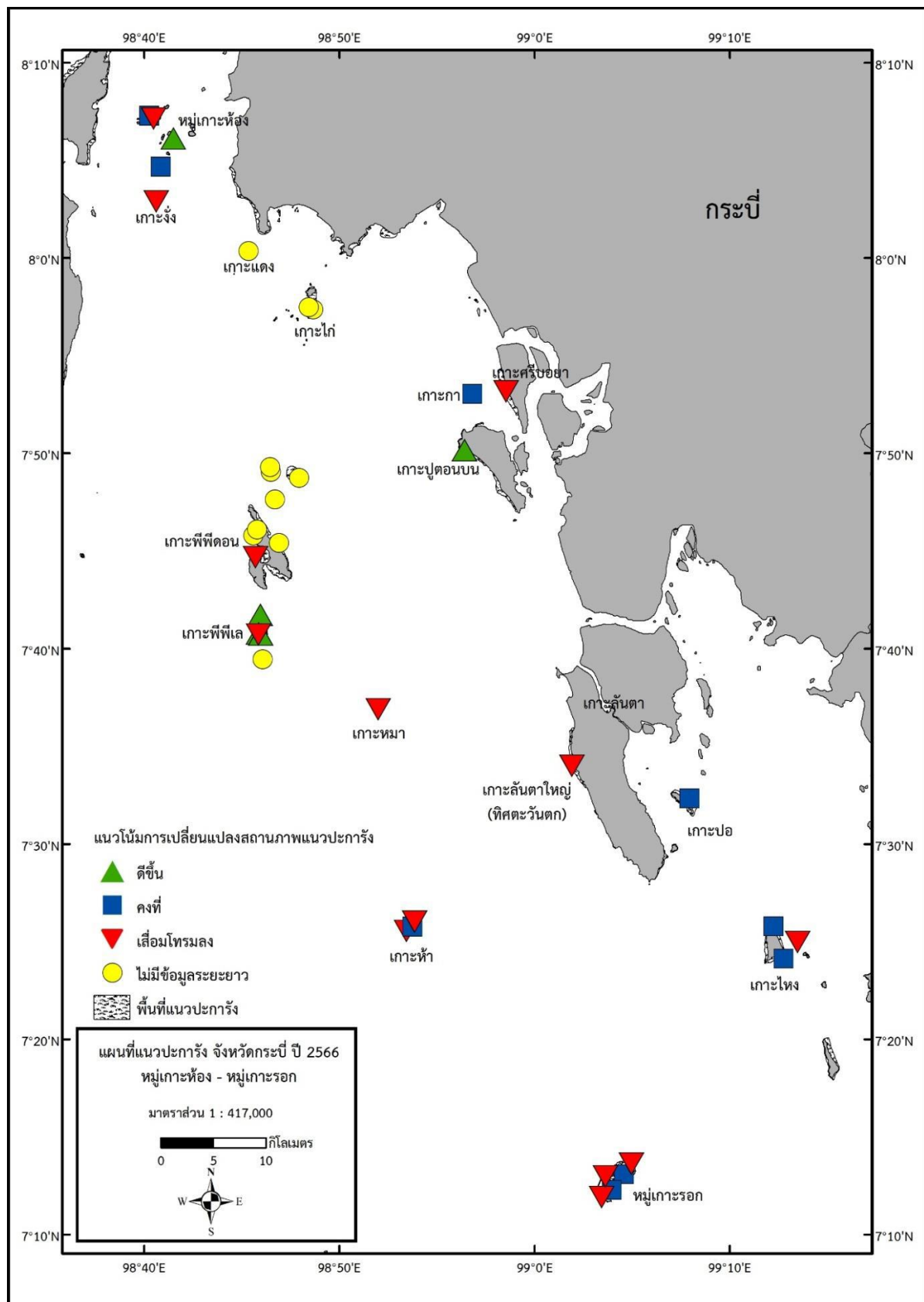
District	Coral reef	Area (ha)	Status
Koh Lanta	กองหินแดง (Hin Daeng Pinnacle)	3.52	Very good
	กองหินม่วง (Hin Muang Pinnacle)	2.56	Very good
	เกาะป้อ (Koh Po)	129.44	Poor
	เกาะกลาง (Koh Kluang)	9.6	Fair-Very poor
	เกาะม้า (Koh Ma)	3.68	Very poor
	เกาะรอกนอก (Koh Rok Nok)	78.72	Poor-Very poor
	เกาะรอกใน (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
	เกาะโหลด้านตะวันตก (Koh Ngai-West)	60.16	Poor-Very poor
	เกาะโหลด้านตะวันออก (Koh Ngai-East)	57.28	Fair-Very poor
	เกาะโหลด้านใต้ (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
	เกาะจางบัง (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
	เกาะบิ๊ะนอก (Koh Bida Nok)	2.4	Fair-Poor
	เกาะบิ๊ะใน (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
	อ่าวตันไทรด้านตะวันตก (Ao Ton Zai West)	17.44	Very good-Very poor
	อ่าวตันไทรด้านตะวันออก (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
	เกาะแม่อูไรตะวันตก (Koh Mae Urai-West)	0.32	Good-Fair
	เกาะแม่อูไรตะวันออก (Koh Mae Urai-East)	0.16	Fair-Poor
	เกาะยะลาฮูตัง (Koh Yala Hutang)	2.72	Good-Poor
	เกาะยาวาชา (Koh Yawazam)	2.24	Fair-Very poor
	เกาะยาวาบน (Koh Ya Wa Bon)	0.96	Good-Fair
	เกาะยาวาบ้องเกาะ (Koh Ya Wa Bong Ko)	2.24	Poor-Very Poor
	เกาะยุง (Koh Yung)	16.32	Fair-Very poor
	เกาะเลเปใต้ (Koh Lao Pe Tai)	0.32	Fair-Poor
	เกาะเลเปเหนือ (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
	เกาะเหลกา (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
	แหลมบ้อง-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
Nuakhleng	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
	เกาะโล๊ะละ (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 16 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

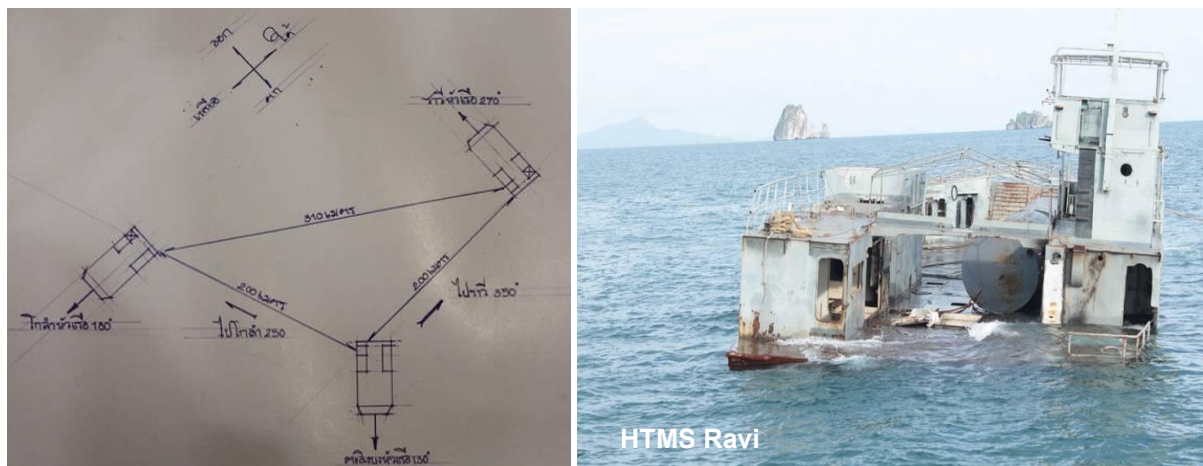
Source: Data from Krabi Provincial Office (2025)

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.

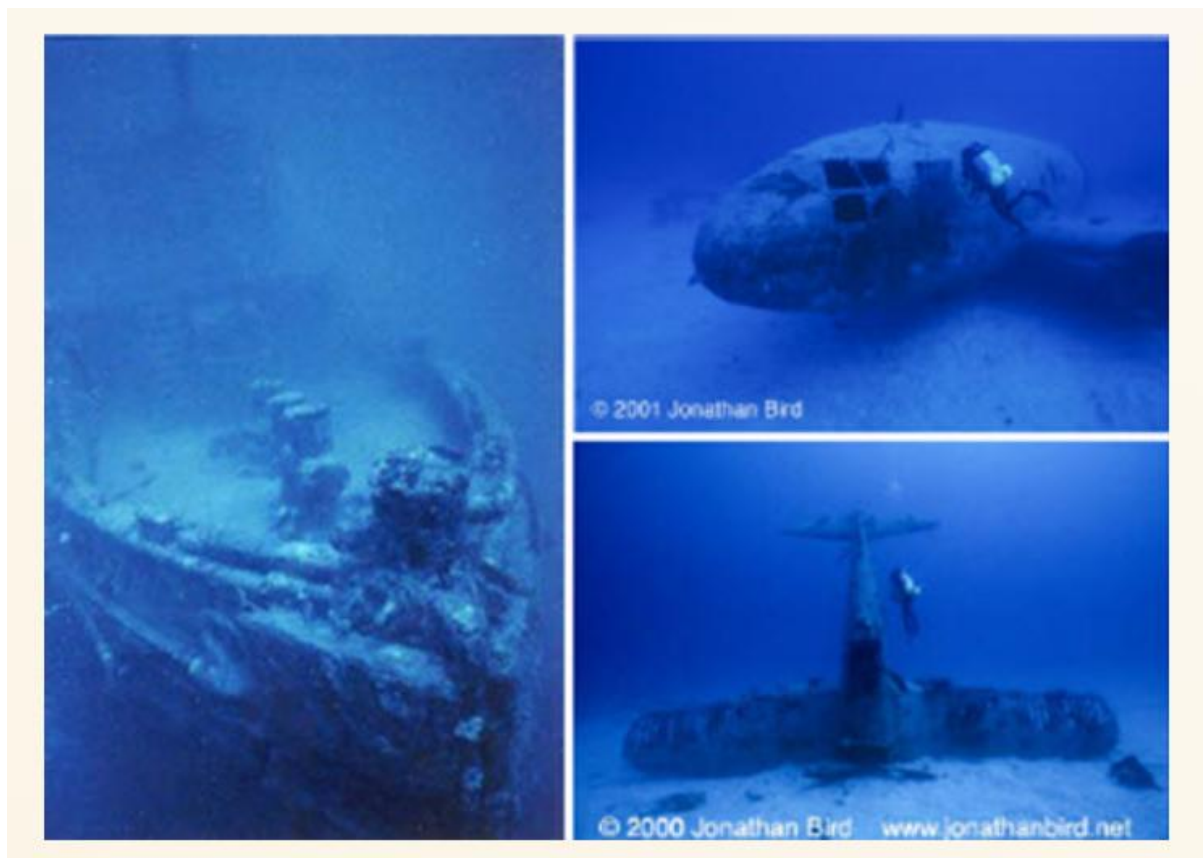
Krabi province has a project to build the Krabi Underwater Education Park by sinking the His Thai Majesty's Ship (HTMS) Talibong, HTMS Kolam, and HTMS Ravi at Koh Yawasam, Mueang Krabi district (Figure 17). HTMS Klet Kaew sank at Koh Phi Phi Le Island, Mueang Krabi District while HTMS Prap Prapak, HTMS 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 18.

Figure 17 Underwater layout plan for (HTMS) Talibong, HTMS Kolam, and HTMS Ravi



Source: Department of Marine and Coastal Resources (2015)

Figure 18 Examples of anthropogenic marine systems



Source: Department of Marine and Coastal Resources (2015)

3.1.4 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 composed 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 19 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

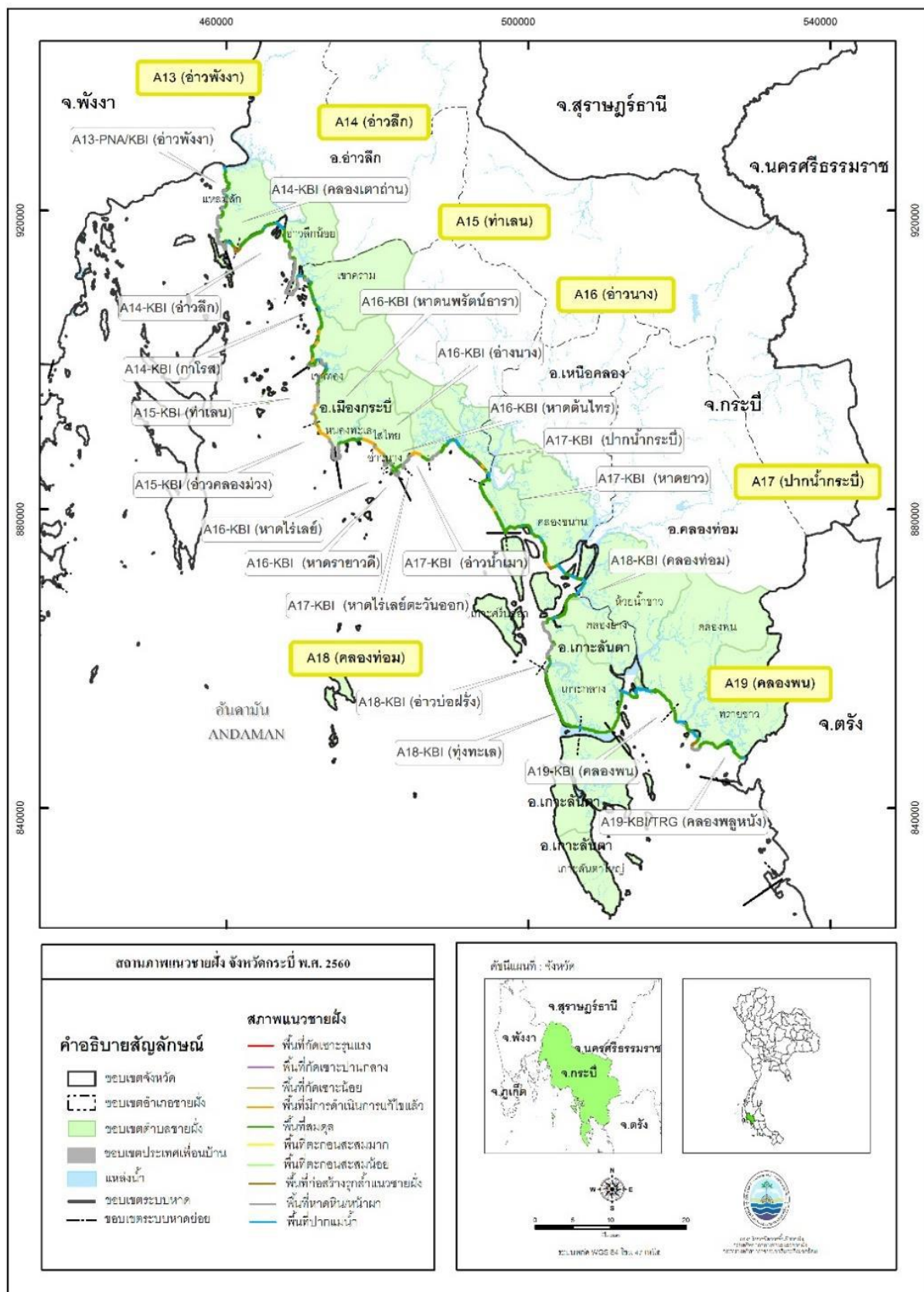
2) Areas with erosion problems that have been corrected, approximately 13.40 kilometers, classified as:

- 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 19 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
	Khlung Prasong	0.28	Ban Klong Kam	VS	Effective	No impact
		0.22	Laem Kham	BP	Ineffective	No impact
Nuakhleng	Taling Chan	0.24	Ban Had Yao	PI VS CPI	Effective	No impact
	Khlung 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)

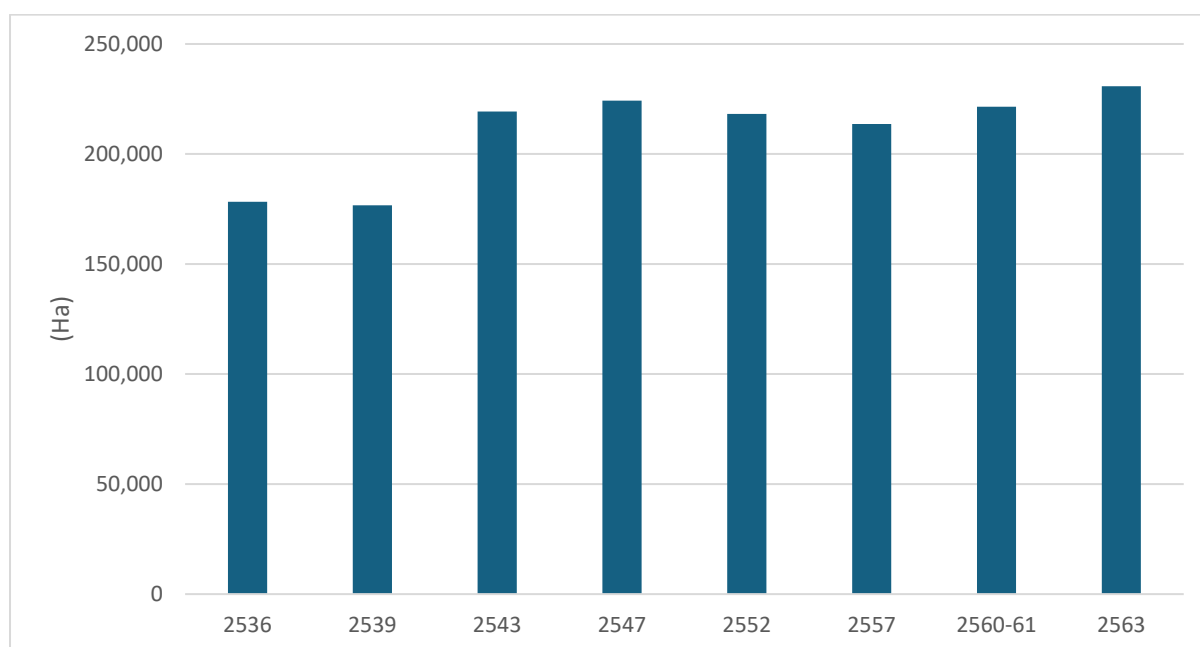
3.1.5 Marine-Freshwater-Terrestrial (MFT)

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 20.

Figure 20 Changes in areas of mangrove forests



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

3.2 Ecosystem services

3.2.1 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)

3.2.2 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)

3.2.3 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)

3.2.4 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, Storm 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)

3.2.5 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

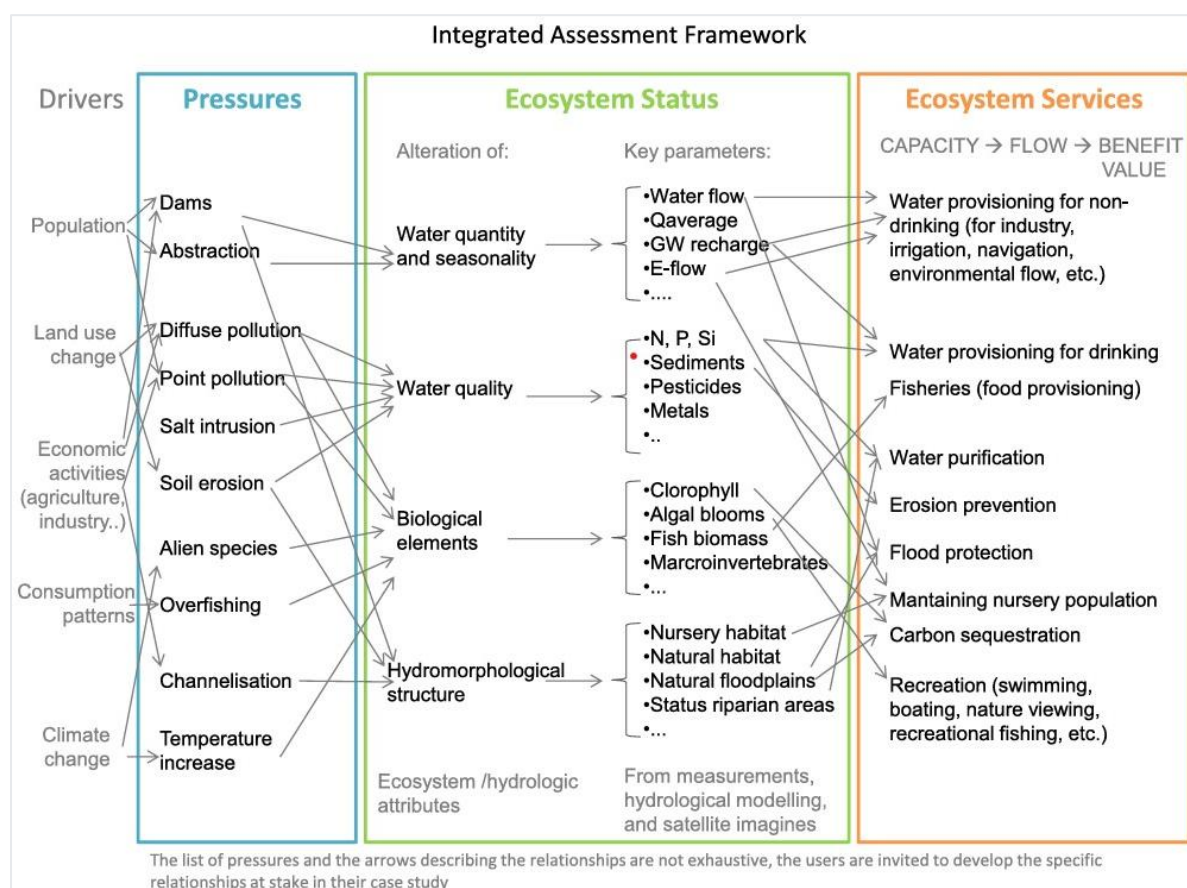
Ecosystem	Ecosystem services		
	Provisioning and cultural	Regulating	Supporting
Intertidal forests and shrublands (Mangrove)	Fish and shellfish harvesting, raw materials, education, and aesthetic	Strom prevention, nutrient cycling, erosion control, carbon sequestration, water purification	Biological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

Source: Revised from Odum and Barrett (2005)

3.2.6 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 21.

Figure 21 Integrated assessment framework of water resource management



Source: Grizzetti et al. (2016)

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

4.1 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.

4.2 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.

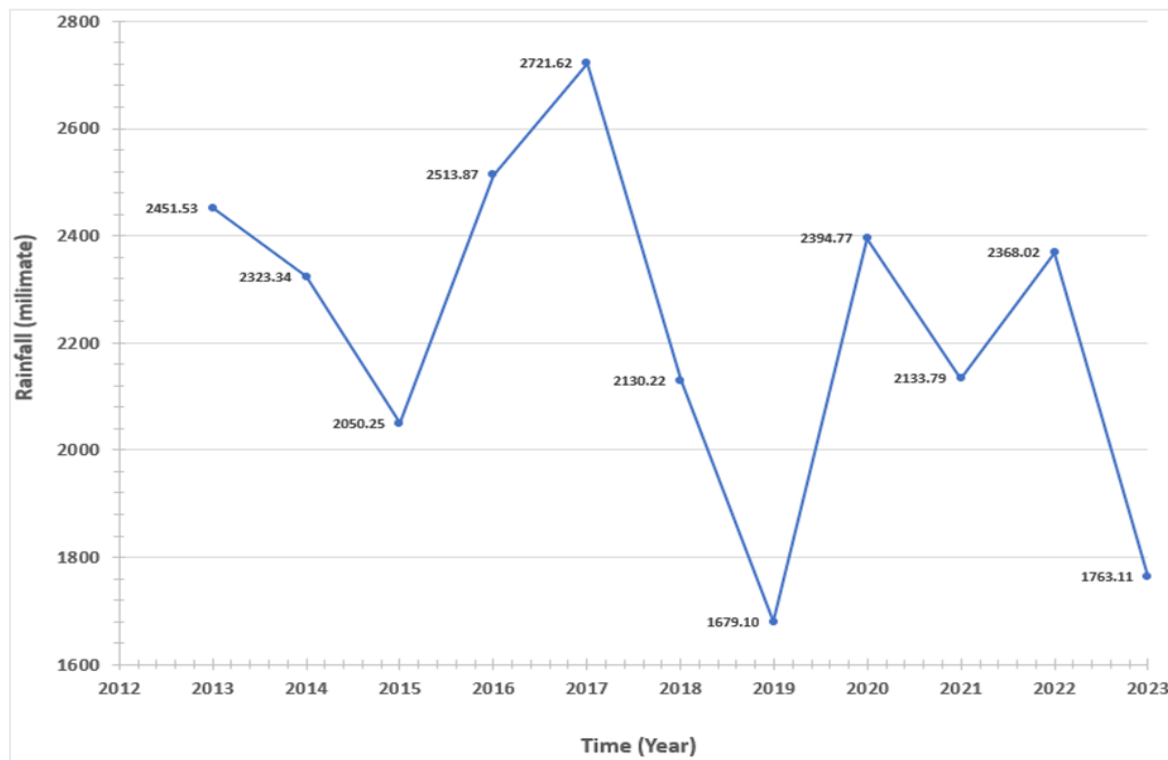
In this study, we used GIS-tool, satellite images from Sentinel-2 MSI: Multispectral Instrument and secondary data from relevant organizations to determine the footprint of water resources.

4.2.1 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 22 and 23.

Figure 22 Rainfall at Krabi Province during 2012-2023

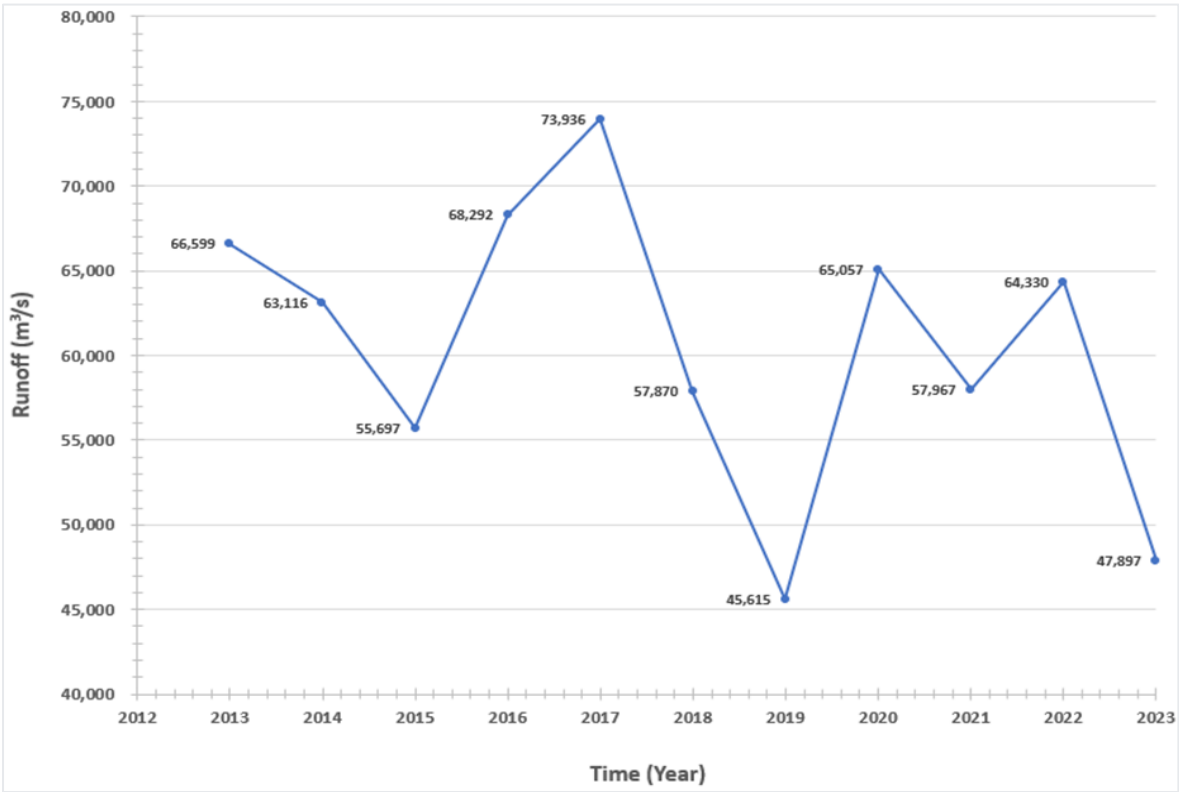


Source: Data provided by Krabi Provincial Water Statistical Office (2024)

For the assessment, the relationship between rainfall and surface water runoff (Figure 24) 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 25, the water area and availability in each year is not

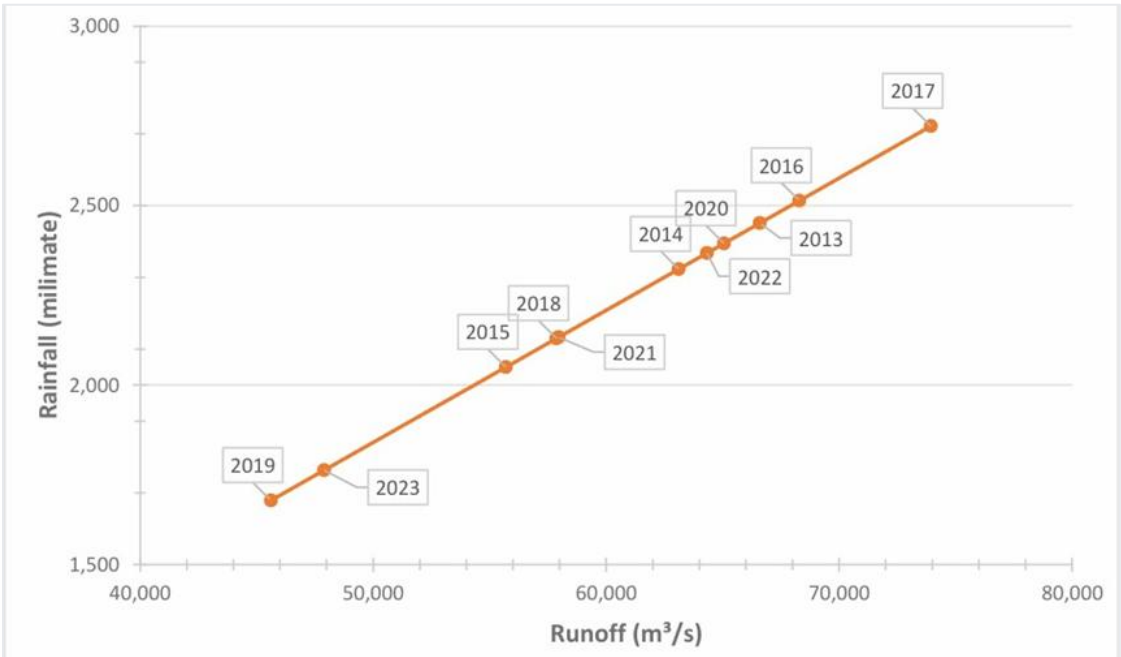
significantly different. It majorly depends on rain fall amount. For surface water quality, Pollution Control Department (2024) indicated that surface water quality in all southern parts of the Thailand was good in 2023.

Figure 23 Runoff water at Krabi Province during 2012-2023



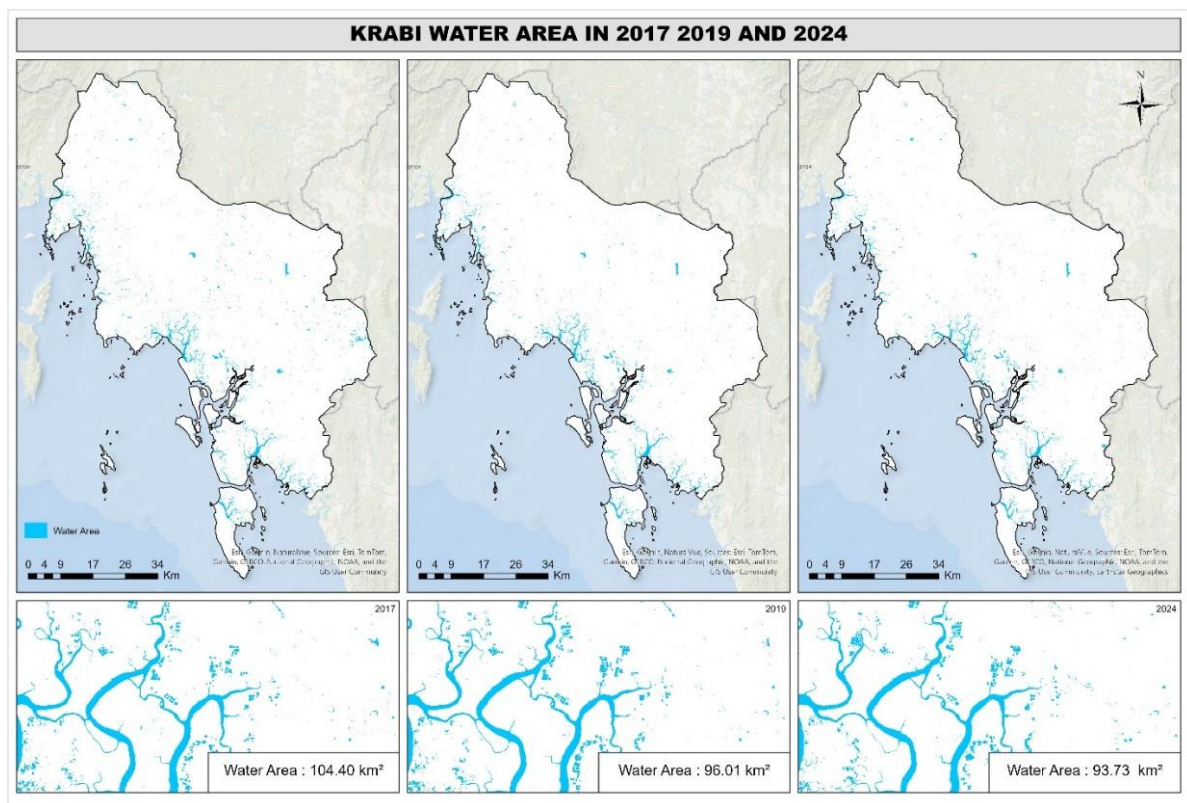
Source: Data provided by Krabi Provincial Water Statistical Office (2024)

Figure 24 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 25 Water resources at Krabi Province



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

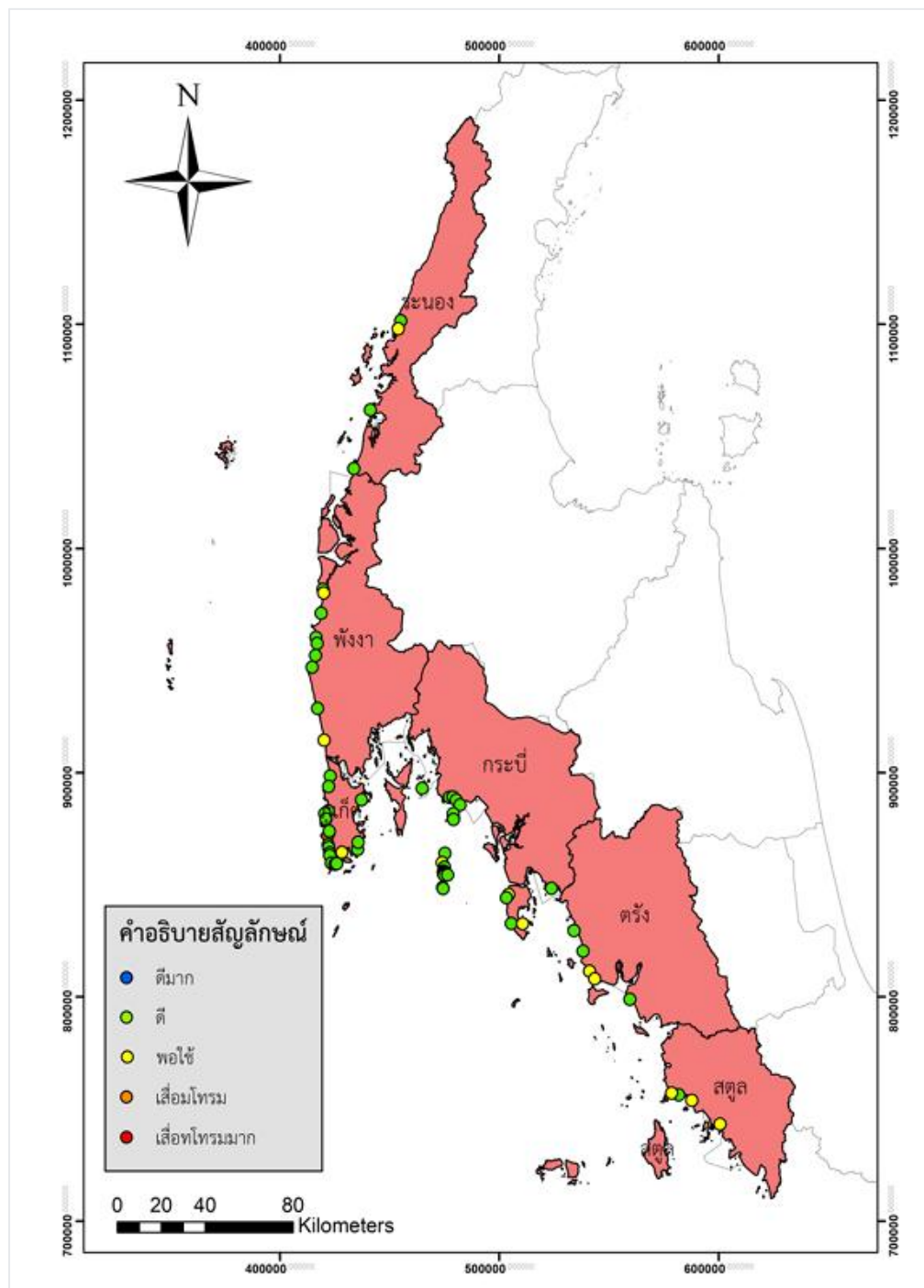
Groundwater Resources

Groundwater serves as a vital water source in Krabi, especially during dry periods. The groundwater map of Krabi Province, Thailand shown in Figure 26. 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 27 A “good” Marine

Figure 27 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.

To evaluate these impacts, GIS-based spatial mapping was utilized to analyze the spatial inter-dependencies between upstream ecosystems and downstream tourism or production sectors. As illustrated in the subsequent figures, this spatial approach provides empirical baseline data to identify specific areas where high-density tourism, aquaculture, and industrial activities directly correlate with degraded surface and marine water quality.

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 28), 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 29) 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 30).

Agricultural Runoff

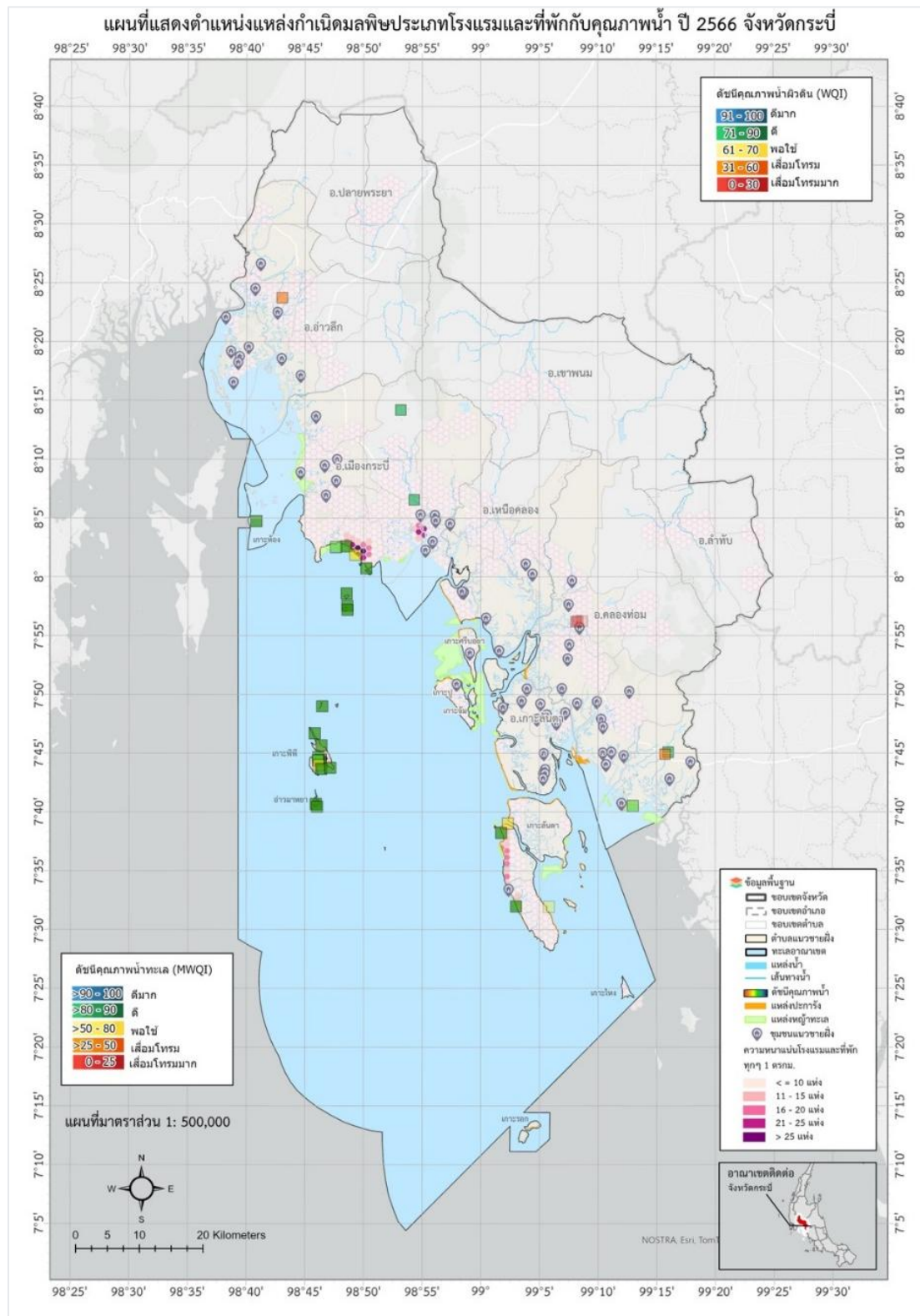
Agricultural activities in Krabi also contribute to water pollution through the runoff of fertilizers and pesticides. Excessive use of nitrogen-based fertilizers leads to nitrate leaching into groundwater, causing contamination. Pesticides can also seep into water sources, posing risks to both human 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 31, 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 32 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

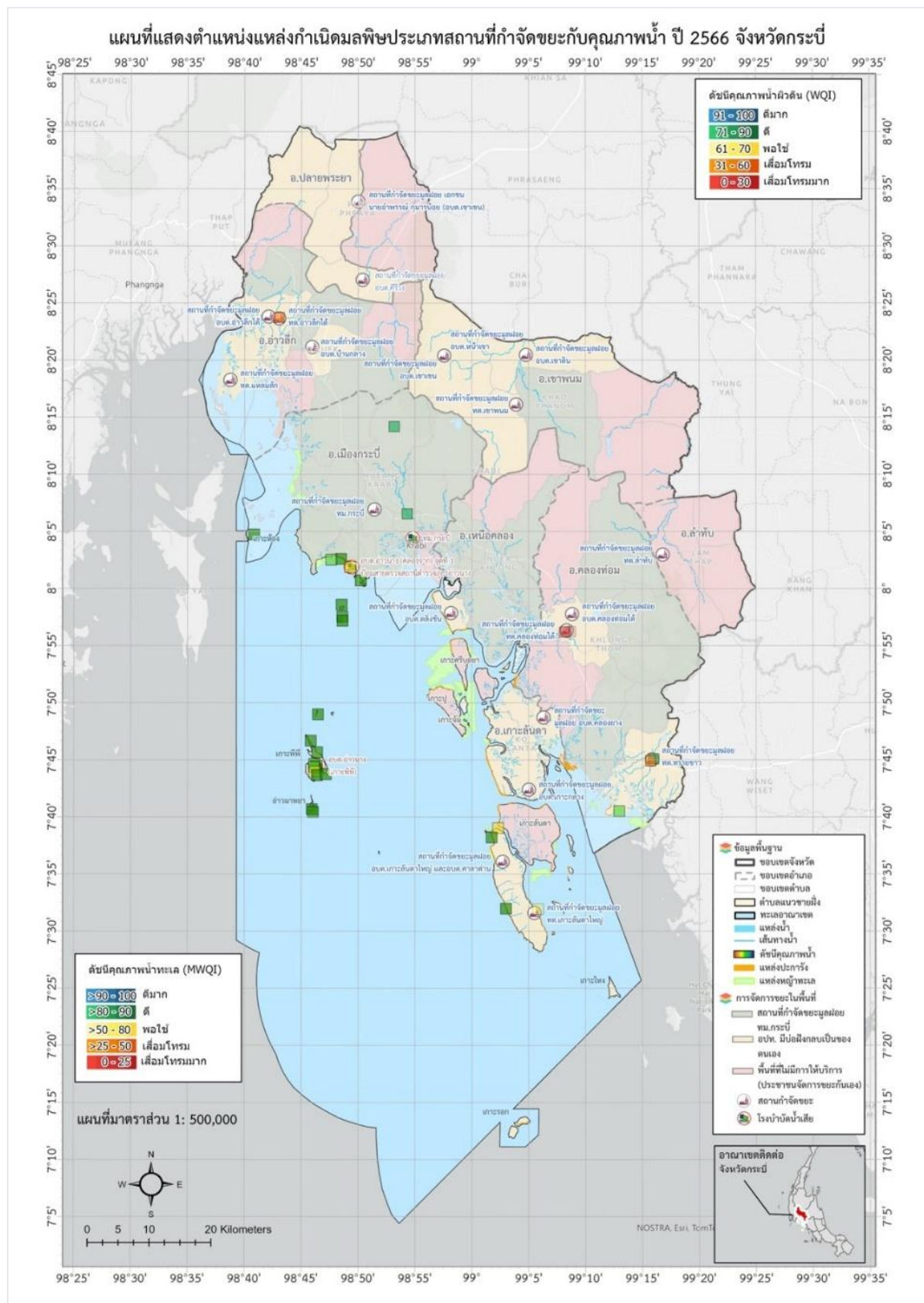
infrastructure leads to the discharge of pollutants into rivers and coastal waters, affecting water quality and marine life. Figure 33 shows the possible water pollution sources from domestic areas at Krabi province and also Figure 34 shows market located at Krabi Province.

Figure 28 Spatial distribution of hotels and accommodation (purple area) at Krabi province, Thailand



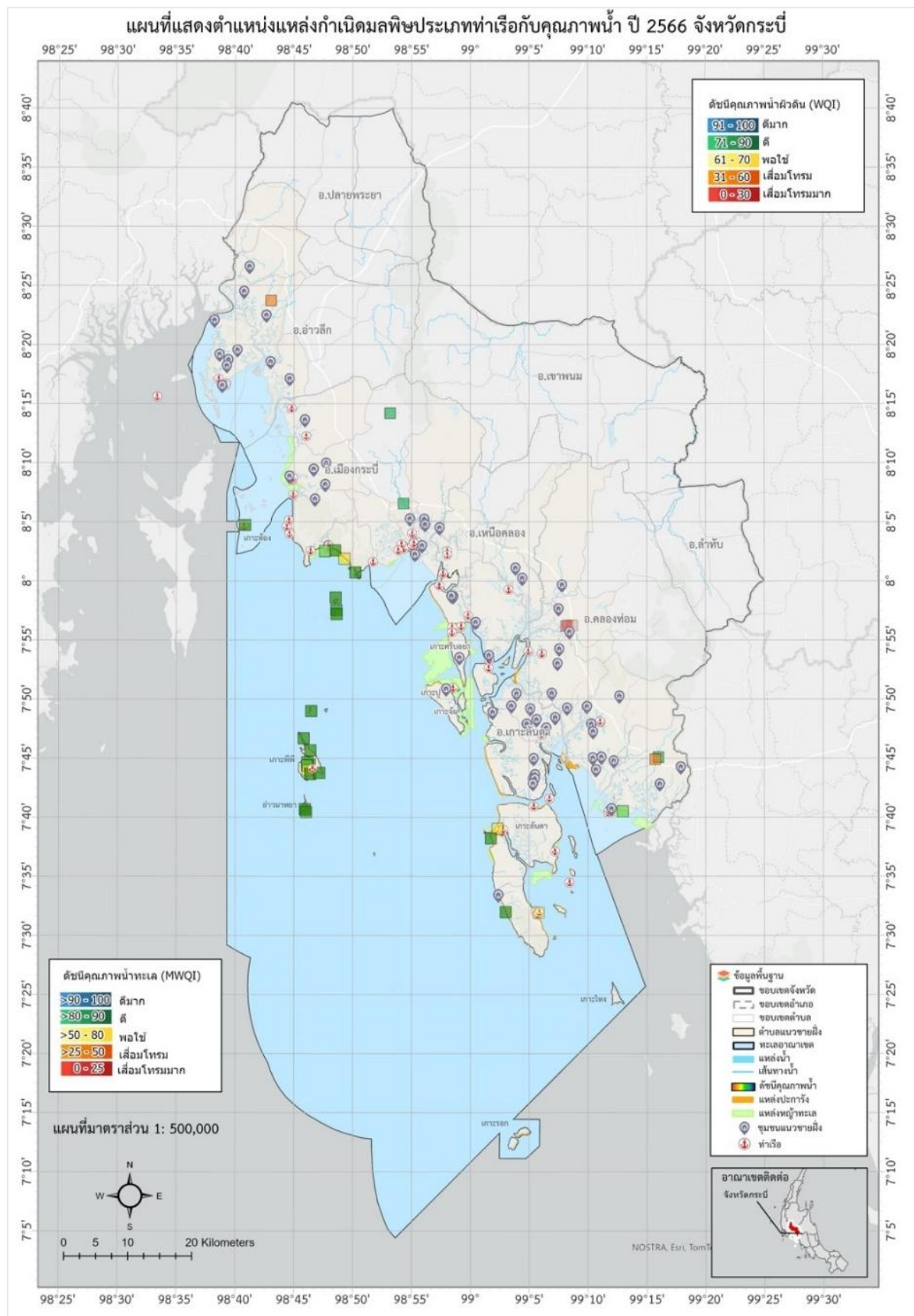
Source: Analysis by TDRI as of 2024

Figure 29 Spatial distribution of landfills at Krabi Provinces, Thailand



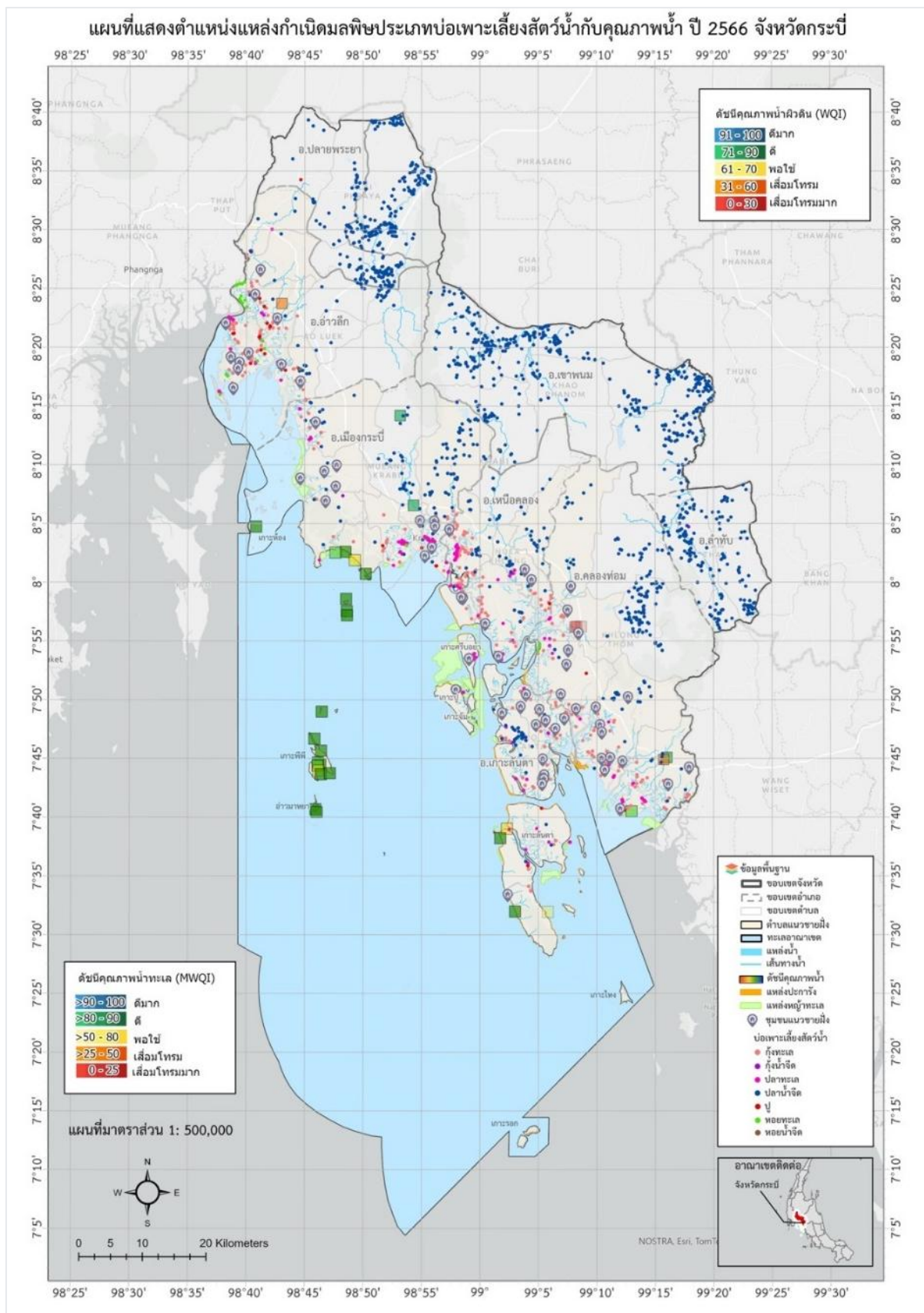
Source: Analysis by TDRI as of 2024

Figure 30 Tourist piers at Krabi Province



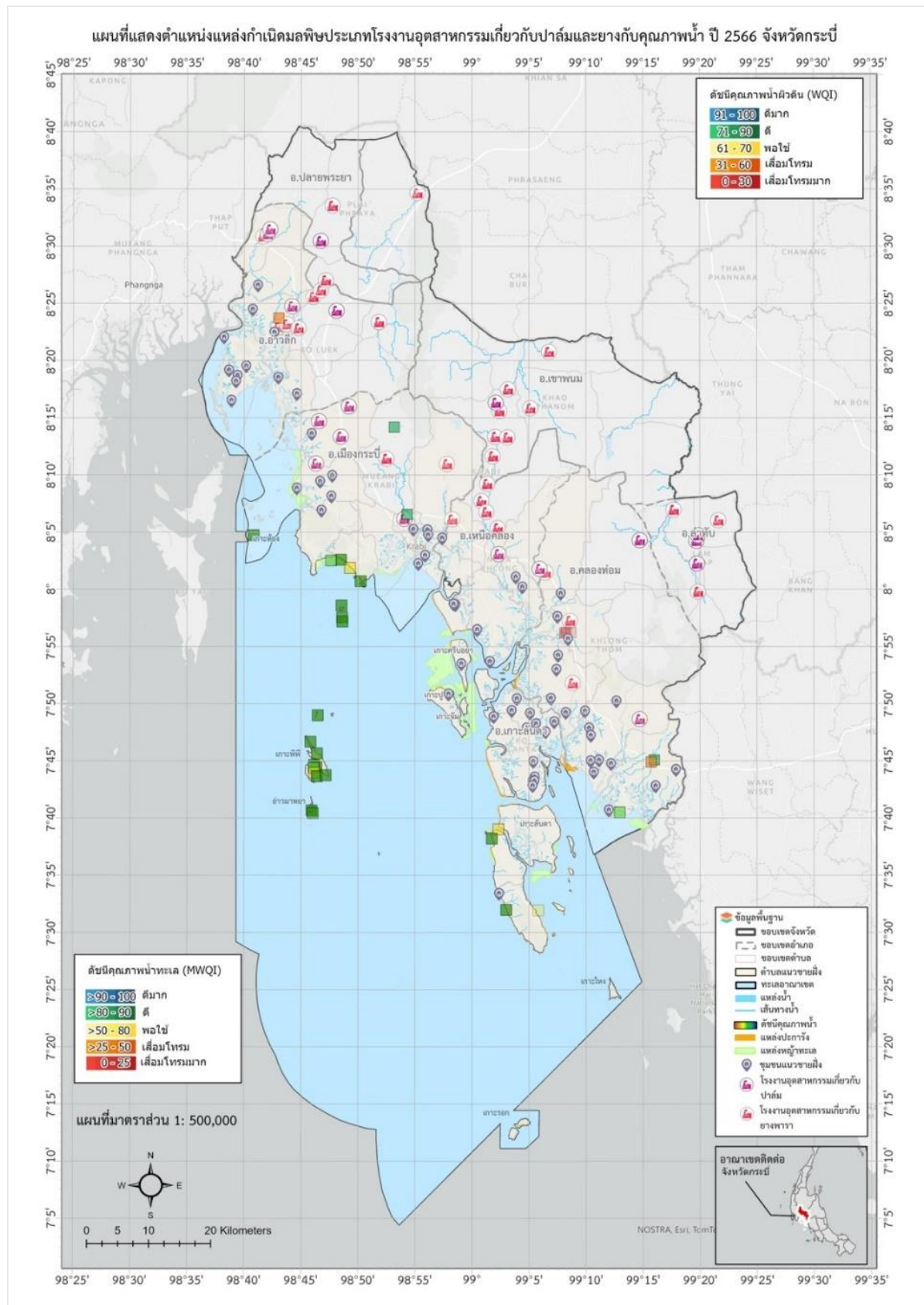
Source: Analysis by TDRI as of 2024

Figure 31 Spatial distribution of aquaculture at Krabi Province



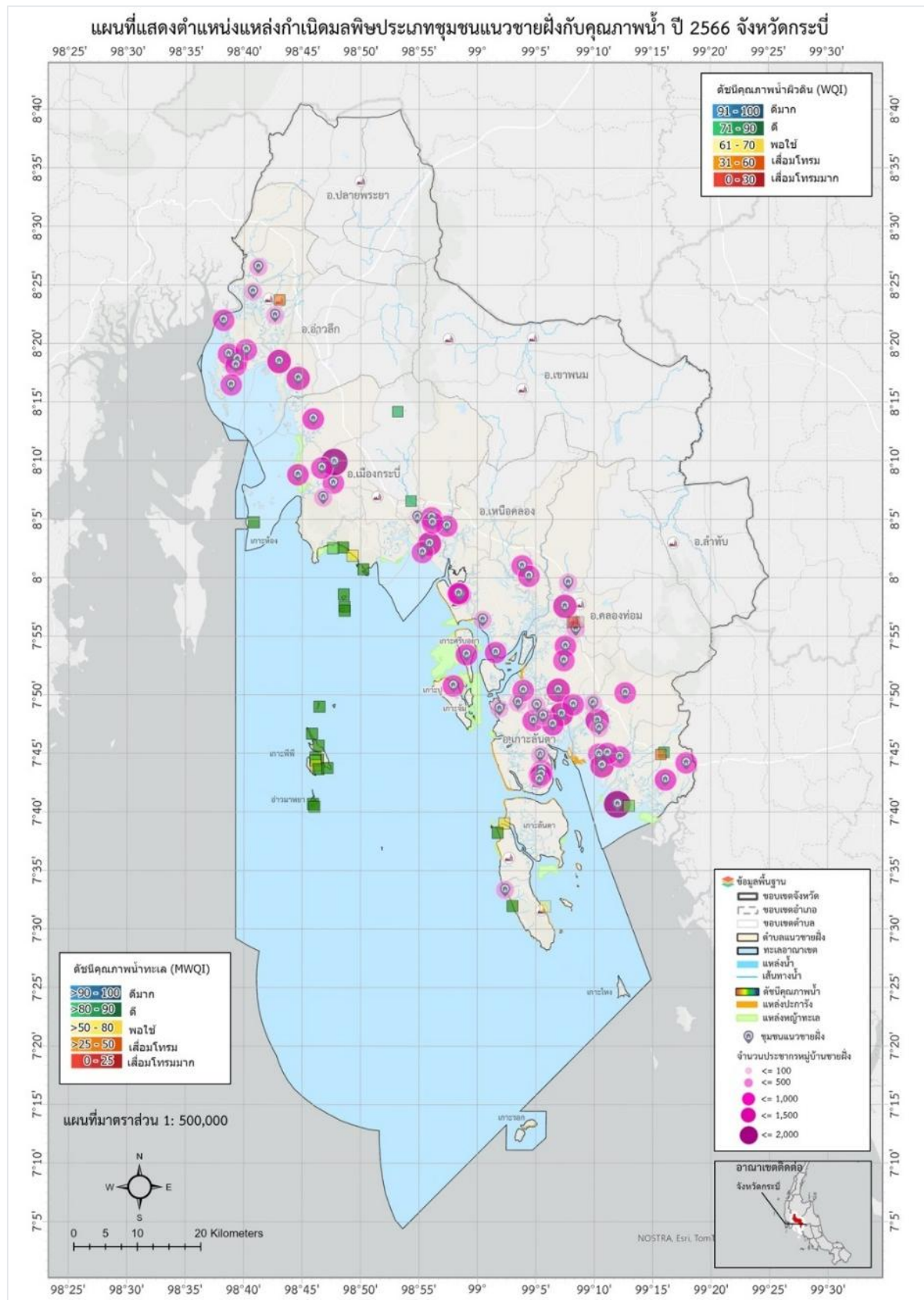
Source: Analysis by TDRI as of 2024

Figure 32 Spatial distribution of oil palm and para rubber industries at Krabi Province



Source: Analysis by TDRI as of 2024

Figure 33 Water pollution sources from domestic areas at Krabi Province



Source: Analysis by TDRI as of 2024

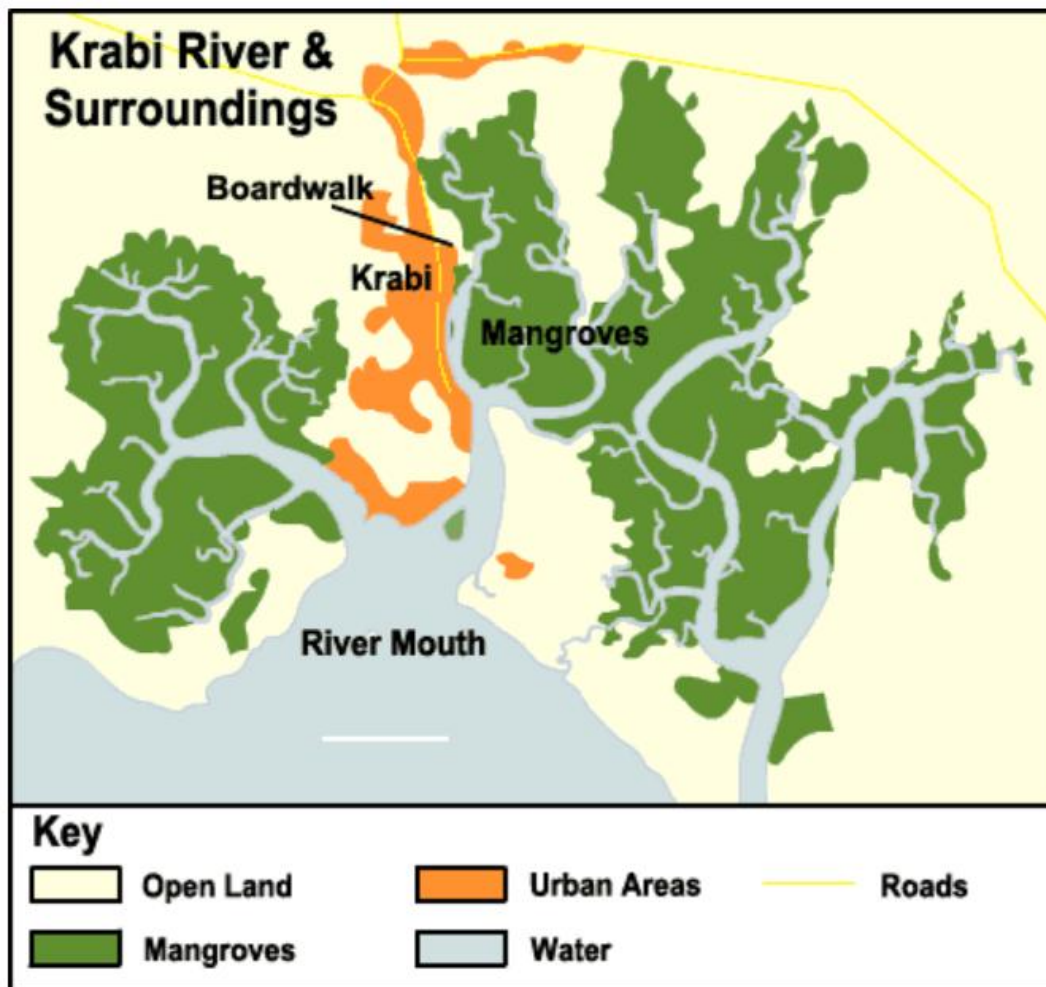
Source: Analysis by TDRI as of 2024



4.2.2 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 35) 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 35 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.

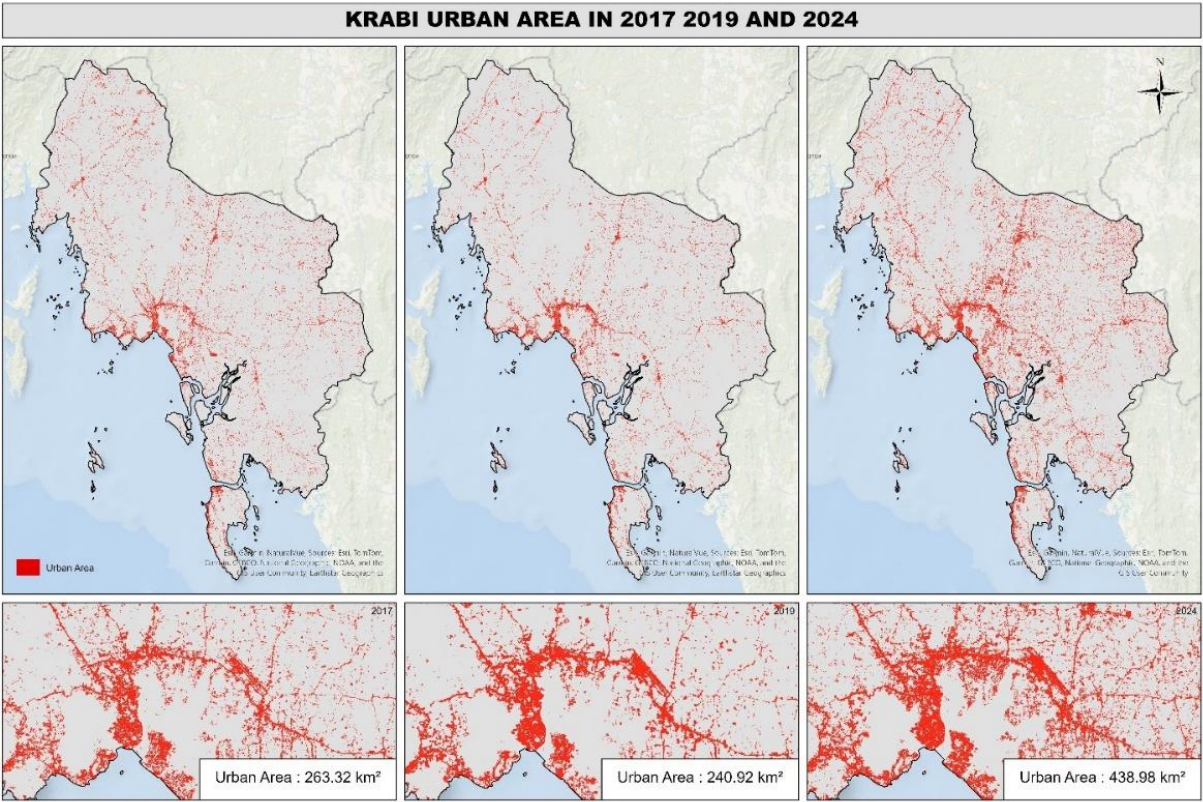
4.2.3 Socioeconomic Interdependencies

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 36 The urban area has significantly increased between 2017 (263.32 km²) and 2024 (438.96 km²) 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 36 The urbanization map of 2017, 2019, 2024



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

4.2.4 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 m³) 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.

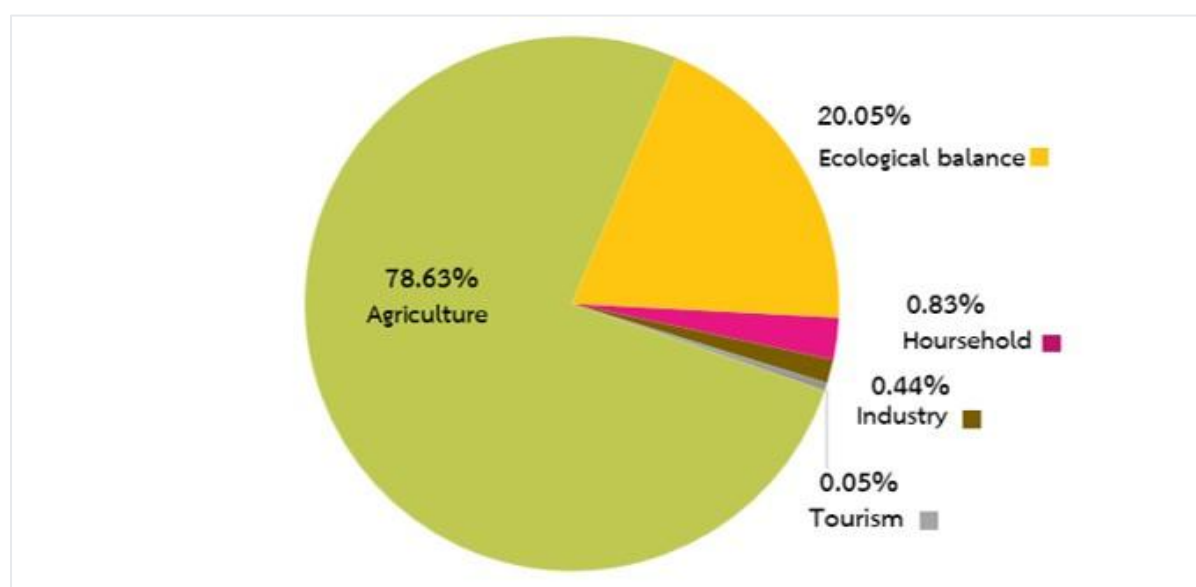
Table 16 Amount of Tourist and estimated water used at Krabi Province

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 37.

Figure 37 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:

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

Where:

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

$$\text{Total Water Risk Score} = 1.05 + 0.25 + 0.50 + 0.65 + 0.30 = \mathbf{2.75}$$

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.

When considering the risks and impacts of alternative development scenarios on water resources, the current moderate water risk level (2.75) may increase if future tourism growth is not supported by effective water management measures. The projected increase in tourist numbers to 18.6 million by 2029 may place additional pressure on freshwater resources, particularly during the dry season when water availability is already limited (score 4). Together with weak water management policies (score 4), this may increase competition for freshwater between the tourism sector and local communities. Furthermore, climate variability (score 4), which is beyond human control, may alter river flows and lead to longer periods of drought, affecting both the tourism sector and public water supply. Therefore, without improvements in water infrastructure and sufficient water storage capacity (score 2), Krabi's overall water risk may increase from a moderate to a higher level. In the long term, these conditions may affect the sustainability of tourism development and the well-being of local communities.

4.3 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

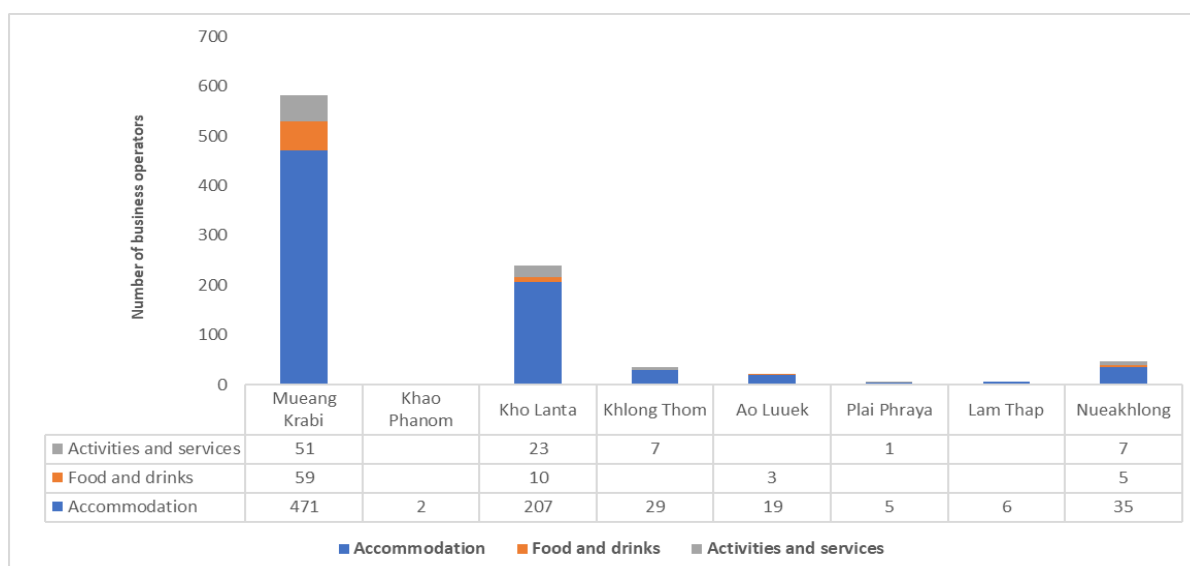
Year	Tourist (person)
2025	9,337,968
2026	11,636,865
2027	13,950,676
2028	16,283,323
2029	18,636,654

4.3.1 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 38.

Figure 38 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

- 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.

Table 22 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.

In conclusion, the tourism sector of Krabi Province currently faces significant challenges, particularly regarding its ecological footprint and environmental pressures. Tourism activities contribute to greenhouse gas emissions through transportation (36.25%), waste (22.91%), food and beverages (21.56%), and accommodation (19.28%), while also increasing pressure on marine ecosystems and waste management systems. When considering the risks and impacts of alternative development scenarios, the overall risk level may increase if appropriate mitigation measures are not implemented. Under a rapid tourism growth scenario, with tourist arrivals projected

to reach 18.6 million by 2029, the increasing number of visitors may place additional pressure on natural resources and existing infrastructure. This may lead to overcrowding at major tourist attractions, habitat degradation, and increased competition for freshwater resources between the tourism sector and local communities.

Furthermore, climate variability and natural disasters may contribute to coastal erosion and coral reef bleaching, reducing the capacity of natural ecosystems to support tourism. Without improvements in infrastructure and the adoption of sustainable tourism policies, tourism-related risks may continue to increase, potentially affecting the long-term sustainability of both the tourism sector and Krabi's natural capital.

Meanwhile, the agricultural sector may also face increasing pressure under alternative development scenarios. The expansion of tourism infrastructure and related developments may increase competition for land and water resources, affecting agricultural activities in some areas. In addition, climate variability may alter seasonal rainfall patterns and water availability, creating further challenges for agricultural production. If these issues are not addressed through appropriate land and water management measures, the overall risk to the agricultural sector may increase from a moderate to a higher level. This may affect local livelihoods, agricultural productivity, and the long-term sustainable use of natural resources in Krabi Province

4.4 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).

Table 23 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

The table 23 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 24.

Table 24 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

Policy Entry Points and Opportunities

- Strategic Planning and Public Budget Allocation
 - **The Link:** The projected growth to 18.6 million tourists by 2029 will severely worsen solid waste accumulation and regional environmental risks.
 - **The Action:** Authorities—coordinated by tourism and environmental sectors—should use these natural capital risk scores to allocate public budgets toward upgrading green infrastructure. Funding must be prioritized to expand waste management and wastewater treatment capacities, which currently process only 5.22% of the daily volume.
- Ecosystem Governance and Market Incentives
 - **The Link:** The data shows a direct link between upstream ecosystems (forests and wetlands) that filter pollutants and downstream tourism infrastructure (hotels and restaurants) facing high water consumption risks. High seasonal tourism strains water resources and drives untreated wastewater discharge, with hotels, restaurants, and tourism activities generating 32,015 m³/day of wastewater alongside massive amounts of solid waste. Without strict controls, this leads to solid waste leakage and illegal wastewater dumping into coastal areas, directly threatening coastal ecosystems and degrading natural capital.
 - **The Action:** Through joint tourism and environmental oversight, decision-makers and authorities must enforce strict and implement rigorous wastewater treatment regulations. This includes mandating functional on-site treatment systems as a prerequisite for commercial operating permits. Concurrently, authorities should introduce market incentives, such as Zero-Waste practices that offer tax reductions for compliant venues, while leveraging tourism fees and Payment for Ecosystem Services (PES) schemes to directly fund coastal waste cleanup and upstream marine restoration.

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