# Ecosystem Assessment for Sustainable Livelihoods in the Lancang-Mekong Basin

ISBN: 978-92-807-4223-7
Job number: ROAP/2705/NA
DOI: https://doi.org/10.59117/20.500.11822/47903



**Suggested citation**

United Nations Environment Programme (2025). *Ecosystem Assessment for Sustainable Livelihoods in the Lancang-Mekong Basin*. Nairobi. https://wedocs.unep.org/20.500.11822/47903

Production: Nairobi, Kenya

URL: https://www.unep.org/resources/report/ecosystem-assessment-sustainable-livelihoods-lancang-mekong-basin

Cover photos (left to right): Raissa Lara Lütolf/Trang Trinh/Tomáš Malík

**Aknowledgements**

The United Nations Environment Programme (UNEP) would like to thank the lead and contributing authors and the project coordination team for their contribution to the development of this report.

Authors and reviewers contributed in their individual capacities and their affiliations are only mentioned for identification purposes.

**AUTHORS (listed by relative contribution)**

Junguo Liu, Southern University of Science and Technology, China (SUSTech); North China University of Water Resources and Electric Power

Yuehan Dou, SUSTech; Xi'an Jiaotong-Liverpool University

Linxiu Zhang, UNEP-IEMP

He Chen, SUSTech

Kai Wang, SUSTech

Aifang Chen, SUSTech

Pengfei Wang, SUSTech

Lanmengqi He, SUSTech

**REVIEWERS (listed in alphabetic order)**

Chao Fu (UNEP-IEMP), Charlotte Hicks (UNEP-WCMC), Guoqin Wang (UNEP-IEMP), Makiko Yashiro (UNEP), Marie-Yon Strücker (UNEP), Rebeca Leonard (UNEP), Tatirose Vijitpan (UNEP-IEMP), Vera Ariadne Pokorny (UNEP)

**SECRETARIAT AND PROJECT COORDINATION**

Tatirose Vijitpan (UNEP-IEMP), Guoqin Wang (UNEP-IEMP), Linxiu Zhang (UNEP-IEMP), Marie-Yon Strücker (UNEP), Makiko Yashiro (UNEP)

**LANGUAGE EDITING**

Strategic Agenda

**DESIGN AND LAYOUT**

René Henrich

**THANKS ALSO TO:**

Mr. Chhin Sophea from Centre for Biodiversity Conservation, Royal University of Phnom Penh, Cambodia; Prof. Xiaodong Yang from the Xishuangbanna Tropical Botanical Garden of the Chinese Academy of Sciences; Mr. Ratt Reouy from the Phnom Kulen CPAs network; Mr. Sakoern Sakada from the Phnom Kulen National Park; Mr. Chou Radina from the Department of Water System and Heritage at the Apsara Authority in Siem Reap; Mr. Sun Kong from the Siem Reap Provincial Department of Environment; Mr. Chheam Taing from Khnorn Phnom Commune; and the residents of Phnom Kulen National Park for their invaluable help and cooperation during the local data collection.

**FINANCIAL AND TECHNICAL SUPPORT**

This knowledge product is prepared under the context of the project "Improving Ecosystem Management for Sustainable Livelihoods within the Framework of Lancang-Mekong Cooperation", funded by the Ministry of Ecology and Environment of the People's Republic of China, through the China Trust Fund to UNEP.

In addition, this knowledge product is partly supported by the National Natural Science Foundation of China (grant no. 42361144001) and the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA20060402).

Special appreciation is extended to the local partners in both Cambodia and China, and most importantly the experts and local communities who were particularly generous in contributing to the interviews and questionnaires despite inconveniences due to time constraints and COVID-19 pandemic restrictions.


Mekong Delta, Viet Nam. Photo credit @Anne Lin

# List of abbreviations

| | |
|---|---|
| **3S** | Srepok, Sesan and Sekong |
| **ABS** | Strengthening Access and Benefit Sharing |
| **APSARA** | Authority for the Protection and Management of Angkor and the Region of Siem Reap |
| **ARIES** | Artificial Intelligence for Environment & Sustainability |
| **CCI-LC** | Climate Change Initiative – Land Cover |
| **CPA** | Community Protected Area |
| **FAO** | Food and Agriculture Organization of the United Nations |
| **GCM** | General circulation model |
| **IGRAC** | International Groundwater Resources Assessment Center |
| **IUCN** | International Union for Conservation of Nature |
| **LMB** | Lancang-Mekong River Basin |
| **LMR** | Lancang-Mekong River |
| **LUCC** | Land use and cover change |
| **MOE** | Ministry of Environment, Cambodia |
| **MRB** | Mekong River Basin |
| **MRC** | Mekong River Commission |
| **NTFPs** | Non-timber forest products |
| **PKNP** | Phnom Kulen National Park |
| **PROBA-V** | Project for On-Board Autonomy – Vegetation |
| **RUSLE** | Revised Universal Soil Loss Equation |
| **SPOT-VGT** | Systeme Probatoire d'Observation de la Terre – Vegetation |
| **STERE** | Stepwise ecological restoration |
| **TSLA** | Tonle Sap Lake Area |
| **LCCS** | United Nations Land Cover Classification System |

# Table of contents

# List of Figures

# List of Tables

# Executive summary

The Lancang-Mekong Basin (LMB) is endowed with incomparable richness, ranging from uncommon fauna amid breathtaking natural vistas to communities with distinct cultural history. It supports more than 60 million people and has some of the most naturally varied environments in the world. However, the LMB is also among the regions of the world that are most susceptible to the effects of deforestation and forest degradation. These processes impact local people, biodiversity and natural resources, and have cascading effects. The LMB is currently confronted with several interventions impacting the environment, with specific consequences for the population and its well-being.

This report sets out to assess changes to ecosystems and to livelihoods dependent on ecosystem services, using case studies demonstrated through pilot activities at selected areas in Cambodia and China. It also provides recommendations from the perspectives of both the case-study level and LMB regional level to comprehensively promote improvements to ecosystem health, natural resources management and sustainable livelihoods. This report consists of a detailed introduction followed by three thematic chapters on land cover changes, water resource changes and analysis of ecosystem services in case studies in the upper and lower LMB, completed by a brief synthesis and recommendation.

**Chapter 1** provides basic information on current socio-ecological conditions in the LMB, as well as the analytical design of this report. **Chapter 2** (Land cover changes in the Lancang-Mekong Basin) assesses land cover changes in the LMB from 1992 to 2020. **Chapter 3** (Water resource changes in the Lancang-Mekong River Basin) assesses surface and groundwater changes due to climate change and human activities. **Chapter 4** (Ecosystem services and livelihoods in the Lancang-Mekong Basin) assesses vital ecosystem services and livelihoods in the upper and lower LMB and anthropogenic impacts on local livelihoods in the Tonle Sap Lake region. **Chapter 5** (Conclusions and recommendations) summarizes the main results of the whole report and proposes recommendations for integrated ecosystem management for sustainable livelihoods in the Lancang-Mekong region, based on analysis of changes to natural resources and case studies demonstrated through pilot activities at selected areas in Cambodia and China.

**Main Finding 1: Land cover.**

Cropland area increased from 261,390 $km^2$ to 279,860 $km^2$ during the study period. Tree cover and shrubland areas decreased, especially in Thailand and Cambodia. Cropland expansion is a major reason for the forest loss. Land cover in the upstream Lancang-Mekong River Basin has changed little as there has been less human influence. There has been a drastic increase in urban areas in the 21st century. Land cover in Mengla County changed dramatically between 1992 and 2000, while changes in the 21st century were relatively small. There was an increasing trend in cropland and tree cover, while shrubland showed a decreasing trend in Mengla County. There was a decreasing trend in tree cover area in Phnom Kulen National Park, while cropland and shrubland showed an increasing trend. Cropland expansion was a main driver for forest loss in Phnom Kulen National Park.

**Main Finding 2: Water resources.**

According to the existing literature, (a) streamflow increased in the upper basin while slightly decreased in the lower basin, and the streamflow of the whole basin is projected to increase in the future; and (b) from 1960 to 2010, streamflow increased during the dry season but declined in the wet season with a minor rise predicted in the future. Groundwater extraction is increasing as industrial and agricultural applications expand. However, groundwater resource studies have less studied than surface water system studies. There is little information available on the breadth and magnitude of the aquifer systems surrounding the Mekong Delta.

**Main Finding 3: Ecosystem services and livelihoods.**

Due to the increase in cash crops (rubber in the upper LMB and cashew nuts in the lower LMB), the natural ecosystems and biodiversity of both regions are threatened. The traditional practice of shifting cultivation for growing rain-fed upland rice and other crops is being rapidly replaced by permanent plantations of cashew trees, converting additional forested areas to agricultural areas in Phnom Kulen National Park (PKNP). The decreased natural resources in PKNP may severely affect ecosystem services, cultural heritage in and near PKNP, and most importantly quality of life for local communities. Rubber demand is causing a loss of biodiversity in the rainforests in south-west China and the industry has replaced traditional swidden-fallow agroecosystems. Given the challenge of meeting the demands of human while maintaining long-term functional capacity of the ecosystem in the Tonle Sap Lake Area (TSLA), this study provides scientific information to comprehend human intervention in forests, which may be important for future sustainable forest management in order to establish a healthy ecosystem in this area.

**Recommendation 1:**
**Involve multilevel stakeholders.**

Ecosystem protection cannot be addressed without participation by surrounding communities. In addition to community-level stakeholders, special attention should be paid to other stakeholder groups (such as women and ethnic minorities) who are at risk of being marginalized. The involvement of multilevel stakeholders has great potential to foster sustainable livelihoods with local equality and public engagement, and to address the complex problems at the intersection of society and the environment.

**Recommendation 2:**
**Coordinate the relationship between cultural customs, local awareness and ecological protection.**

The national economic development plan could be used to coordinate the relationship between culture and customs in environmental protection, advocating new culture-benefited ways of life and living and contributing to sustainable livelihoods. To fully involve companies, local communities, and the general public in local and regional ecological protection, awareness of the importance of ecosystem management must be developed among enterprises, local communities, and the general public. Corporate social responsibility is a critical component of ecosystem management. Communities' capacity to participate in ecosystem management should be strengthened, especially through public and school education.

**Recommendation 3:**
**Explore limited land for more agroforestry production.**

In both the upper and lower LMB, ecosystem health and the capacity to provide ecosystem services have been negatively affected by the expansion of single-crop farming.

Alternatives with complex ecosystems produce a broader range of crops, are more adaptable, and are better equipped to respond to market changes.

Tra Su Cajuput Forest in An Giang, Viet Nam. Photo credit @diGital Sennin

**Recommendation 4:**
**Incorporate stepwise ecological restoration to reverse the trend towards degradation of natural ecosystems.**

New ecological restoration modes and programmes should be planned at international level and implemented in different regions of the LMB. Stepwise ecological restorations (STERE) are suggested to improve the ecological conditions of natural ecosystems according to different levels of degradation, and in different social and economic contexts.

Selecting appropriate restorative modes and paths can help to progressively recover ecological processes, functions and services as well as biodiversity.

**Recommendation 5:**
**Increase eco-compensation and financial support.**

Enhancing ecosystem health and sustainable livelihoods along the entire LMB requires significant investment, and this is dependent on sustained and stable policies, financial support and public participation. Multilevel, multichannel and diversified financing methods should be explored, whilst ensuring that both women and men from vulnerable populations and local communities are benefiting from these initiatives. In addition, eco-compensation regulations and experimental initiatives should be developed to enhance the ecosystem services supported by their beneficiaries. Through cooperation among countries, departments and industries in the Lancang-Mekong region, resources should be invested in ecological improvement to jointly promote sustainable development of the ecosystem.

Mekong Delta. Photo credit @Jack Young

CHAPTER 1

# Introduction

Mekong Delta in Viet Nam. Photo credit @Raissa Lara Lütolf

# 1. Introduction

## Overview of the region

The Lancang-Mekong River, which has a length of 4,880 km and a total area of 795,000 km$^2$, is one of the most significant transboundary rivers in the world (Liu *et al.* 2022). With a 446 km$^3$ annual mean discharge, it ranks as the eighth-largest flow in the world (Mekong River Commission 2019). The Lancang-Mekong River originates in the Qinghai-Tibet Plateau, passing through three provinces in China then through Myanmar, the Lao People's Democratic Republic (Lao PDR), Thailand, Cambodia and Viet Nam. Within China, it flows from north to south through the Tibet Autonomous Region and Yunnan Province, as the Lancang River. The Lancang-Mekong Basin (LMB) has complex geographic and climatic conditions. From May to November, the region has a wet season dominated by the south-west monsoon, which is responsible for over 70 per cent of the region's annual precipitation (Chen, Chen and Azorin-Molina 2018). The wet season precipitation represents a significant source of the Mekong River discharge and is crucial for regional agriculture (Hoang *et al.* 2016). In addition, the downstream discharge may be impacted by the snowmelt from Qinghai-Tibet Plateau, especially in the dry season (Johnston and Kummu 2012). There is an elevation difference in this basin of more than 5,060 m from Tibetan Plateau to the estuary reaches, with an average slope of 1.04 per cent.

The LMB is the livelihood region of around 72 million inhabitants (Campbell 2009). It is renowned for its wide cultural diversity, hosting more than 70 different ethnic groups living in small settlements with different languages and customs (Mekong River Commission 2018b). To support their everyday lives, many ethnic groups rely on knowledge, practices, and land-use systems that are inextricably linked to the surrounding environment and resources (United Nations Environment Programme 2006). The natural resources support the normal lives of more than 60 million people (Bui *et al.* 2016). The LMB is particularly productive, with many aquatic economic activities, since it benefits from the natural hydrological cycle, with a vital flood pulse occurring during the monsoon season (Meur, Phu and Gratiot 2021). The big fishing industry in the lower LMB produces 2.6 metric tons per year and receives a total income of around $7 billion per year (Mekong River Commission 2018b). A significant section of the population depends on agricultural practices for a living, and the agricultural industry is likewise prominently represented (Smajgl *et al.* 2015). Large portions of the lower basin naturally flood during the wet season, and this flooding is controlled for agricultural optimization (Aires *et al.* 2020).

Over the past several decades, the region's economy and population have increased, in part due to peace and China's recent and rapid expansion (Meur, Phu and Gratiot 2021). Meanwhile, the high demand for electricity and the mountainous landscape resulted in 176 dams being built or planned throughout the whole basin. This produced a total hydropower capacity of 60 GW and indirectly increased the use of the lower part of the Mekong River for irrigation (Grumbine, Dore and Xu 2012a; Mekong River Commission 2016; Nhan and Cao 2019). The economic development in urban areas attracts rural people through better payment and services and is a major cause of migration and urbanization (Water Environment Partnership in Asia 2010). Migration and urbanization also have gendered implications that require attention. For example, seasonal migration occasioned by weather disasters may also mean that many men leave their homes in search of jobs and this shift further impacts local communities as traditional gender roles are reversed. Women then take on the roles that men previously undertook, including the head of the household, resulting in additional responsibilities that can be overburdening in some cases whilst providing opportunities in others. Understanding such dynamics is crucial and ensures that local women and men can get the right kind of assistance, and this will then lead to more effective policies and practices and improved outcomes which are crucial towards sustainability. Although urbanization occurs in all countries in the LMB, over 85 per cent of the population lives in rural regions (Food and Agriculture Organization 2011; Li *et al.* 2017).

The upper Lancang River Basin comprises for 21 per cent of the total basin area, and the water supply here mainly comes from precipitation and snowmelt. After entering the lower part, the river is known as the Mekong River and finally flows to the South China Sea. The lower Mekong River Basin (MRB) is shared by Lao PDR (accounting for 25 per cent of the total basin area), Thailand (23 per cent), Cambodia (20 per cent), Viet Nam (8 per cent), and Myanmar (3 per cent). The upper LMB makes up 24 per cent and the lower LMB 76 per cent of the basin's total area (Mekong River Commission 2010) (Table 1.1). In the upper LMB, the northern part is a typical alpine valley with an average altitude of 3,500–5,000 m, and the southern part is a wide valley with altitude of 1,000–3,500 m. Yunnan province in south China similarly has a monsoon climate, albeit the local geography varies greatly. The climate transitions from tropical and subtropical monsoons in the south to temperate monsoons in the north as elevation rises from 2,500 m to 4,000 m above sea level in the most upstream area. Myanmar and the northern part of Lao PDR have a large mountainous area, the midstream terrain in Thailand and Lao PDR is a transition region from mountain to plain, and the downstream area in Cambodia and southern Viet Nam is mostly plains.

The lower LMB has a large area of floodplains, including the central floodplain from the town of Kratie to the border of Viet Nam, the Tonle Sap floodplain with the Tonle Sap Lake and surrounding tributaries, and the Viet Nam Delta floodplain. The south-west monsoon, which typically lasts from May until late September or early October and coincides with the flood season in the lower basin, dominates the climate of the lower LMB (Food and Agriculture Organization 2011).

The annual average rainfall throughout the Cambodian floodplain and the Mekong Delta is less than 1,500 mm, while it is more than double that in the Central Highlands of Lao PDR and inside the mainline valley at Pakse. Rainfall is distributed seasonally similarly to the lower basin. The main source of water for the upper LMB's dry season and spring floods is snow, which is scarce in the lowlands but important at higher elevations (Figure 1.1).

**Table 1.1 Overview of countries in the Lancang-Mekong River Basin (LMB)**

| Country[1] | Area of the country in LMB ($km^2$) | As proportion of the country's total area (per cent) | As proportion of LMB's total area (per cent) |
|---|---|---|---|
| Cambodia | 155 000 | 86 | 20 |
| China | 165 000 | 2 | 21 |
| Lao PDR | 202 000 | 85 | 25 |
| Myanmar | 24 000 | 4 | 3 |
| Thailand | 184 000 | 36 | 23 |
| Viet Nam | 65 000 | 20 | 8 |
| *Total Area of LMB* | *795 000 $km^2$ / 3.8 per cent of South-East Asia* | | |

[1] Countries are listed in alphabetical order.

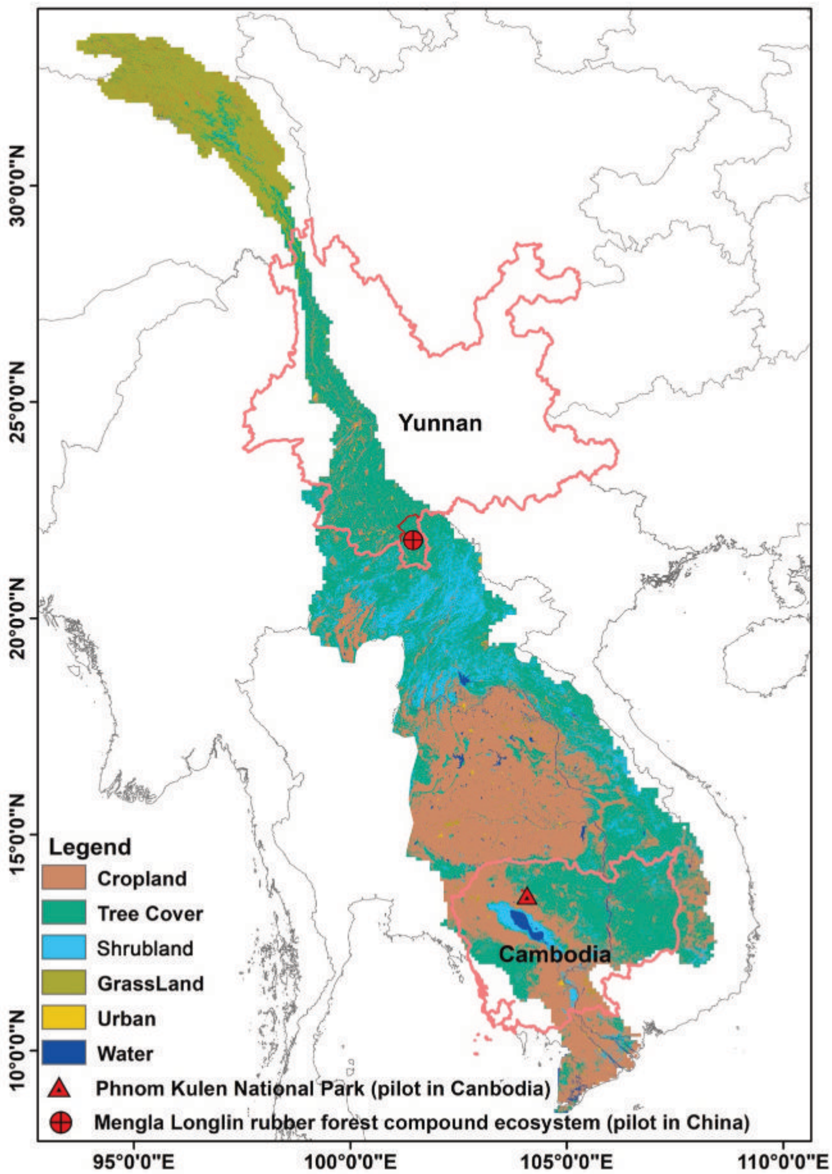



**Figure 1.1 The Lancang-Mekong River Basin (LMB) and pilot sites in Cambodia and China**

# Ecosystems and livelihoods

## 1.1.1. Rivers and wetlands

The LMB's connectivity and natural fluctuation of flows enable outstanding production, while sediments and nutrients support the landforms, agriculture, and marine fisheries of the Mekong Delta.

The river system supports the world's largest known fish migration.

In addition to the great potential for hydropower and water resources, the lower reaches of the Mekong River system also contribute to the regional economy and livelihoods by providing waterways to support shipping, which is the primary mode of transportation in most parts of the LMB. Additionally, shipping is crucial for both international trade and tourism (Mekong River Commission 2018b).

Mekong River at the Lao-Thai border. Photo credit @Tatirose Vijitpan

Millions of people who live in rural regions rely on the unique and irreplaceable ecosystems that the wetlands of the Lower Mekong Basin offer for a variety of fish, plant, and animal species. They also provide an essential supply of food and water. For example, during the dry season the Tram Chim National Park in Viet Nam hosts almost the entire global population of the threatened Eastern sarus crane (the tallest flying bird on earth and one of the world's 15 species of crane). The region's freshwater wetlands are also crucial for many species such as migratory egrets and shorebirds, and the coastal intertidal areas for shorebirds from North-East Asia (Friederich 2004).

The largest known wetland within the upper LMB is the 250 $km^2$ Er Hai Lake in Yunnan province. The LMB wetlands also have many essential ecological functions with high economic value, such as nutrient recycling and pollution removal, sediment trapping, flood protection, carbon capture and surface and groundwater storage.

In terms of the relationship between humans and the ecosystem, rivers and wetlands of the LMB have gender-differentiated impacts on local communities. In addition to developments within these areas sometimes having adverse impacts on biodiversity, the reduced natural resources often have adverse impacts on local communities and these impacts are especially burdened on women whose gender role comprises a high reliance on natural resources, for example, in collecting or utilizing water for domestic consumption (cooking, cleaning, drinking, washing, etc.).

The situation is further worsened during periods of environmental stresses such as floods and droughts and is exacerbated by social barriers, which means they have reduced adaptive capacities to these environmental stressors. Therefore, initiatives that take into account the differentiated needs of both women and men from local communities and vulnerable populations are the ones that are sustainable and thus highly recommended.

Wetlands in the lower LMB. Photo credit @Mekong River Commission

## 1.1.2. Forests

The LMB comprises diverse forest types that provide millions of people with food, livelihoods and other ecosystem services (Brewer *et al.* 2020). Forests in this region perform essential functions as carbon sinks, biodiversity hotspots and sources of socioeconomic stability for local populations (Sodhi *et al.* 2010). Located in the Indo-Burma biodiversity hotspot, they also sustain essential and charismatic wildlife species, including the tiger, the Asian elephant and the endemic saola (World Wide Fund for Nature 2014). Many forest-dwelling and forest-dependent animal species in the LMB are threatened by forest loss, fragmentation, and degradation, which also endanger the continuing provision of forest ecosystem services. If current trends continue, it is estimated that by 2030 just 14 per cent of forests will be large enough to maintain thriving populations of large animal species (such as the tiger and the Asian elephant) in the Greater Mekong Subregion (World Wide Fund for Nature 2013).

The increased cultivation of economic crops such as cacao, cashew, coconut, coffee, rubber, tea, and timber/pulp is a major driver of forest conversion in the LMB. Economic growth is heavily reliant on primary industries (particularly agricultural plantations), and there is a sizable international commercial market for wildlife hunting.

Rapid infrastructural development, including as transboundary economic corridors and massive hydroelectric power plants, has also carved vast swaths across the LMB's forests. Local ethnic minorities and migrants with few economic alternatives typically practice shifting farming. Continued forest destruction will deprive them of this source of income, presumably deepening their poverty and widening the gender gap. Current research indicates that women comprise the majority of the poorest in society and rely heavily on forest products for domestic use. For example, a study in Lower Mekong found that women value forests for food, firewood, and fodder, whereas men value forests for earning cash by selling wood to pulp or furniture makers. Reduced forest cover means that women increasingly invest more time in daily chores, further impeding their involvement in productive activities, including education or capacity-building initiatives.

Thus, understanding how different population's livelihoods are impacted by forest cover is crucial.

### 1.1.3. Wildlife

The LMB is home to a vast biodiversity of great worldwide significance, containing a variety of species that are threatened with extinction internationally and have a high rate of endemism. Recent estimates of the Greater Mekong Subregion's biodata include approximately 20,000 plant species, 430 mammal species, 1,200 bird species, 800 reptiles, 850 fish species and various amphibian species, with new species still being discovered (Asian Development Bank 2015). Over 3,007 new species have been described since 1997 (Whitney 2022), underlining the significance and potential of the region in providing valuable genetic and biochemical resources, as well as sources of bio-inspiration for future generations.

However, many potential threats are making the biodiversity of the Mekong River Basin vulnerable. These include land conversion, pesticide application, intensive agricultural irrigation, main river constructions (such as reservoirs and dams and use of hydropower), overfishing and unpredictable climate change (Valbo-Jørgensen, Coates and Hortle 2009; Dugan *et al.* 2010). For instance, many species of large-bodied fish, including the critically endangered gigantic catfish, considered to be the biggest freshwater fish in the world, appear to be on the decline. The population of amphibians and reptiles has been decimated and many important bird habitats degraded or lost.

Yin-yang frog (*Leptobrachium leucops*) southern Viet Nam. Photo credit ©Jodi J. L. Rowley/Australian Museum

## 1.1.4. Fisheries

Fisheries are crucial for millions of people in the LMB who depend on them for food security and livelihoods. The LMB contains the third-most diversified fish population in the world, after the Amazon and Congo River basins, with 1,148 species (Mekong River Commission 2018a). The lower LMB has the greatest inland capture fisheries in the world, with an estimated annual fish catch of 2.3 million tons, valued at $11 billion. The Mekong fisheries also help to drive the basin's social and economic development. Despite their importance, the Mekong fisheries are under growing strain as a result of a variety of consequences from basin development as well as climate change. These negative consequences are caused by the building of hydroelectric dams, the growth of irrigated agriculture, the development of flood protection infrastructure, and other water resource development projects. The net present value of the fisheries industry in all lower LMB nations is anticipated to fall by $22.6 million by 2040 (Cambodia, Lao PDR, Thailand and Viet Nam). Given the increasing population in the region, it is particularly important to ensure the sustainability of fisheries (as both food source and industry to provide employment).

Declining fish supplies due to developments within the LMB often carries significant adverse impacts on women who are often tasked with food security and sustenance at the household level. Women's gendered roles in terms of being responsible for growing, collecting, and preparing food, means that they face significant challenges when fish stocks are low. This reliance on declining natural resources means that it takes more effort and longer time to fulfil the need for sustenance; it impacts adversely on women's time and energy, leaving little room for other empowerment activities. The adoption of gender-responsive strategies, plans, policies and laws that take into account the needs of women alongside those of men and vulnerable populations is thus a highly recommended approach.

Traditional fish catching in LMB

Fisherman in LMB. Photo credit @Quang Nguyen Vinh

## 1.1.5. Agriculture

Over 65 million people in the LMB depend on agriculture for their livelihoods, making it the foundation of the region's economic growth. (Asian Development Bank 2015). Agriculture is essential for improving livelihoods, living conditions, and alleviating poverty in the basin (Food and Agriculture Organization 2011). Planted on over 10 million hectares, rice is the main crop in the region, followed by cassava, sugar cane, soybean, cashew nut and corn. The area planted with rice is highly insufficient given the output required and the contribution to regional food security. In contrast to Cambodia and Lao PDR, where agriculture is less established, intense rice and other crop cultivation is found in Thailand and Viet Nam. To fulfill expanding regional and worldwide demand, agriculture in the LMB is changing from traditional subsistence to modern commercial farming. For example, the net present value of the agricultural sector in the Lower Mekong Basin is expected to increase by $104 billion by 2040 (Mekong River Commission 2018a). With the increasing demand for agricultural products, agriculture – together with fishing and forestry – employs 85 per cent of people in the Lower Mekong Basin (Mekong River Commission 2018b). Women and men play different roles in agriculture; for instance, in Mekong Delta, women may be tasked with weeding, transplanting, and harvesting, while men may be tasked with land preparation, plowing, transportation, irrigation, and fertilizer and pesticide applications. However, even though both women and men are involved in agriculture, not everyone benefits from related development initiatives. For example, despite the critical role that women play in agriculture towards nutrition and sustenance at the household and community levels, women's roles are often ignored and considered not to be productive and thus the roles remain unpaid and underrepresented in literature and in assistance programmes.

Subsequently, women are then left out of initiatives that may have built their knowledge, capacities or improved their economic situation; and this inevitably results in higher levels of poverty and reduced adaptive capacities amongst women. With the understanding of these linkages, it is recommended that specific efforts are made to ensure the inclusion of women and various vulnerable groups at all levels of environmental initiatives.

## Background and context

The LMB is home to incomparable treasures, including villages with unique cultural histories and unique fauna in breathtaking natural settings. The LMB has experienced unprecedented social and economic growth, making conservation efforts particularly urgent and important. The most significant risks are the expansion of hydropower, climate change, the illegal trafficking of wildlife, and habitat degradation. The ecosystem dynamics and their impacts on local livelihoods have gained increasing attention in relation to its sustainable development requirements.

The project entitled Improving Ecosystem Management for Sustainable Livelihoods within the Framework of Lancang-Mekong Cooperation is funded by the UNEP-China Trust Fund.

Rice farming in the lower LMB.
Photo credit @Mekong River Commission

It aims to increase awareness and facilitate cooperation among countries, and across sectors, for the adoption of an integrated ecosystem management approach in the Lancang-Mekong region, with ecosystem management for sustainable livelihoods demonstrated through pilot activities at selected areas in Cambodia and China. To achieve its objective, the project has three components: (1) Assessment and knowledge generation on integrated ecosystem management in the Lancang-Mekong region; (2) Capacity development for integrated ecosystem management in the Lancang-Mekong countries; and (3) Integrated ecosystem management pilots.

This report is the output from the task of ecosystem assessment for sustainable livelihoods in the Lancang-Mekong Basin. Ecosystem changes in the LMB have been analysed in terms of land cover changes, water resource changes, and impacts – especially on ecosystem-dependent livelihoods. This report also presents an assessment of ecosystem services and biodiversity in two case studies: Phnom Kulen National Park in Cambodia and Mengla County in Xishuangbanna Dai Autonomous Prefecture in China. These are the pilot sites for the overall project to demonstrate integrated ecosystem management for ecosystem protection and restoration and improvement of livelihoods. Case studies from the upper and lower parts of the Lancang-Mekong Basin are introduced below.

## 1.1.6. Pilot site in the lower LMB: Phnom Kulen National Park (PKNP)

Phnom Kulen National Park (PKNP) is a 37,375-hectare protected area in the districts of Banteay Srey, Svay Leu, and Varin in Siem Reap province, northern Cambodia. The most populated area is the Knang Phnom Commune in Svay Leu District, which consists of nine villages (Figure 1.2). There are almost 1,000 households (approximately 5,000 people) living across PKNP. Among these, 427 households are within the five Community Protected Areas (CPAs) located inside the park, which have a total area of around 1,000 hectares. PKNP was designated a national park by Royal Decree of King Norodom Sihanouk in 1993 for its conservation, scientific, educational and recreational value.

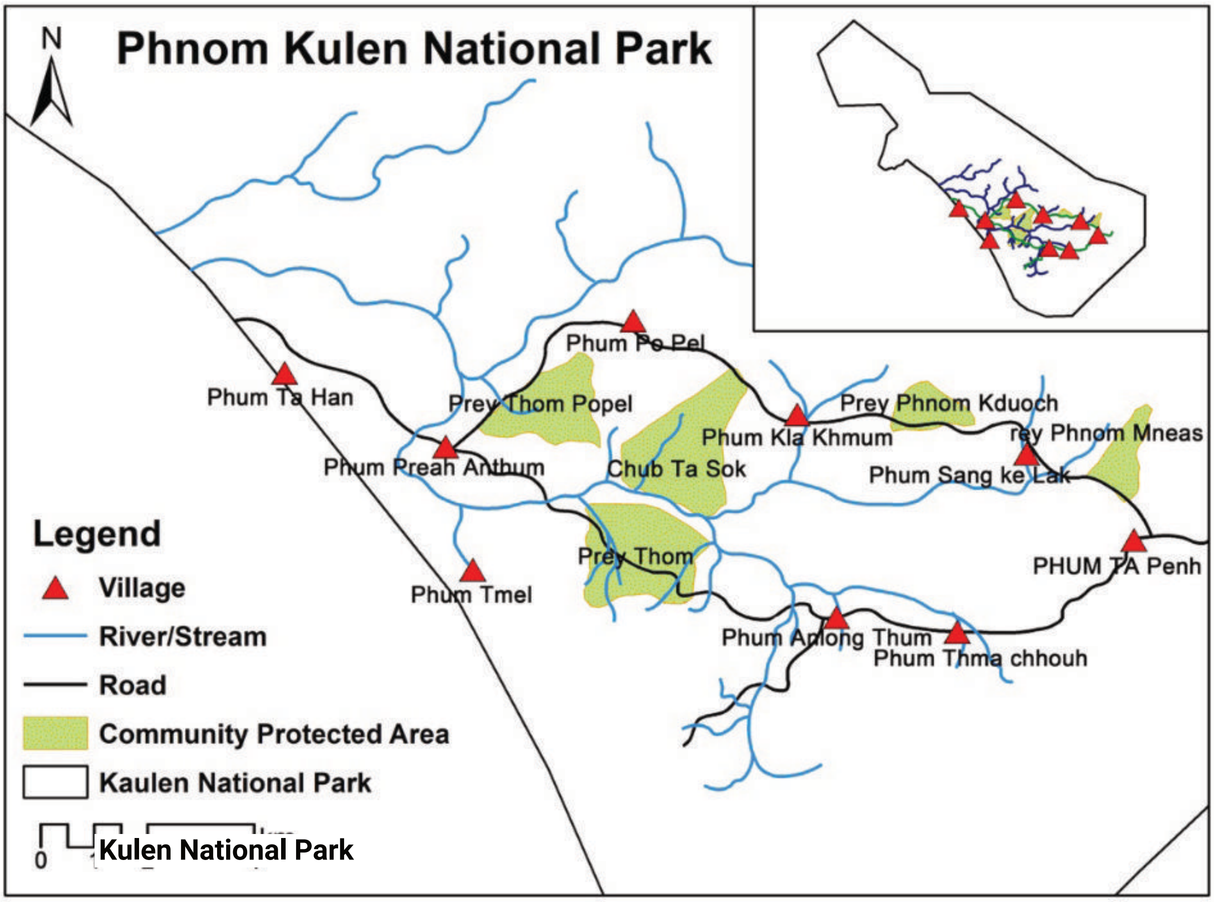



Figure 1.2 Phnom Kulen National Park, the pilot site in Cambodia

### 1.1.7. Pilot site in the upper LMB: Mengla County

Mengla County, the subject of the upper LMB case study, is a roughly 6,900 km$^2$ county in China's Yunnan Province that is bordered to the south by Lao PDR and to the southwest by Myanmar (Figure 1.3). It's mostly rocky and rough environment with heights that range from 480 meters in the south to 2,023 meters in the north (Jin and Fan 2018).

Numerous rare and endangered plant and animal species can be found in the study area. It has grown to be an essential component of the Indo-Burma biodiversity hotspot region (Myers *et al.* 2000).

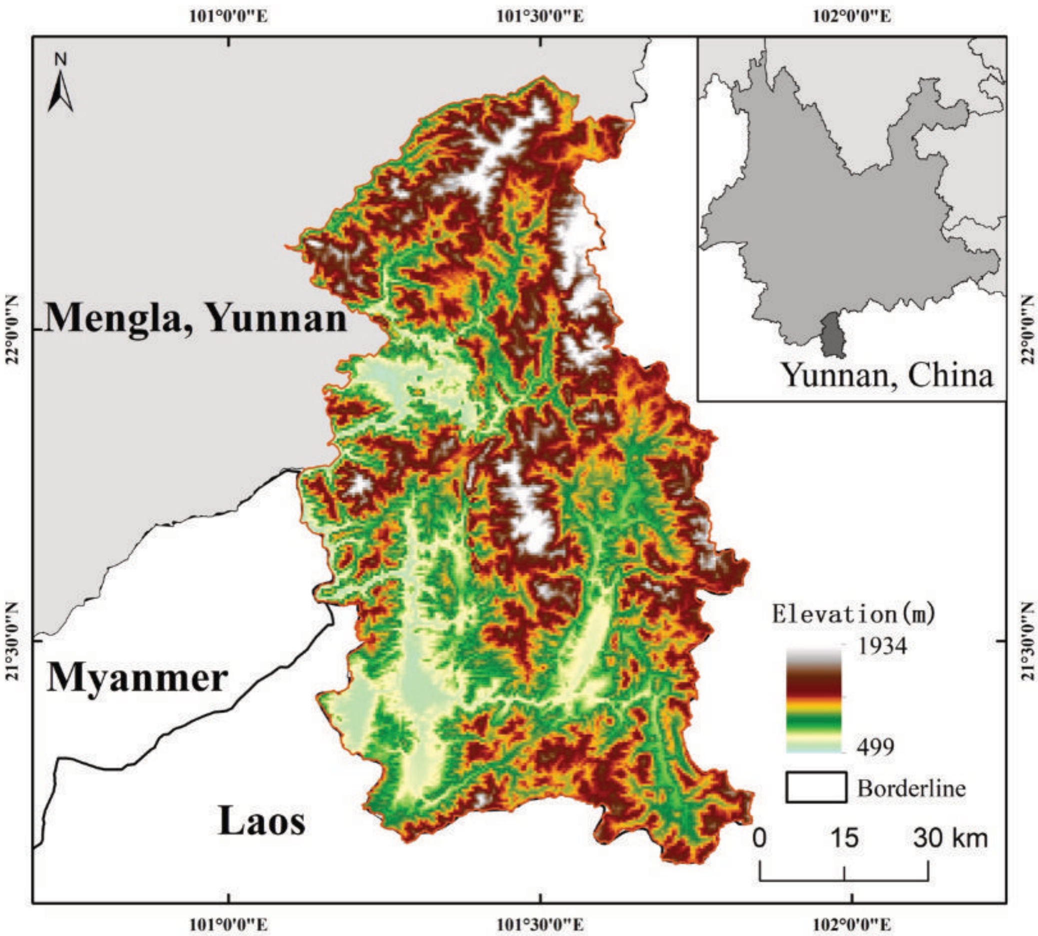



**Figure 1.3 Location of Mengla County, the pilot site in China**

# Methodological framework and data sources

## 1.1.8. Ecosystem service analysis

Ecosystem services analysis entails reducing knowledge of intricate ecological structures and processes to a manageable set of ecosystem functions and services. Despite the fact that there are several methods for categorizing ecosystem services, the research adheres to the widely used framework suggested by the Millennium Ecosystem Assessment in 2005. Based on a review of the literature, the services offered by each ecosystem were identified and allocated.

In relation to local livelihoods, the ecosystem services analysis was used to figure out the ecosystem services of highest importance in the case study area. Land cover data, field-collected data and the Ecosystem Services Valuation Database were used in this analysis. To prepare for potential data limitation, the integrated modelling tool Artificial Intelligence for Environment & Sustainability (ARIES) (https://aries.integratedmodelling.org/) was used to simulate ecosystem services in the two pilots.

ARIES is built on the ground-breaking k.LAB technology, which allows independent researchers to submit models and data, which are then housed on a network and automatically combined into model workflows.

### 1.1.9. Land cover analysis

Farmers working at Sa Dec Flower Village. Photo credit @Tran Le Tuan

The products of the European Space Agency Climate Change Initiative-Land Cover (CCI-LC) project were used to analyse land-use changes in the Lancang-Mekong River Basin (LMB) from 1992 to 2020 (the dataset can be downloaded from www.esa-landcover-cci.org/?q=node/164).

The Advanced Very High-Resolution Radiometer (AVHRR) data from 1992 to 1999, the SPOT-VGT data from 1998 to 2012, the Project for On-Board Autonomy - Vegetation (PROBA-V), and the Sentinel-3 OLCI (S3 OLCI) time series from 2013 were the initial data sources utilized to construct CCI-LC. CCI-LC has a resolution of 300 m* 300 m. It is based on the GlobCover unsupervised classification chain, which employs a machine learning method. CCI-LC employs the United Nations Land Cover Categorization System (LCCS) hierarchical classification system, which was designed by the Food and Agriculture Organization of the United Nations (FAO).

The land cover situation was analysed at least every five years: in 1992, 1995, 2000, 2005, 2010, 2015 and 2020. The proportion of several main land cover types was calculated for these years. In addition, the changes in proportions of these land cover types were analysed to demonstrate land-use changes on a 19-year timescale.

## 1.1.10. Water resources analysis

A comprehensive review was conducted to investigate changes in water resources in the Lancang-Mekong River Basin (LMB). The review mainly focused on surface and groundwater changes in both the upper Lancang River Basin and the lower Mekong River Basin, over a historical period from 1960 to 2014 and with a future projection up to 2099. The surface water reviews included absolute changes and change ratios of streamflow, at both annual and seasonal scales. Potential drivers of streamflow changes include climate change, dam construction and other human activities (e.g. irrigation).

Basin and sub-basin levels were investigated for surface water reviews. However, the regional level was the main spatial scale for groundwater reviews, due to data and model availability. Changes in groundwater extraction and groundwater levels were reviewed, with potential drivers including land-use changes, dam construction, flood pulse and groundwater recharge. Assessing how these changes impact the livelihoods of local women and men is also crucial information for formulating gender-responsive policies and strategies.

## 1.1.11. Analysis of hydroclimate and human-derived impacts in Tonle Sap Lake

Large-scale atmospheric circulation index data were also employed, notably in connection to the El Nio Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and Indian Ocean Dipole (IOD), since climate affects the hydrology of the MRB and the flood regime of Tonle Sap Lake. These have strong ties to the MRB's hydroclimate. The data for these three indices are accessible at the NOAA Earth System Research Laboratories (www.esrl.noaa.gov/psd/gcos wgsp/Timeseries). The ENSO data used (Nio 3.4) are accessible from 1870 to the present, the PDO data from 1900 to the present, and the IOD data (Dipole Mode Index) from 1870 to the present. The annual ENSO index was computed as the average monthly Nio 3.4 from December to the following February; the annual PDO index as the average monthly PDO from November to the following March; and the annual IOD index as the average monthly IOD from June to November.

Given the complexity of the Tonle Sap Lake system and the paucity of observations, it is challenging to estimate how human activity's effects on the flood pulse have changed based on the data now available. Seasonal changes in discharge at the upstream Stung Treng station, a station near the lake with a long observation time series, could reflect potential impacts on flood pulse from the hydropower development given the rapid increase in dams in the upper stream of the lake, which primarily shifts the seasonal flow regime. The following discharge data were used to measure trends in high flow and low flow:

- observed discharge at the Stung Treng station for 1960–2019, including both climatic and anthropogenic impacts;
- simulated discharge from Global Flood Awareness System (GloFAS) global streamflow reanalysis products from 1979, without information on subsequent hydropower construction and therefore representing mainly climatic influences on discharge.

CHAPTER 2

# *Land cover changes in the Lancang-Mekong Basin*

Mekong Delta of Viet Nam. Photo credit @Trang Trinh

# 2. Land cover changes in the Lancang-Mekong Basin

## Introduction

One of the world's biggest river systems, the Lancang-Mekong River (LMR) drains an area of 795,000 km$^2$ over a distance of around 4,880 km (www.lmcchina.org/eng). The Tibetan Plateau is located in the upstream part of the Lancang-Mekong Basin (LMB), which has an average height of more than 4,000 meters (Yao *et al.* 2019). It is in a near-natural state due to the little effect of human activity. The LMB provides assistance to over 230 million people and significantly contributes to the socioeconomic development of the nations through which it flows (www.lmcchina.org/eng).

With the rapid economic development in the LMB, there have been significant changes to land cover, especially in the lower LMB (Spruce *et al.* 2020). Cropland has been observed to have expanded fast in the 21st century (Zeng *et al.* 2018). Rapid urbanization in this area is leading to urban expansion, especially in populous areas (Yao *et al.* 2019). These changes are resulting in many ecological problems, such as forest loss, forest patching and changes to the water cycle. Analysis of land cover changes in the LMB over the past few decades can clarify the current land cover situation and demonstrate the influence of human activities, such as the rapid economic development of South-East Asian countries and the expansion of urban areas and cropland.

## 2.1. Data processing

In this study, the data produced by the European Space Agency Climate Change Initiative – Land Cover (CCI-LC) project were used to analyse land cover changes in the Lancang-Mekong Basin. CCI-LC was developed using three satellite data types: AVHRR data from 1992 to 1999, Système Probatoire d'Observation de la Terre - Vegetation (SPOT-VGT) data from 1999 to 2012, and Project for On-Board Autonomy - Vegetation (PROBA-V) data from 2013 to present.

The LCCS, which is entirely compatible with the Plant Functional Types used in many models, includes 36 land cover types. In this assessment, the land cover types were reclassified into cropland, tree cover, shrubland, grassland, sparse vegetation, bare, urban, water and snow/ice to describe the land cover changes more clearly (Table 2.1).

**Table 2.1 Reclassification scheme for CCI-LC data**

| CCI-LC legend value | Label | Reclassified land cover type |
|---|---|---|
| 0 | No Data | No Data |
| 10 | Cropland, rainfed | Cropland |
| 11 | Herbaceous cover | Cropland |
| 12 | Tree or shrub cover | Cropland |
| 20 | Cropland, irrigated or post-flooding | Cropland |
| 30 | Mosaic cropland (>50 per cent) / natural vegetation (tree, shrub, herbaceous cover) (<50 per cent) | Cropland |
| 40 | Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50 per cent) / cropland (<50 per cent) | Tree cover |
| 50 | Tree cover, broadleaved, evergreen, closed to open (>15 per cent) | Tree cover |
| 60 | Tree cover, broadleaved, deciduous, closed to open (>15 per cent) | Tree cover |
| 61 | Tree cover, broadleaved, deciduous, closed (>40 per cent) | Tree cover |
| 62 | Tree cover, broadleaved, deciduous, open (15-40 per cent) | Tree cover |
| 70 | Tree cover, needle-leaved, evergreen, closed to open (>15 per cent) | Tree cover |
| 71 | Tree cover, needle-leaved, evergreen, closed (>40 per cent) | Tree cover |
| 72 | Tree cover, needle-leaved, evergreen, open (15-40 per cent) | Tree cover |
| 80 | Tree cover, needle-leaved, deciduous, closed to open (>15 per cent) | Tree cover |
| 81 | Tree cover, needle-leaved, deciduous, closed (>40 per cent) | Tree cover |
| 82 | Tree cover, needle-leaved, deciduous, open (15-40 per cent) | Tree cover |
| 90 | Tree cover, mixed leaf type (broadleaved and needle-leaved) | Tree cover |

(Table continues on the next page)

(Continuation of table from previous page)

| CCI-LC legend value | Label | Reclassified land cover type |
|---|---|---|
| 100 | Mosaic tree and shrub (>50 per cent) / herbaceous cover (<50 per cent) | Tree cover |
| 110 | Mosaic herbaceous cover (>50 per cent) / tree and shrub (<50 per cent) | Shrubland |
| 120 | Shrubland | Shrubland |
| 121 | Evergreen shrubland | Shrubland |
| 122 | Deciduous shrubland | Shrubland |
| 130 | Grassland | Grassland |
| 140 | Lichens and mosses | Lichens and mosses |
| 150 | Sparse vegetation (tree, shrub, herbaceous cover) (<15 per cent) | Sparse vegetation |
| 152 | Sparse shrub (<15 per cent) | Sparse vegetation |
| 153 | Sparse herbaceous cover (<15 per cent) | Sparse vegetation |
| 160 | Tree cover, flooded, fresh, or brackish water | Tree cover |
| 170 | Tree cover, flooded, saline water | Tree cover |
| 180 | Shrub or herbaceous cover, flooded, fresh/saline/brackish water | Shrubland |
| 190 | Urban areas | Urban |
| 200 | Bare areas | Bare |
| 201 | Consolidated bare areas | Bare |
| 202 | Unconsolidated bare areas | Bare |
| 210 | Water bodies | Water |
| 220 | Permanent snow and ice | Snow/Ice |

## 2.2. Land cover change in the Lancang-Mekong Basin

There were significant changes to land cover in the LMB from 1992 to 2020. Tree cover area indicated an increasing trend before 2000 and a decreasing trend in the 21st century. Tree cover area has decreased by 2,668.32 km$^2$ in the past 20 years (Figure 2.1). Cropland area showed an overall increasing trend over the study period but decreased slightly after 2013; overall, cropland area increased by 18,478.53 km$^2$ between 1992 and 2020.

South-East Asia, including the LMB, is a hotspot for tropical tree cover loss due to agricultural expansion. Zeng *et al.* (2018) estimated that 82,000 km$^2$ of forest or other land covers had been developed into cropland in the South-East Asian highlands. From 1992 to 2020, shrubland areas decreased by 17,036.19 km$^2$, while urban areas increased by a factor of 4.54, from 498.96 km$^2$ to 2,262.87 km$^2$

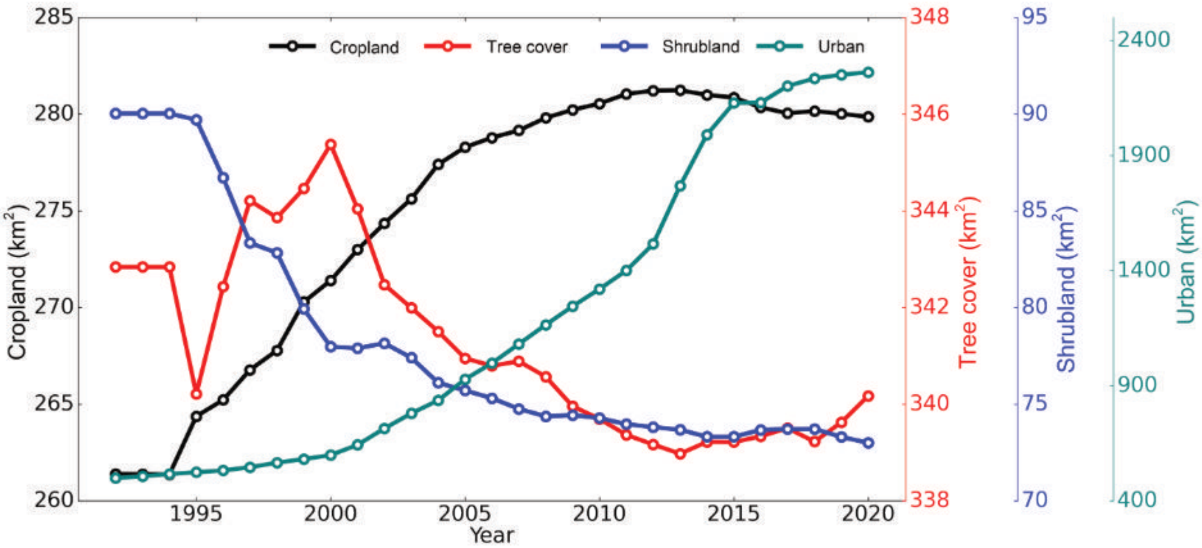



**Figure 2.1 Changes in area of key land cover types identified in LMB, 1992 to 2020**

Cropland expansion mainly occurred in the middle and downstream portions of the LMB. Thailand and Cambodia experienced significant cropland expansion, resulting in loss of tree cover or shrubland in both countries. Around Tonle Sap Lake, there is noticeable cropland expansion at the expense of tree cover and shrubland. Grassland is the dominant land cover type in the upstream portion of the LMB, while tree cover and shrubland account for small areas.

Due to the high elevation and complex terrain, there is little direct impact from human activities in this region. There have been few changes to grassland and other land cover types over the past 20 years (Figure 2.2). There was significant increase and expansion in urban areas in Thailand, Cambodia and the Lancang-Mekong Delta.

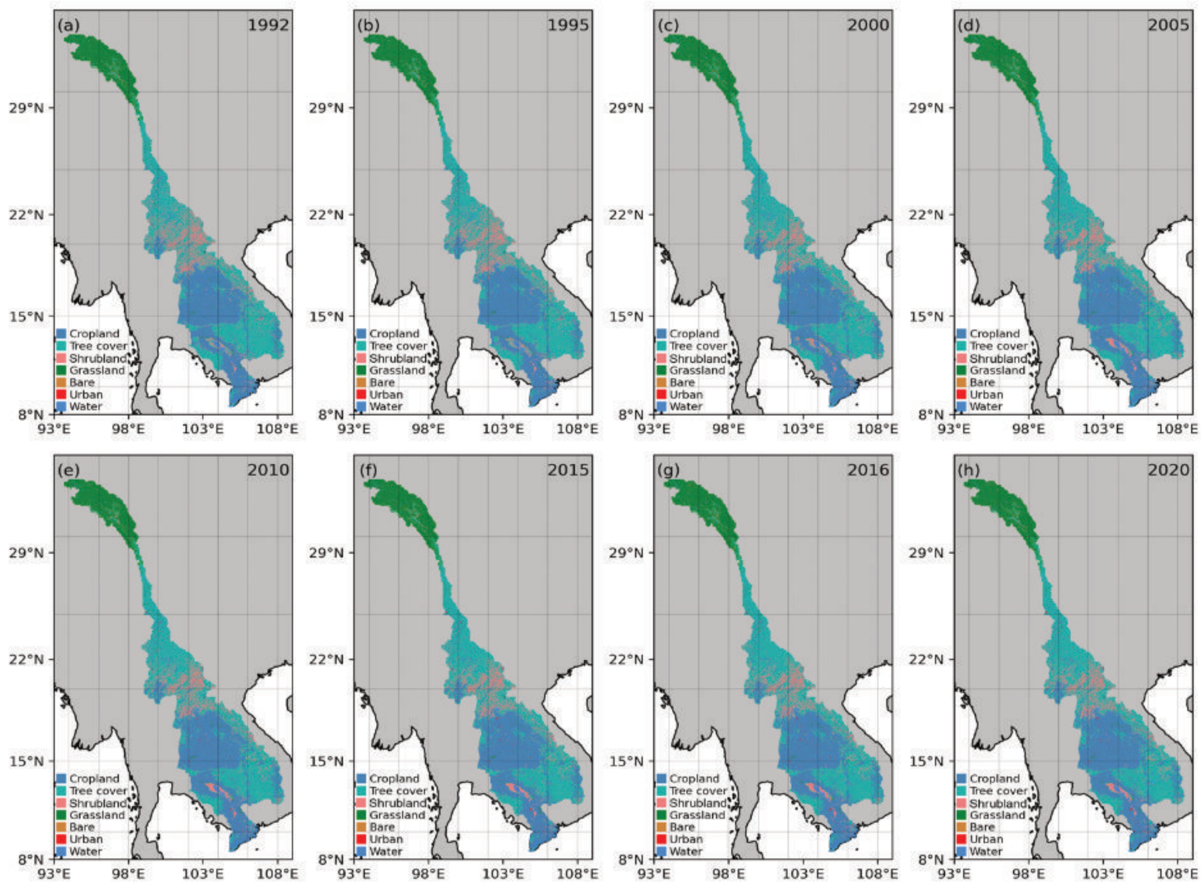



**Figure 2.2 Land cover changes in the LMB in different years**

## 2.3. Land cover change in Mengla County

Mengla County (area 7,056 km$^2$) is in the east of the Xishuangbanna Dai Autonomous Prefecture, located in the south of Yunnan Province. It borders Lao PDR to the east and south and Myanmar to the west. Due to the small area of Mengla County, not all land cover types in the revised CCI-LC land cover classification were included. Therefore, this assessment only analysed changes to areas of cropland, tree cover and shrubland, which account for more than 90 per cent of the total area.

Cropland and tree cover area indicated a rapidly increasing trend in 1992-2000, and tree cover area has still displayed an increasing trend in the 21st century (Figure 2.3). Cropland area continued to show an increasing trend from 2000 to 2009 but decreased from 2010 to 2020. This may be a result of China's policy of returning farmland to forest. The area of shrubland indicated a decreasing trend over the study period.

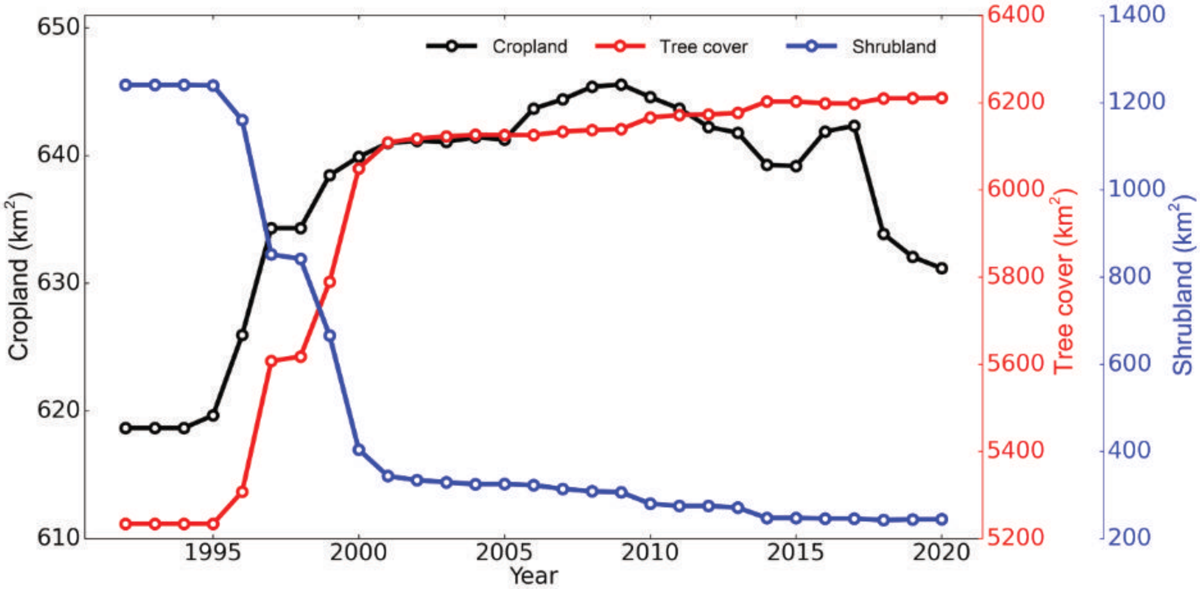



**Figure 2.3 Changes in area of key land cover types identified in Mengla County, 1992 to 2020**

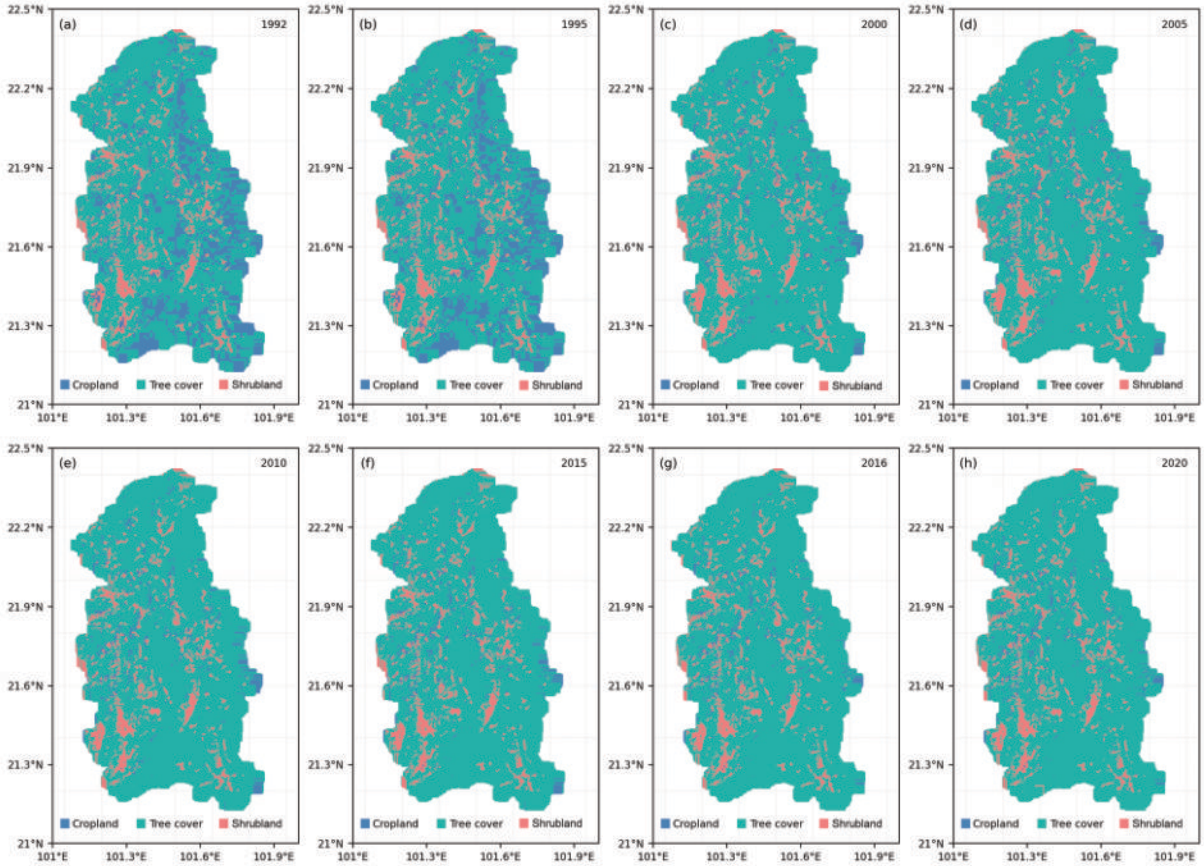



**Figure 2.4 Land cover changes in Mengla County in different years**

## 2.4. Land cover change in Phnom Kulen National Park

Phnom Kulen National Park was established in 1993 and covers an area of 373.76 km$^2$. The area of tree cover – the primary land cover type – decreased from 318.06 km$^2$ to 214.2 km$^2$ between 1992 and 2020 (Figure 2.5). Tree cover area experienced a rapid decrease from 1992 to 2004, then remained stable from 2005 to 2017.

Cropland area showed an increasing trend from 1992 to 2004 and a steady state from 2005 to 2015. The area of shrubland displayed a similar trend to cropland, but it showed an increasing trend from 2015 to 2020 while cropland showed a decreasing trend.

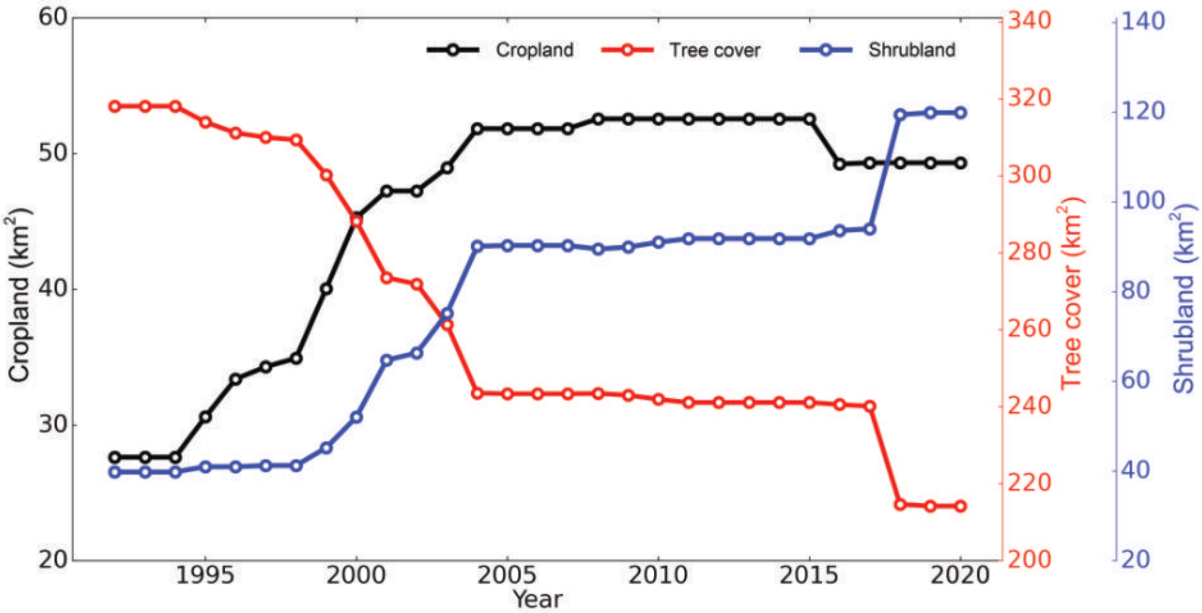



**Figure 2.5 Changes in area of key land cover types identified in PKNP, 1992 to 2020**

In Phnom Kulen National Park, cropland expansion was apparent in the middle and eastern parts (Figure 2.6). Cropland expansion mainly occurred at the expense of tree cover, partly at the expense of shrubland. As a result, forest fragmentation was increasing. There was also an expansion in shrubland in the western part of Phnom Kulen National Park.

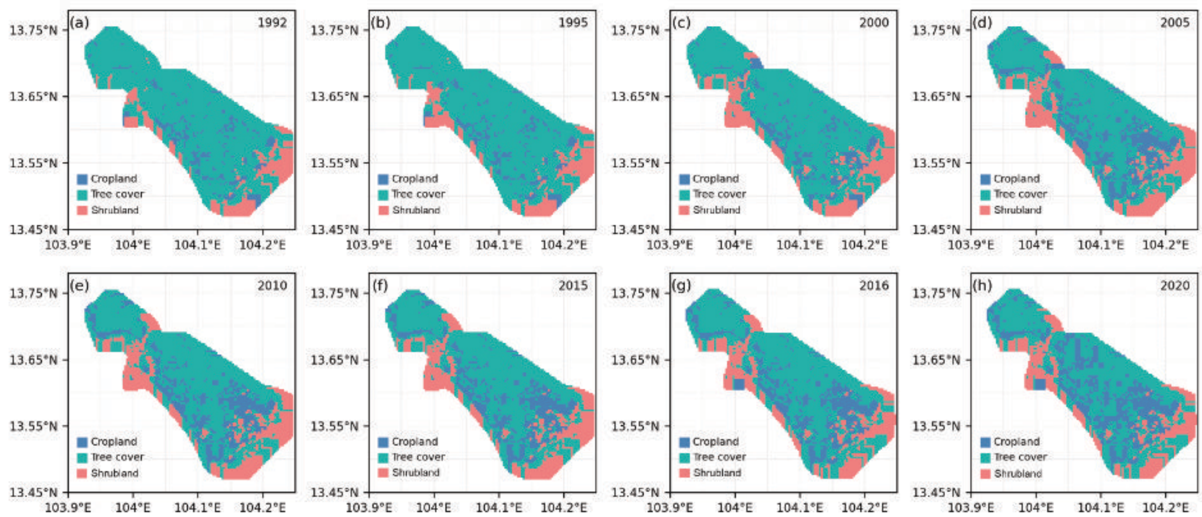
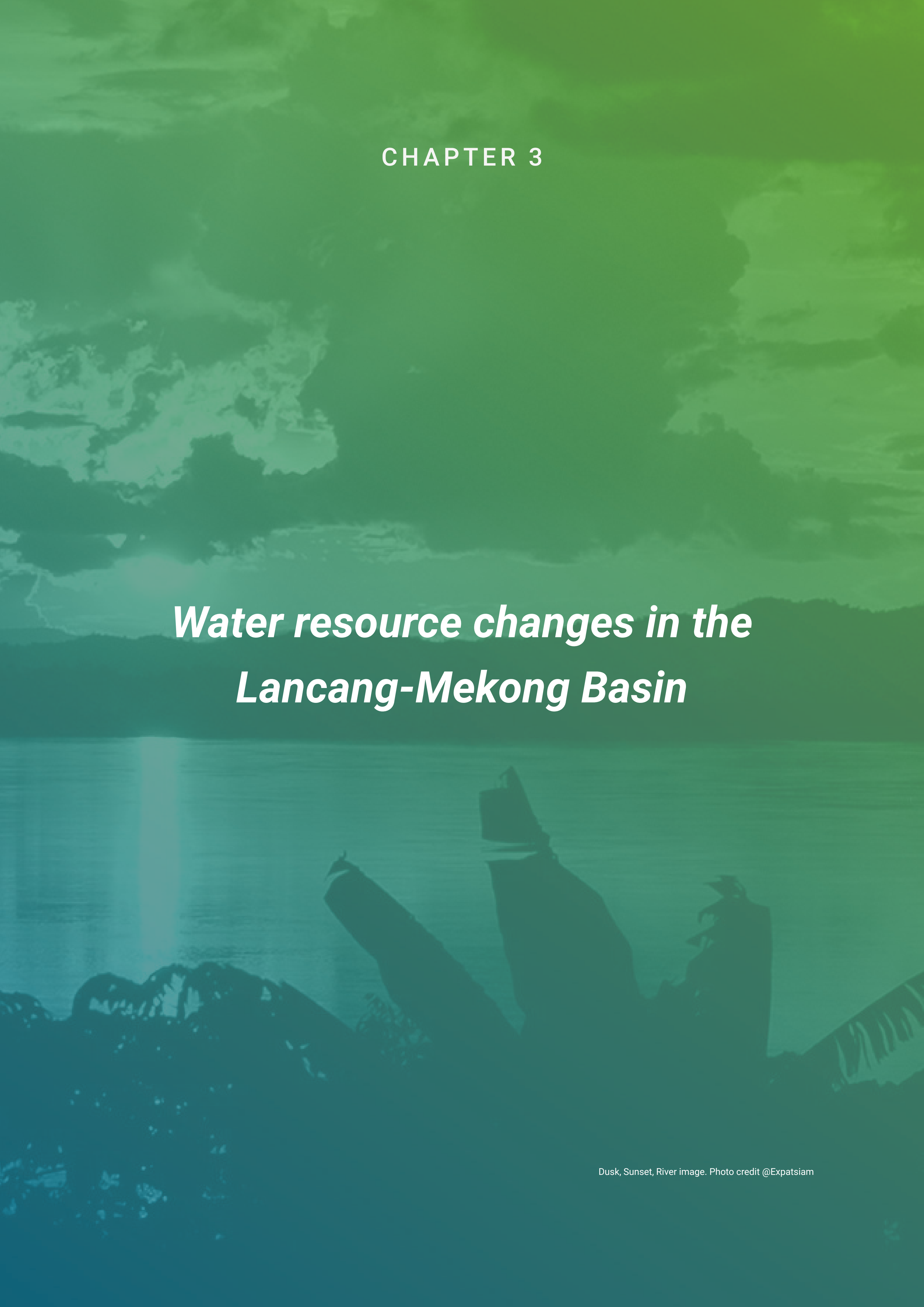



**Figure 2.6 Land cover changes in PKNP in different years**

Mekong river. Photo credit @dariasophia

CHAPTER 3

# *Water resource changes in the Lancang-Mekong Basin*



Dusk, Sunset, River image. Photo credit @Expatsiam

# 3. Water resource changes in the Lancang-Mekong Basin

## Introduction

The area of the Lancang-Mekong Basin (LMB) is shared between China (21 per cent), Myanmar (3 per cent), Lao PDR (25 per cent), Thailand (23 per cent), Cambodia (20 per cent) and Viet Nam (8 per cent). The river originates in the Tibetan Plateau, flows through China's Qinghai Province, Tibet Autonomous Region, and Yunnan Province (known as the Lancang River Basin (LRB)), and then continues into the lower section of the basin, also known as the Mekong River Basin (MRB), at the boundary between Myanmar and Lao PDR. The river flows through Lao PDR before establishing the border between Lao PDR and Thailand in the MRB and then reentering Lao PDR. The river travels through Cambodia and Viet Nam as a complicated delta system before emptying into the South China Sea (Mekong River Commission 2005).

Large-scale agricultural expansion and hydropower development across the LMB are primarily to blame for the dramatic land cover changes and changes to hydrological and ecological systems that have resulted from the rapid economic development and rising demand for food and energy in riparian countries (Johnston and Kummu 2012). Many studies have found that climate change and human activities have significantly affected streamflow in the Lancang-Mekong River's main stem and tributaries, resulting in more frequent severe events and longer dry seasons (Thilakarathne and Sridhar 2017). Changes in the LMB's hydrologic regime, for example, have resulted in the degradation of natural resources in the region, such as fish, water, and land, on which millions of people in MRB nations rely (Chea, Grenouillet and Lek 2016).

## 3.1. Surface water changes in the LMB

The literature identifies changes to surface water in the LMB; the key studies are listed in Table 3.1. A general downward trend in annual streamflow was observed in the LMB from 1960 to 2010. However, no clear trend was detected after 2010 (Ruiz-Barradas and Nigam 2018). Due to the different data and methodologies used in each study, most studies indicated a declining trend in historical streamflow in the LMB, whereas a few studies found the contrary - a rising trend in streamflow.

The combined effects of climate change and human activity are to blame for the variations in streamflow. Over various areas and eras, different relevant elements contribute differently. Before 2010, streamflow changes in the LMB were mostly caused by climate change (relatively low precipitation and high evaporation), but human actions, particularly dam construction, were primarily responsible for the downward trend that followed. This finding has been confirmed by observational (Li *et al.* 2017) and modelling studies (Shin *et al.* 2020).

While human activities contributed 61.9 per cent of the changes to streamflow in the post-impact era of 2010-2014, climate change controlled the changes to annual streamflow during the transition period of 1992-2009, accounting for 82.3 per cent of the changes (Li *et al.* 2017). Regarding annual streamflow and water-level variations, the LRB's hydrological response is regarded to be more responsive to climatic factors than to human activities when compared to the MRB (Li and He 2008). This discrepancy also reveals the growing effects of heavy human activity on local hydrological systems, particularly in the MRB in recent years (Shin *et al.* 2020).

**Table 3.1 Overview of literature on changes to streamflow over the LMB and its upper (LRB) and lower (MRB) parts (adapted from Liu *et al.* 2022)**

| Reference | Region | Data | | Period | Annual Streamflow | Seasonal Streamflow | |
|---|---|---|---|---|---|---|---|
| | | Variable/ Model (Source) | Observation | | | Dry Season | Wet Season |
| He and Chen 2002 | LRB | Discharge (MRC) | Yes | 1962-2000 | Base flow is increased | Substantial increase in flow | Discharges are reduced by 25 per cent |
| Kummu and Varis 2007 | LRB | Water level & discharge (MRC) | Yes | 1962-2000 | Mean flow is increased in the post-dam period (1993-2000) compared to pre-dam period (1962-1992). | N/A | N/A |
| Lu *et al.* 2008 | MRB | Water level & discharge (MRC) | Yes | 1962-2003 | Both water level and baseflow are decreased | Minima flow increased | N/A |
| Kummu and Sarkkula 2008 | MRB | Water level & discharge (MRC) | Yes | 1923–1965<br>1997–2006 | Water level is decreased | Water level is increased | Flood peaks are reduced |
| Delgado *et al.* 2010 | LMB | Discharge (Southern Institute of Water Resources | Yes | 1913-2007 | Flood magnitude is decreasing but variability is increasing | N/A | Flood magnitude is decreasing but variability is increasing |
| Piman *et al.* 2012 | LMB | SWAT simulation | No | 1987-2006 | N/A | 63 per cent increase in dry season flows | 20–22 per cent decrease in June–November flow |
| Räsänen *et al.* 2012 | LMB | VMod simulation | No | 1990-2008 | Not clearly determined | 90 per cent increase in December–May flows | 20–22 per cent decrease in June–November flow |

(Table continues on the next page)

(Continuation of table from previous page)

| Reference | Region | Data | | Period | Annual Streamflow | Seasonal Streamflow | |
|---|---|---|---|---|---|---|---|
| | | Variable/ Model (Source) | Observation | | | Dry Season | Wet Season |
| Cochrane *et al.* 2014 | LMB | Discharge (MRC) | Yes | 1960-2010 | Water levels are slowly decreasing in downstream MRB | Mean water levels are increased by 30 per cent | Mean water levels are increased by less than 5 per cent |
| Räsänen *et al.* 2017 | LMB | Discharge (MRC) and VMod simulation | Yes | 1960-2014 | N/A | Increased by 121-187 per cent in LRB and increased by 4174 per cent in MRB | Increased by 32-46 per cent in LMR and increased by 06 per cent in MRB |
| Li *et al.* 2017 | LMB | Discharge (MRC) | Yes | 1960-2014 | Streamflow is increased in the LRB, but no clear trend is found in the MRB, resulting a no significant change in the LMB (less than 3 per cent) | Increased by 23-55 per cent in LRB and by 9-69 per cent in MRB | Decreased by 10-32 per cent in LMR and decreased by 0-13 per cent in MRB |
| Hoang *et al.* 2018 | LMB | VMod simulation forced by CMIP5 (RCP4.5 & RCP8.5) | No | 2036-2065 | No clear trend is determined | Sharply increased by 45-150 per cent | Decreased by 0-25 per cent |
| Kingston *et al.* 2011 | LMB | SLURP model simulation | No | 2° C war-ming across seven GCMs | Mean monthly river discharge changes from -16 per cent to +55 per cent | Greatest increases in May and June | Greatest decreases are found in July and August |
| Eastham *et al.* 2008 | LMB | Hydrological simulation based on 11 GCMS | No | 1951-2030 | Increased by 21 per cent with a range from -8 per cent to 90 per cent | N/A | N/A |
| Västilä *et al.* 2010 | LMB | VIC simulation | No | 1995-2004<br>2010–2049 | Only a 4 per cent increase in annual streamflow | Decreased | Increased by 5 per cent |

The LRB and MRB differ in the change ratio of streamflow given the natural controls on these two areas' hydrological systems by various climate factors (Pokhrel *et al.* 2018a). Snowmelt and precipitation have a greater impact on the flow regime in the LRB than they do in the MRB, which is dominated by heavy monsoon season rainfall (Delgado, Apel and Merz 2010). Climate change, mainly in the form of precipitation, has increased streamflow in the LRB. In addition, the majority of the MRB showed a somewhat declining trend between 1960 and 2014 as a result of the combined effects of climate change and human activity (Li *et al.* 2017). Between 1961 and 2001, the magnitude and frequency of flood occurrences were found to have grown in the LRB, and this trend is anticipated to continue from 2011 through 2095 (Tang *et al.* 2015). However, dams in the LRB might potentially minimize this tendency in climate-change-induced flood events (Wang *et al.* 2020).

The main stream of the Lancang-Mekong River has an intrinsically seasonal cycle due to clear and regular dry-to-wet transitions. As a result, streamflow seasonality diminished with the installation of dams in the main stem of the river (Pokhrel *et al.* 2018b). Reservoirs alter flow regimes by water storage during wet seasons and releasing it during dry seasons. (Pokhrel *et al.* 2012). Prior to the construction of dams, streamflow amplitude has often increased, but maximum flows have generally trended downward after dam construction (Li *et al.* 2017; Hoang *et al.* 2019). Dam operation in the watershed attenuates flow seasonality by increasing flow during dry seasons while decreasing it during rainy seasons (Hoang *et al.* 2019; Shin *et al.* 2020). According to a research based on discharge measurements made at the Chiang Saen station between 1985 and 2010, the Lancang River's cascade of dams boosted discharge in the dry season by an average of 34.155 per cent and decreased discharge in the wet season by 29-36 per cent (Räsänen *et al.* 2012). Between 1986 and 2005, flow in one of the LMB's major tributaries, the Srepok, Sesan, and Sekong ("3S") basin, which contributes the most to the Mekong River's discharge, grew by 63-88 per cent in the dry season and fell by 22-24.7 per cent in the rainy season as a result of dam building (Piman, Cochrane and Arias 2016; Trang *et al.* 2017). In comparison to the baseline period of 2000–2005, the annual flow from the 3S basin is predicted to rise by 10.7 per cent by the 2030s, 14.8 per cent by the 2060s, and 13.9 per cent by the 2090s under Representative Concentration Pathway 4.5 (RCP4.5) (Trang *et al.* 2017).

Despite the fact that streamflow seasonality has decreased, it has been discovered that streamflow variability has increased in the dry season along the river due to the combined impacts of various reservoir operating plans and changes in land cover in the LMB (Mohammed *et al.* 2018; Hecht *et al.* 2019). As a result, the basin's flood amplitude, duration, and maximum water level have all decreased (Delgado, Apel and Merz 2010; Li *et al.* 2017; Pokhrel *et al.* 2018b). This has caused a significant delay to the start, peak and end of the seasonal flood pulse (Räsänen *et al.* 2012; Pokhrel *et al.* 2018b). These modifications to flood dynamics are anticipated to be accentuated if several of the big dams proposed are built in the main stem of the Mekong River.

Specifically, the Tonlé Sap Lake and Mekong Delta systems' flood dynamics will be impacted by this (Pokhrel *et al.* 2018b). Such changes in flood pulse can help to prevent flood disasters, but also impact aquatic biodiversity as well as flood-based agriculture (Campbell 2012). For instance, the river's hydrological shift may obstruct fish migratory routes, and the sediment load moving downstream may cause erosion at the delta's seaward border, reducing the amount of arable land (Campbell 2012). Alongside changes to the flow regime caused by dam construction, extreme floods and low flows were more likely between 1924 and 2000 due to large-scale atmospheric processes such as radiation, convection, and aerosol movement (Pokhrel *et al.* 2018a).

Aside from climate change and dam construction, other human endeavors like farmland expansion and irrigation have changed the LMB's water resources. Studies have shown that, although these activities have caused only small average changes to streamflow at basin scale, they have caused significant changes over highly irrigated areas – mainly in the downstream region of the MRB (Pokhrel *et al.* 2012). About 62 $km^3$ of water, or 13 per cent of the normal annual discharge, was reported as the total water withdrawn from the whole LMB. Viet Nam makes up over 52 per cent of this withdrawal, followed by Thailand at 29 per cent, China at 9 per cent, Lao PDR at 5 per cent, Cambodia at 3 per cent, and Myanmar at 2 per cent (Frenken 2012). Surface water withdrawal typically makes up 97 per cent of the total amount of water withdrawn from the basin, while groundwater extraction makes up 3 per cent (Freniken 2012). Agriculture uses 80–90 per cent of the water withdrawn in the MRB, however this sector's yearly water demand for agriculture is still less than 4 per cent of the region's total annual streamflow (Nesbitt, Johnston and Solieng 2004).

Studies predict an increasing tendency for streamflow in the LMB despite diversity in climatic factors and models. However, the flow regime is extremely vulnerable to a number of causes, including the building of dams, the growth of irrigation, changes in land use, and climate change. Significant adjustments to the yearly and seasonal flow are anticipated, coupled with an overall upward tendency (Hecht *et al.* 2019; Hoang *et al.* 2019). Even though it has a negligible impact on overall yearly flows, the growth of hydropower has the largest seasonal impact on streamflow, outweighing the other factors with a rise in the dry season and a decrease in the rainy season (Hoang *et al.* 2019). Irrigation development would result in a marginal 3 per cent reduction in annual streamflow for the whole period of 2036–2065 compared to the period of 1971–2000, whereas climate change may result in a 15 per cent increase. The World Climate Research Programme Coupled Model Intercomparison Project, Phase 5 data that were statistically downscaled for this research (CMIP5). VMod, a distributed hydrological model with a spatial resolution of 0.5 degrees (about 50 km at the equator), was employed (Hoang *et al.* 2019).

The dry season's change ratio (+70 per cent) is greater than the rainy season's (–15 per cent). According to projections, streamflow in the 3S tributary will rise by 96 per cent in the dry season and fall by 25 per cent in the wet, indicating that the 3S system is more sensitive to climate change and human activity than the whole LMB (Shrestha *et al.* 2016).

The streamflow change situations differ regionally, particularly in the MRB (Dang, Cochrane and Arias 2018). Although streamflow is anticipated to increase in the LMB in the future, there are still significant uncertainties in these predictions. Studies based on 11 general circulation models (GCMs) predict that by the 2030s, yearly runoff would rise by 21 per cent (range from -8 per cent to 90 per cent) compared to the previous period (1951-2000) (Eastham *et al.* 2008). By the 2040s, Västilä *et al.* (2010) only anticipated a 4 per cent rise in yearly flow in the LMB. With a geographical resolution of 25 km, these scientists drove a distributed hydrological model called Variable Infiltration Capacity (VIC) using dynamically downscaled data from the ECHAM4 climate model. Other studies have shown very minor increases in mean annual flow in the LMB, ranging from 3 per cent to 10 per cent, based on CMIP5 datasets for the near future (2036-2065) (Västilä *et al.* 2010; Hoang *et al.* 2019).

Extremely high flow occurrences are expected to grow in size and frequency. In contrast, studies that just consider the effects of climate change predict that low flow occurrences will happen less frequently (Hoang *et al.* 2019). Flood dangers in the LMB might increase when severe high flow occurrences occur more frequently. Over the next 20 to 30 years, it is anticipated that the vast hydropower development (both current and prospective) that is causing discharge variations would have a greater impact on hydrography than climate change (Lauri *et al.* 2012). Furthermore, there may be different patterns of water changes in different sub-basins of the LMB. By the end of the 21st century (2080-2099), it is also anticipated that there will be more rainy days, which might raise the danger of flooding but decrease the chance of droughts and low flow times (Kiem *et al.* 2008). The expected change ratio is location dependent. For instance, Hoang *et al.* (2019) demonstrated that the annual streamflow change in sub-basins between 2036 and 2065 varied from +5 per cent to +16 per cent (depending on location), relative to the baseline of 1971-2000. Figure 3.1 depicts a thorough assessment of current and upcoming streamflow changes.

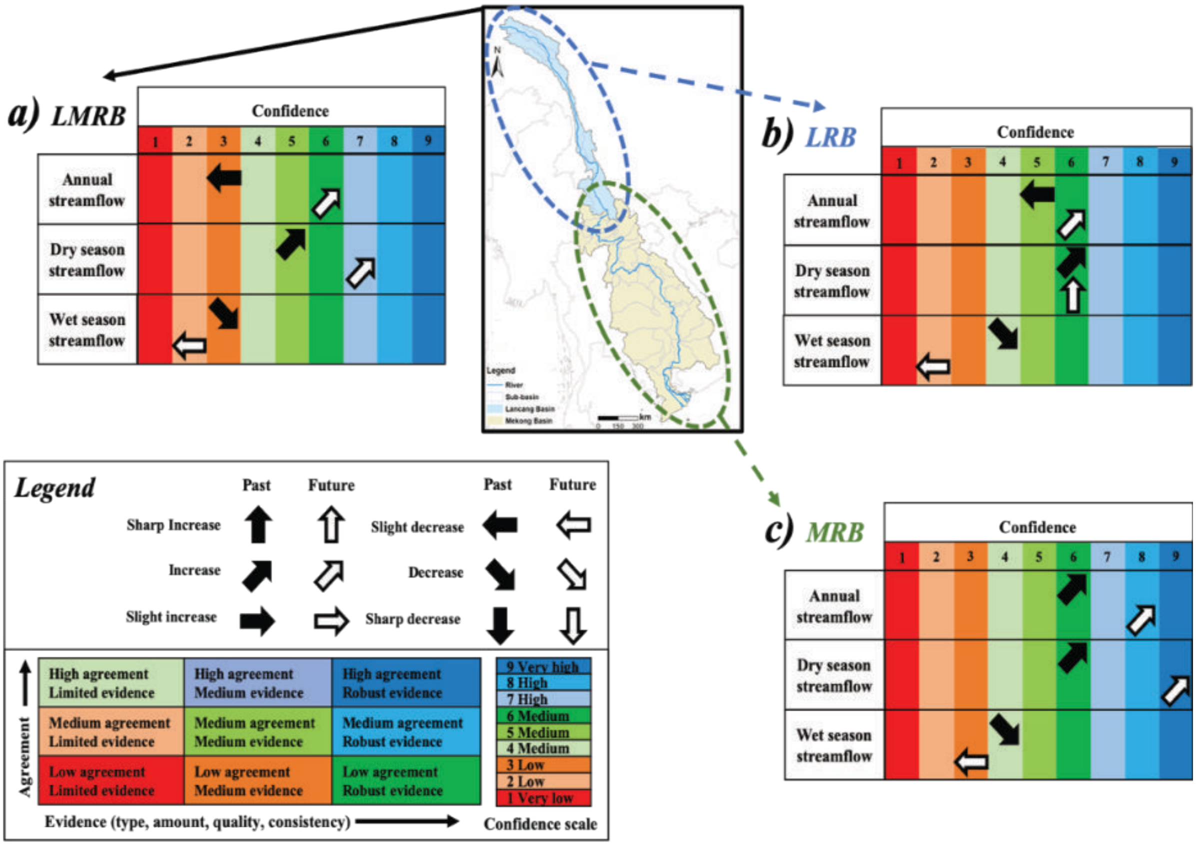



**Figure 3.1 Changes in streamflow over (a) the LMB, (b) the LRB, and (c) the MRB, based on publications in Table 3.1 (Liu *et al.* 2022)**

## 3.2. Groundwater changes in the LMB

In the LMB, groundwater is a vital source of water (Pokhrel *et al.* 2018b). More than 4.5 million people who depend on groundwater for their residential and agricultural activities in the Mekong Delta are connected to the farming system, wetland ecology, and their livelihoods (Pokhrel *et al.* 2016). Additionally, it is essential for avoiding saltwater intrusion (International Union for Conservation of Nature 2011). There has not previously been sufficient investigation into groundwater in the LMB. References in the literature related to volume, use and quality of groundwater resources are restricted because little information is available on several local areas of the MRB (Eastham *et al.* 2008).

The Mekong Delta stretches from central Cambodia to Viet Nam's East Sea, covering 50,000 $km^2$ of fertile alluvial plain (International Union for Conservation of Nature 2011). In the delta region, over a million wells have been constructed to draw groundwater for agricultural, household, and industrial purposes. The number of wells in the delta area has expanded considerably from a small number prior to the 1960s (Erban *et al.* 2013). According to the International Groundwater Resources Assessment Center's (IGRAC) inventory, roughly 0.55 $km^3$ of groundwater was drawn from the LMB (mostly from the MRB) in 2000 (Wada *et al.* 2010). This figure, however, has been proven to be much lower than that stated in country-specific statistics (Ha *et al.* 2015). This discrepancy may be caused by the fact that the IGRAC's global database does not account for the groundwater consumed by specific houses within the basin (Pokhrel *et al.* 2018b).

The LMB's groundwater system is largely influenced by changing hydrological systems and intensive human activities that alter groundwater balance in terms of recharge and withdrawal (White 2002). According to monitoring data collected over 30 years in the Mekong Delta, the area's groundwater level has significantly decreased (International Union for Conservation of Nature 2011). Particularly, since 1995, the groundwater level in Ca Mau Province, Viet Nam, has decreased by as much as 10 m (International Union for Conservation of Nature 2011). In Viet Nam, groundwater levels have likewise been steadily dropping at a pace of around 0.3 m per year (based on data from nested monitoring wells), which results in an average annual rate of land subsidence of about 1.6 cm (Erban *et al.* 2013).

Increased water demand and decreased water availability are the main causes of these declining trends in groundwater levels (International Union for Conservation of Nature 2011). The region's availability of clean water has decreased as a result of rising population levels and increasing agricultural, which has led to increased groundwater extraction (International Union for Conservation of Nature 2011). Reduced groundwater recharge is mostly the result of changes in land use, such as the clearing of forests and the expansion of farming (White 2002). Due to the artificially managed, relatively high water level that dams maintain throughout the dry season, several studies have shown that dams may have a favorable influence on the groundwater system (Pokhrel *et al*. 2018b). The dynamics of terrestrial water storage, as a result of water impoundment behind dams, can generally have an influence on groundwater systems. They can reduce saline intrusion (Pokhrel *et al*. 2012) by further off-setting sea-level rise (Felfelani *et al*. 2017).

Furthermore, comparatively high groundwater levels as a result of greater dry season water levels caused by dams may assist irrigation systems by lowering energy costs (Pokhrel *et al*. 2018b). In addition to multiple factors impacting quantity, the quality of groundwater in the region is being affected by sea-level-rise induced saltwater intrusion, agrochemical use and inherent arsenic pollution (Erban *et al*. 2013; Erban, Gorelick and Zebner 2014; Minderhoud *et al*. 2017). Groundwater overuse has also been observed to worsen the effects of arsenic pollution in the Mekong Delta (Fendorf, Michael and van Geen 2010). Climate change may exacerbate this by increasing water demand, particularly during the dry seasons (Eastham *et al*. 2008; Podgorski and Berg 2020; Zheng 2020).

Changes in downstream flood pulses and groundwater recharge patterns caused by climate change are also likely to have an influence on the LMB groundwater system in the future (Smajgl *et al*. 2015). However, as with observed alterations to groundwater, information is limited on projected groundwater in the LMB. Shrestha, Bach and Pandey (2016) investigated the Mekong Delta and investigated groundwater change under several RCP scenarios. Their findings indicate that groundwater recharge would decline by 3 mm per year under RCP8.5 and 1.5 mm per year under RCP4.5 from 2010 until the end of the 21st century. The entire fall in groundwater level is expected to be 1.5 m to 41 m by the end of the 21st century (depending on location). This reduction may have an impact on groundwater storage in this region (Shrestha, Bach and Pandey 2016). However, a recent worldwide modeling research found that groundwater recharge will rise under various future warming scenarios, particularly in sections of the MRB (Reinecke *et al*. 2021).

Due to the fast socioeconomic growth and the decline of surface water supplies brought on by anthropogenic activities and climate change, the demand for groundwater has significantly grown in the LMB (International Union for Conservation of Nature 2011). In some regions, groundwater overexploitation and climate change have already caused widespread environmental problems, such as deterioration in water quality, saltwater intrusion and depletion of aquifer storage (Erban, Gorelick and Zebker 2014; Merola *et al.* 2015; Smajgl *et al.* 2015; Minderhoud *et al.* 2017). The compound effects on the groundwater system may be far more complex. Therefore, it is both required and urgent to carry out a comprehensive review of water resources that considers groundwater and human health. This is required to provide a comprehensive picture of the wide range of hydrological, ecological, health, and socioeconomic repercussions that may be impending due to climatic change, socio-economic expansion, and changes in water management.

## 3.3. Potential impacts of water resource changes

Significant adjustments to the LMB's water resources will probably have a significant impact on the long-term sustainability of water management. The projected modifications to the basin's flow regime are anticipated to have a variety of detrimental effects. Large changes to flow regimes would disrupt aquatic ecosystems by altering fish migration patterns, native species' natural habitats, and plant distribution (Arias *et al.* 2012; Schmitt *et al.* 2019; Whitehead *et al.*, 2019). Fish abundance and catch in the lower regions of the basin are also anticipated to be significantly altered by changes in flow regime brought on by dams. Reduced river streamflow during the rainy season might obstruct overland water flows that trigger the natural sedimentation process on floodplains, hurting agriculture that depends on floods. Reduced sedimentation will have an even greater impact on agricultural yields since it will reduce the nutrients delivered by the silt during flood events (Hoang *et al.* 2019).

Water consumption is predicted to rise dramatically in the LMB due to fast socio-economic development and population expansion, which are outpacing the increase in accessible water resources (Eastham *et al.* 2008). The number of individuals who are subject to water stress might rise as a result, creating further issues for water security in the near future. The hotspot locations for water shortage, according to research, also tend to be located downstream in areas where dams severely control flow (Veldkamp *et al.* 2017). According to the predicted decrease in accessibility of surface water due to climate change, the LMB is likely to see a major increase in groundwater demand (Eastham *et al.* 2008). Deep groundwater arsenic might be released by vertical movement as a result of extensive groundwater extraction, which could potentially cause widespread land subsidence (Wagner *et al.* 2012). This will reduce agriculture output and seriously jeopardize future human health (Merola *et al.* 2015).

Rice farmer in lower LMB. Photo credit @Pixabay

CHAPTER 4

# *Ecosystem services and livelihoods in the Lancang-Mekong Basin: case studies in China and Cambodia*

Viet Nam, Market, Mekong image. Photo credit @Tho-Ge

# 4. Ecosystem services and livelihoods in the Lancang-Mekong Basin: case studies in China and Cambodia

## Lower Lancang-Mekong River Basin: case study in Phnom Kulen National Park, Cambodia

### 4.1.1. Natural and cultural resources of Phnom Kulen National Park

Phnom Kulen National Park plays an essential role in biodiversity maintenance, environmental conservation and provision of resources for local livelihoods. A diverse and complex mosaic of habitats dominates the area. With an elevation of up to 500 metres above sea level, PKNP presents a distinctive sandstone geographical feature in the essentially flat lowland landscape. The Siem Reap River, along with the other major rivers in the Angkor area, originates in the same mountain range (Puok and Roluos). It plays a significant part in supplying the area's aquifer and surface water. Before reaching Angkor, it drains the majority of the plateau. Through a network of channels, it nourishes the city's entire hydraulic system, the main reservoir (baray), and the temples or city moats. It then empties into the enormous Tonle Sap Lake.

The majority of the forest cover consists of evergreen and semi-evergreen forests, with tiny pockets of deciduous dipterocarp forest. The remaining forest patches, with agricultural land, cover the plateau area. Mostly in the southern section, it is made up of regenerating and secondary forests, combined with highly degraded woods, cassava plantations, and cashew plantations (Singh *et al.* 2019). The total botanical record for PKNP includes 775 wild species (native, endemic and pioneer species). Flagship threatened animal species include pileated gibbon, Indochinese silvered langur, Bengal slow loris and binturong. Additionally, it is thought that this location has a different medicinal value from other Cambodian regions due to the presence of 389 different species of medicinal plants (Sothearith *et al.* 2020).

In addition to its abundant natural riches, PKNP is a well-known sacred tourism destination with significant spiritual, cultural, and historical significance (Davies 2013). It has been included as a possible World Heritage cultural site on the Government of Cambodia's tentative list since 1992. The peak is referred to as Mahendraparvata, or "the mountain of the Great Indra", in ancient Khmer writings, notably the Sdok Kak Thom inscription. Several temples may be seen at this ancient city, which was the Khmer Empire's former capital and was built between the late eighth and early ninth centuries (United Nations Educational, Scientific and Cultural Organization 2020). As King Jayavarman II declared independence from Java in 802 CE from the city of Mahendraparvata, Phnom Kulen had significant symbolic importance for the ancient Khmer Empire (United Nations Educational, Scientific and Cultural Organization 2020).

The ancient Mahendraparvata on Phnom Kulen is now a largely wooded site with around 40 brick temples, including one pyramid mountain-temple, historic reservoirs, dykes with spillways, waterways, ponds, plots, platforms, and earthen mounds, all part of an ancient urban system.

The cultural and natural resources (Figure 4.1) of PKNP support various types of local livelihoods. They provide multiple ecosystem services, such as water and climate regulation, provision of food, water and other raw materials, pollination, habitats for many species, recreational and spiritual services, opportunities for education and sciences, carbon sequestration and soil conservation, etc. The resources and ecosystem services also support local life in many ways, both directly and indirectly. Local livelihoods range from farming of rice (and other crops), cashew planting, subsistence hunting for food and gathering of traditional medicine, to natural or cultural tourism.


**Figure 4.1 Examples of the natural and cultural resources supporting local livelihoods in PKNP. Figures 4.1(a) to 4.1(f) show examples of natural resources used by local residents to support livelihoods; Figures 4.1(g) and 4.1(h) show examples of cultural resources to support tourism. (All photos © Chhin Sophea)**

### 4.1.2. Livelihoods in Phnom Kulen National Park

In interviews with local environmental experts and government officers (the list of interviewees is attached as Appendix A and the interview scripts as Appendix B), they were asked to talk about perceptions, observations or concerns in PKNP from many perspectives (such as in relation to livelihoods, natural resources and local communities), as well as the issues they believed to be important to PKNP and the local community.

The frequently mentioned words have been shown in Figure 4.2. Not surprisingly, "forest", "water" and "(cashew nut) planting/plantation" were the most mentioned frequently words.

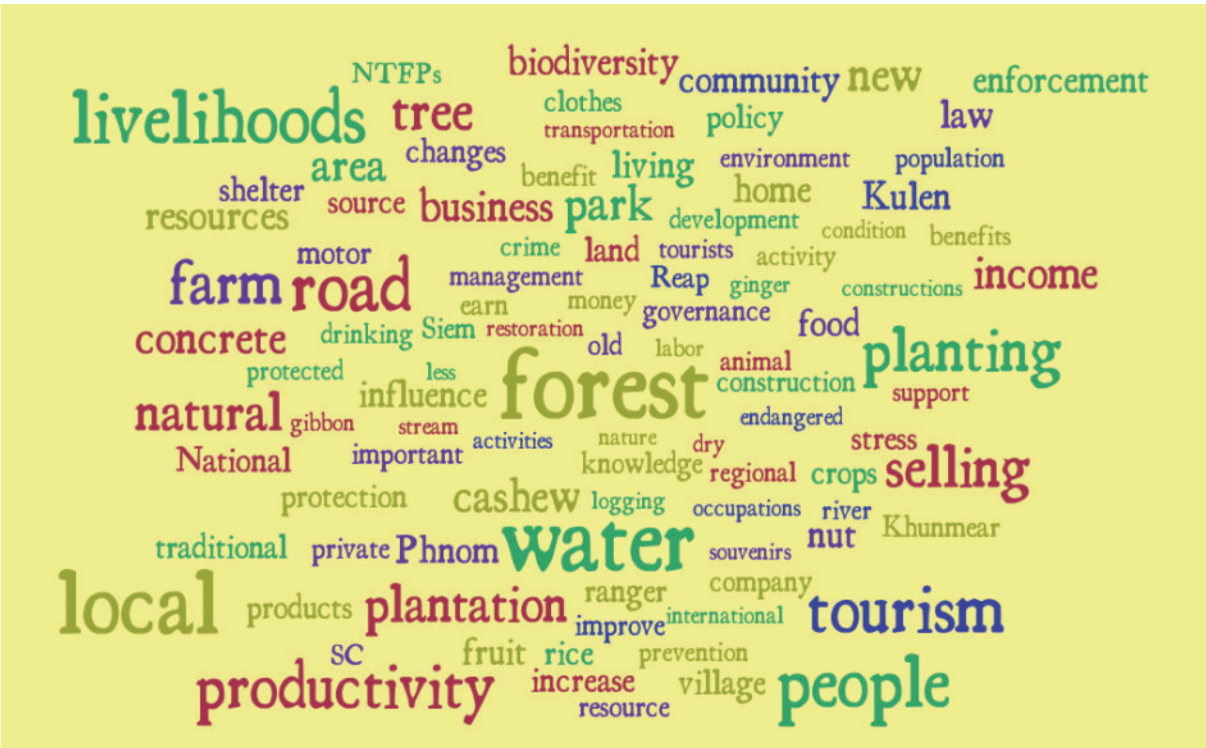



**Figure 4.2 Terms most frequently mentioned by local PKNP residents in the interviews. Photo credit © Author team**

As stated by the interviewees, as well as being reported in recent publications, more and more natural forest has been converted into chamkar (farm). The amount of non-timber forest products (NTFPs) gathered has decreased over time. Due to their minimal maintenance requirements and high market value, cashew nut plantations have largely replaced the forest during the last decade (Koerper 2019). Kulen (lychee, which fruits only every two years), khun mear (*Ancistrocladus tectorius*) and mushrooms create additional income during the harvest season. Growing cashew nuts now provides the stable primary income for almost everyone living on this mountain. Planting of cashew nuts has therefore significantly influenced local income and livelihoods over the past 10 years.

In the meanwhile, there have been large waves of inbound and outbound migration in PKNP. People were compelled to leave their villages during the Khmer Rouge regime in the 1970s to labour in the mountain's rice fields (Koerper 2019). People returned to their towns once the regime fell and mainly stayed, despite greater competition for fertile land (Koerper 2019). Because of the mountain's reputation for having a wealth of natural resources, a lot of people have moved there during the previous 20 years. During the interview, Mr. Ratt Reouy (head of Phnom Kulen CPA network) referred to a time approximately 10 years ago (when the cashew nut became popular in the area) as the moment of change.

There has been significant inward migration in recent years, primarily due to development of tourism and cashew plantations. The increase in population and more frequently observed water stress have changed people's choice of livelihoods. Local residents are growing less of the plants that need more water (vegetables and rice) and shifting to cashew farming because it requires less water and effort.

The traditional practice of shifting cultivation for growing rain-fed upland rice and other crops has been quickly replaced by permanent plantations of cashew trees. However, these changes have uneven consequences. On the one hand, the increase in cashew plantations has fragmented and reduced natural forests. It has affected families who depend on collection of natural resources. "The people with larger size of their farm earn more and more; however, the people that depend on the natural product is worse and worse." (Quote from Mr. Ratt Reouy[2]) Meanwhile, families that shifted to farming as a result of economic stress earned noticeably more income.

[2] Head of Phnom Kulen CPA network, lives on this mountain and used to work with other CPAs as well as the Siem Reap Provincial Department of Environment and non-governmental organizations to improve local livelihoods.

In addition to the interview with experts, a face-to-face community survey was also conducted among the villages located in and near PKNP (demographic information on respondents is listed as Appendix C). The local residents were asked to answer questions about their living conditions (including affordability of housing and electricity, etc.), PKNP, their income source and their perception of other non-material benefits (such as aesthetic and spiritual value), generally over the past decade. The questionnaire used in PKNP is attached as Appendix D.

According to the responses from 100 local residents from 11 villages in PKNP, 91 per cent reported that their livelihood had been influenced by the national park (other detailed results are shown in Appendix E). They are generally exposed to little stress in relation to electricity, housing or wild animals. Although PKNP is the source of the Siem Reap River, over 50 per cent of local respondents still experienced water stress, and 5 per cent of respondents had experienced stress collecting enough water for irrigation several times. As one of the most influential demographic characteristics, gender also presents differences in the local survey results.

Among all randomly selected respondents from 11 villages in PKNP, women were less educated than men. Around 33 per cent of female respondents have no educational background, while this number is only 15 per cent for males. In addition, women are less represented (35 per cent) in higher income livelihoods, such as cashew farming and tourism. Meanwhile, in the "squeezed" relatively low-income livelihoods such as traditional medicine collection and crops (other than rice and cashew), the proportion of women is over half at around 55 per cent.

The reported influences of PKNP on local lives are mainly reflected in the role it plays in their livelihoods. Local livelihoods are highly dependent on the Phnom Kulen National Park itself. They can generally be categorized into two types: material resource-dependent livelihoods such as farming (rice, crops, etc.), cashew plantation and traditional medicine collecting; and non-material resource-dependent livelihoods such as tourism attracted by the natural scenery (and cultural heritage sites) of PKNP.

Synthesizing the information from both local residents and other stakeholders such as local experts and government officers, the changes in livelihoods are summarized in Figure 4.3.


**Figure 4.3 Changes to ecosystems and livelihoods in PKNP, the pilot site in Cambodia. Photo credit © Author team**

A vicious circle was started by introducing cashew plantations to the local communities without proper intervention (planning and management). Originally, local people lived on the natural resources of PKNP (traditional farming and NTFPs) and cultural heritage. Cashew nut was brought in as a cash crop to improve local incomes. Growing cashew nuts was profitable in a purely economic context; however, it led to fragmentation of natural forests. This exacerbated pressure on the livelihoods of those relying on traditional farming or natural forests. More and more local families shifted their livelihoods to cashew plantations to secure a better income. It is expected to raise issues about food security and nutrition because many households no longer cultivate their own food, instead opting to spend their cashew nut earnings on food.

In addition, more people came to PKNP to sell their labour to buy land for cashew cultivation or tourism. The higher population increased competition for local natural resources, with consequences such as water stress. Families then had to change their crops from rice and vegetables to cashews because they need less water and care. The increased cashew cultivation will further disturb natural ecosystems and aggravate fragmentation of natural forests. The degraded natural ecosystem may provide fewer materials and support less biodiversity and scenery.

### 4.1.3. Ecosystem services in Phnom Kulen National Park

Overuse of rich resources has also led to negative environmental consequences such as deforestation, forest fragmentation and even forest decimation. The natural habitats of PKNP are facing significant challenges, due to illegal logging and hunting, inadequate knowledge about forest conservation, population growth (legal and illegal immigrants), increased cashew cultivation and rice fields, and increased development of infrastructure. Overlapping management powers and lack of planning of new settlements by immigrant families are also believed to be issues in PKNP. The decrease in natural resources in PKNP may severely affect the provision of ecosystem services, the cultural heritage in and near PKNP, and most importantly the quality of local lives. Based on previous findings (Chapters 2 and 3) and the local focus of attention (Figure 4.3), this section will assess critical ecosystem services closely related to or supporting local livelihoods but less studied, such as carbon sequestration, soil conservation, pollination and cultural services.

The assessment of ecosystem services conducted through the Artificial Intelligence for Environment & Sustainability (ARIES) platform uses logical statements and data, as well as models when insufficient information is available, to build more detailed dynamic flow models. The models use publicly available global- and continental-scale data as defaults. Four specific ecosystem services (carbon sequestration, pollination, soil conservation and outdoor recreation) are assessed according to the concrete local conditions in the lower LMB case study (Figure 4.4). In addition to outdoor recreation, other cultural ecosystem services were also assessed by perception analysis, including cultural heritage, social relations, natural identification, aesthetic services, sense of place, spiritual and religious services, physical and mental health, inspiration, environmental education and nature connectedness. More detailed methods are shown in Appendix F.

[2] The PKNP is technically under the authority of the Ministry of Environment (MOE), but it is also co-managed and administered by a number of major agencies. APSARA (Authority for the Protection and Management of Angkor and the Region of Siem Reap) is in charge of some archaeologically significant places. The rest is within the MOE's jurisdiction. The MOE's mandate includes five Community Protected Areas (CPAs) that have been developed and administered by local villages with oversight and help from the MOE. The park's villages are administered by the Commune Council, which is part of the Ministry of Interior's administration system.

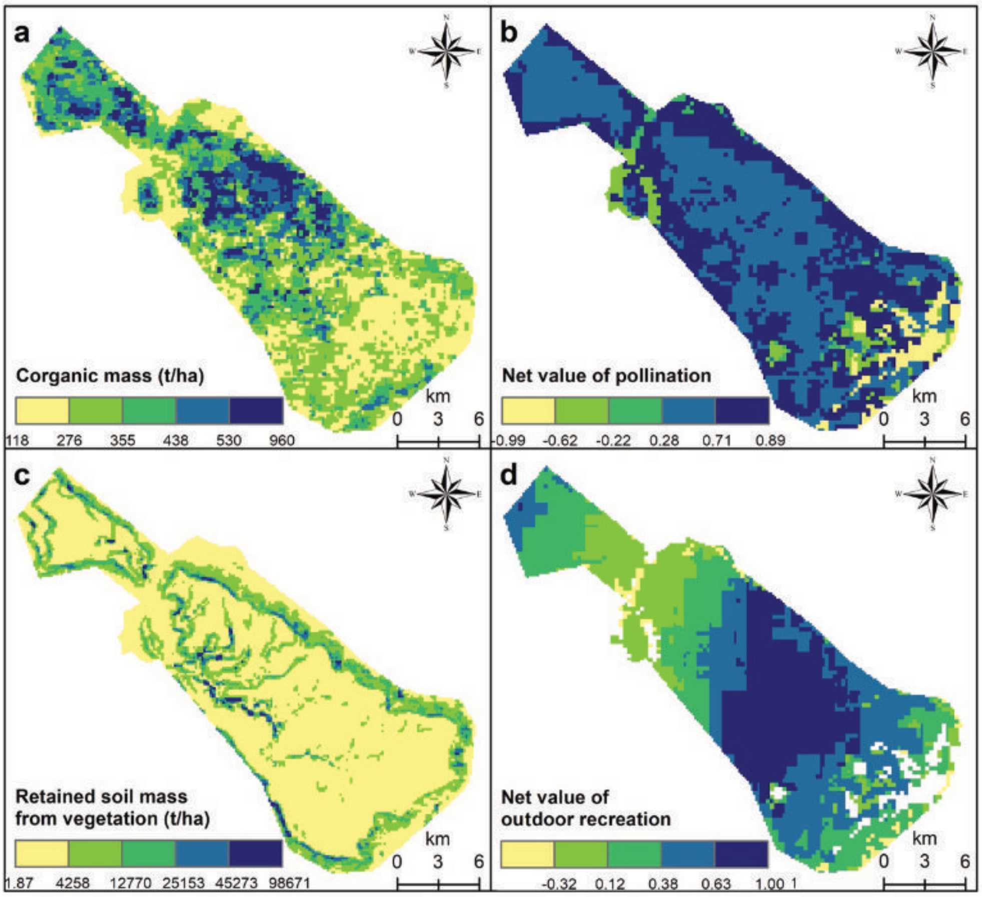



**Figure 4.4 Maps of the values of (a) carbon sequestration (corganic mass: the carbon stored in vegetation and soil), (b) pollination services (net value of pollination: the surplus or deficit of pollination services), (c) soil conservation (retained soil mass: avoided soil erosion attributable to vegetation) and (d) outdoor recreation (the normalized use-value) in PKNP, Cambodia**

Figure 4.4a shows the amount of carbon stored in the soil and vegetation (in both above-ground and below-ground biomass). As one of the climate regulation services, carbon sequestration significantly supports the local ecosystem by maintaining natural resources, while also contributing to climate change mitigation at larger spatial scales. The value of carbon sequestration is quantified as the sum of above-ground and below-ground biomass carbon storage (Gibbs and Ruesch 2008) plus the amount of carbon stored in the first 200 cm of soil – see spatially explicit global soil carbon storage data by ISRIC World Soil Information (www.isric.org/explore/soilgrids). The main natural resources, natural forests and crops that provide carbon sequestration are in decline (as stated in Chapter 2) and are being replaced by cashew plantations. The highest value of carbon sequestration (960 tons of carbon per hectare stored in soil and vegetation) was likely to be provided by the natural forests in the upper central area of PKNP, followed by mixed forest/cropland areas. Shrubland is likely to provide least carbon sequestration, with an estimated lowest value of 118 tons per hectare. The value of carbon sequestration provided by forests is also influenced by the frontier forests (a proxy for the degree of forest degradation). Therefore, not only will livelihood-derived conversion from natural forests to cashew crops (shrubland) result in reduced total carbon biomass, the degradation of natural forests will also decrease capacity to provide carbon sequestration.

Figure 4.4b represents the normalized surplus or deficit of pollination in each landscape parcel. Animal pollination is a crucial ecosystem function that connects agricultural landscapes to natural environments since 70 per cent of the world's most important crop species rely to some extent on pollinators. Based on land use, cropland, and weather patterns, this model of pollination generates spatially explicit ranking estimates of supply and demand for insect pollination services. The net value of pollination indicates the balance of supply and demand in PKNP. Only a small area of the whole national park has a balance between demand and provision of pollination. The yellow (mostly the shrublands in the lower right PKNP and the croplands that have increased over the past 20 years) indicate areas where pollination services are required but there are inadequate resources to meet demand. Navy areas (forests and large patches of shrubland/cashew trees) can provide pollinators, but no pollinator-dependent crops are cultivated to benefit from the diversity of pollinators. Areas in green or close to green are where a balance exists between provision and use of pollination services. Figure 4.4b indicates that the existing trend of converting croplands to cashew plantations may further negatively influence pollination services provided by the local ecosystem. Together with the trend for crop simplification, provision of pollination is likely to decrease and further affect agriculture-dependent local livelihoods.

Figure 4.4c depicts biophysical estimates for soil loss if all land cover was removed and separates the findings to estimate averted soil erosion due to vegetation. Soil conservation is calculated using the sediment regulation model of the Revised Universal Soil Loss Equation (RUSLE). The assumption is that the soil erosion avoided can be used to represent the value of soil conservation. The results showed the highest value of soil conservation in the outer ring of forests and in mixed forest/cropland areas. Although soil conservation was influenced by slopes and landscape composition, natural forests tend to provide more soil conservation than shrubland, which means that the conversion of natural forest may also lead to higher risks of soil erosion.

Figure 4.4d shows the net normalized use value of outdoor recreation in PKNP. The value of outdoor recreation, a representative cultural ecosystem service that influences local livelihoods through tourism, is calculated by using the travel efficiency function (demand for outdoor recreation) and Euclidean distance (theoretical supply) to protected areas, water bodies and sites of touristic relevance, etc. (Paracchini *et al* 2014). In general, the net value of outdoor recreation represented the balance of demand (from people using natural and cultural resources for outdoor recreation) and supply (capacity of cultural and natural resources that can be used, reflecting distance, distribution, etc.). According to the results, the core natural forests have the highest potential to provide outdoor recreational opportunities. Local respondents were also asked to assess the cultural significance of PKNP by ranking it on a 5-point Likert scale (Dou *et al.* 2021a). The indicator questions used in the survey are provided in Appendix D. The perceived values of local perceptions were calculated; the calculation rules are shown in Table 4.1.

**Table 4.1 Assignment rules for the perceived values of each cultural ecosystem service (adapted from Dou *et al.* 2021a).**

| Description | Degree of agreement with each statement related to the proposed cultural ecosystem service | Assigned perceived value | Mean perceived value (0 to 3) |
|---|---|---|---|
| (Strongly) Disagree with/ have no idea about the statement/have never participated in related activities. | 1<br>2 | 0 | (0–1)<br>Low value |
| Not sure about the statement/May have participated in related activities. | 3 | 1 | (1–2)<br>Medium value |
| Agree with the statement/ have occasionally participated in related activities. | 4 | 2 | (2–3)<br>High value |

In addition to recreational services, PKNP is also perceived to provide cultural services (such as cultural heritage, social relations and natural identification), which support local livelihoods as cultural resources (Table 4.2). Due to the rich cultural sites in and around PKNP, cultural heritage has the highest perceived value.

The perceived cultural ecosystem services offer enormous potential for supporting sustainable environmental management through local participation and tackling complicated issues at the nexus of society and nature (Liu, Bawa and Seager 2019; Dou, Yu and Liu 2021).

**Table 4.2 Non-material ecosystem services provided by PKNP and their perceived values**

| Non-material ecosystem service | Perceived values |
|---|---|
| Cultural heritages | 1.92 |
| Social relations | 1.80 |
| Natural identification | 1.78 |
| Aesthetic services | 1.74 |
| Sense of place | 1.70 |
| Spiritual and religious services | 1.72 |
| Physical and mental health | 1.51 |
| Inspiration | 1.62 |
| Environmental education | 1.57 |
| Nature connectedness | 1.54 |

## Upper Lancang-Mekong River Basin, the case study of Mengla County, Xishuangbanna, Yunnan Province, China

### 4.1.4. Natural and cultural resources: Mengla County, Xishuangbanna

Mengla is a transliteration of a term in the Dai language that means "the place of teeming tea". As highlighted by its name, it is the origin of the famous pu'er tea. More than 4,000 species of plants have been identified in the county, representing about 12 per cent of the total plants in China. There are more than 6,000 species of known fauna, which include 16 per cent of the total number of bird species, and 25 per cent of the total terrestrial vertebrate species in China. It is known as the "kingdom of animals and plants" and the "gene pool of species". There are around 0.3 million hectares of well-preserved original forest in the territory, with a forest coverage rate of 88 per cent. It is a national key ecological function area[3] and a national eco-model area[4].

In addition to its natural resources, Mengla also has a long history and splendid culture. It is one of the most ethnically mixed regions in China, with 26 ethnic minorities – including Dai, Hani, Yi, Yao, Miao, Zhuang and Lahu – together making up 76.8 per cent of the registered population. It is also believed to be the hometown of the "peacock Princess" in Dai folk tales.

[3] China's national key ecological function areas refer to important ecological functions such as water conservation, soil and water conservation, windbreak and sand fixation, and biodiversity maintenance, which are related to the ecological security of the whole country or a larger area, and need to limit large-scale and high-intensity industrialization in the development of national land and space. Areas developed for urbanization to maintain and improve the supply capacity of ecological products. Currently, there are 676 National key ecological function areas, around 53 per cent of the country's land area.

[4] China's national eco-model areas was established on March 6, 2000 by Ministry of Environmental Protection of the People's Republic of China and the State Environmental Protection Administration. The title of commendation is given to the units with outstanding performance in the construction of the ecological demonstration zone.

Rubber is called one of the “four strategic resources” in China (alongside steel, oil and coal). It plays an extremely important role in national economic construction, modern industry and defence. Because of its appropriate climate, Mengla County is one of the most suitable areas to plant rubber. It has also been the key area for development of the rubber industry in China. The natural rubber industry is the industry with the largest planted area and the largest number of employees in Mengla County, and it is also the pillar industry. However, in the early 21$^{st}$ century, driven by the economic benefits, large areas were planted with rubber against natural laws, such as beyond the upper altitude limit or in areas with a comparatively steep slope for rubber plantation, which also occurred in Yunnan.

These unsustainable cultivation methods contributed to regional water shortages and soil erosion, aggravated pests and diseases, and exacerbated biodiversity loss in the region (Ziegler, Fox and Xu 2009). In addition, large-scale rubber plantations have reduced forest area, leading to forest degradation and affecting wildlife habitats and a major food source for local people (i.e. forest foods). Given the moves to optimize and upgrade industrial structure and to promote industrial development to improve quality and efficiency, there are still many challenges.

Rubber plantations in Xishuangbanna. Photo credit ©Dietrich Schmidt-Vogt/ICRAF

### 4.1.5. Livelihoods of Mengla County, Xishuangbanna

Natural forests in this region are being changed to other land-use/land-cover types at a phenomenal rate due to growing demand for natural rubber brought on by China's fast economic expansion in recent decades (Chen *et al*. 2016). Currently, the region's primary land uses/land covers are natural forest, which makes up more than half of the area, followed by rubber plantations (42 per cent), tea plantations (2 per cent), arable land (3 per cent), and built-up land (1 per cent) (Jin and Fan 2018). Due to the transformation of forests into artificial plantations and agricultural land during the past 20 years, Mengla County has seen a sharp decline in its forest cover. Despite the implementation of various forest protection measures, rather rapid deforestation (a loss rate of around 58.76 $km^2$ per year) of natural forests, along with decelerating spread of artificial plantations, has persisted.

Tropical seasonal rainforest was the area's natural vegetation, although it is currently covered with community woods, rubber plantations, and swidden fallow (Fu *et al*. 2009). Since the 1940s, rubber has been farmed in southern Yunnan, and in the 1950s, state farms set up under the post-liberation administration saw an upsurge in output. Since 1980, the brisk growth of rural rubber plantations has given rural people a more consistent source of income. The most significant sector in the Xishuangbanna Province's economy, of which Mengla is a part, is now rubber plantation.

Rubber plantation size has come to be seen as a key indicator of household wealth in recent years. In Xishuangbanna, cash crops are now deeply ingrained. The previous 30 years of history, however, show that the farming community lacks confidence in the sustainability of its means of subsistence. Price changes have prompted quick changes in crop selection and the renunciation of a variety of outdated cultivars and methods.

Rubber demand has resulted in the conversion of land to plantations and the loss of high biodiversity rainforests in south-west China (Yongneng *et al.* 2006), replacing traditional swidden-fallow agroecosystems and undermining their critical role in conserving traditional agroecosystems and crop variety diversity (Zhai and Xu 2022). The changes in livelihoods in Mengla County have been summarized in Figure 4.5.

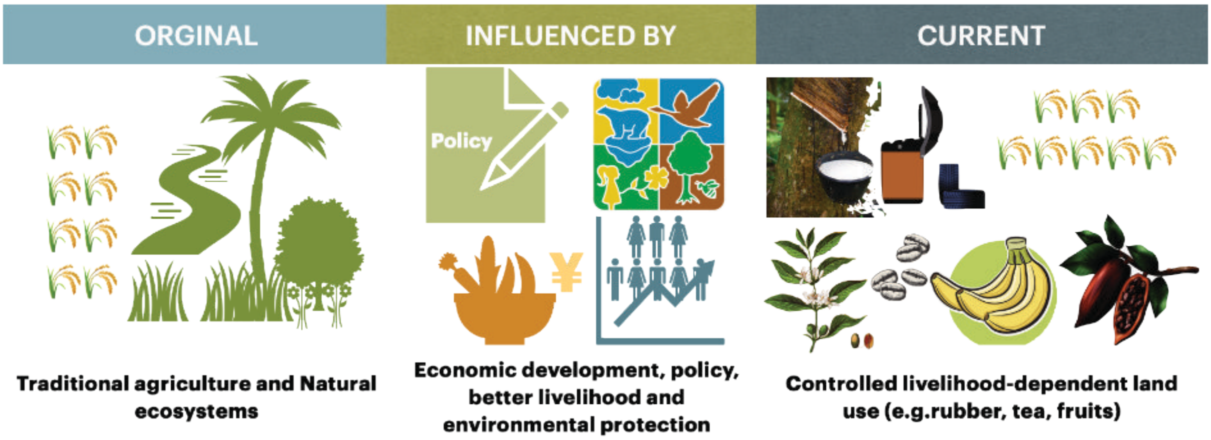



**Figure 4.5. Changes in livelihoods in Mengla County, the pilot site in China. Photo credit ©Author team**

## 4.1.6. Ecosystem services and biodiversity in Mengla County, Xishuangbanna

The assessment of ecosystem services conducted in ARIES uses logical statements and data, as well as models with publicly available global- and continental-scale data as defaults when insufficient information is available, to build more detailed dynamic flow models.

Four specific ecosystem services are assessed according to the concrete local conditions in the upper LMB (Figure 4.6).

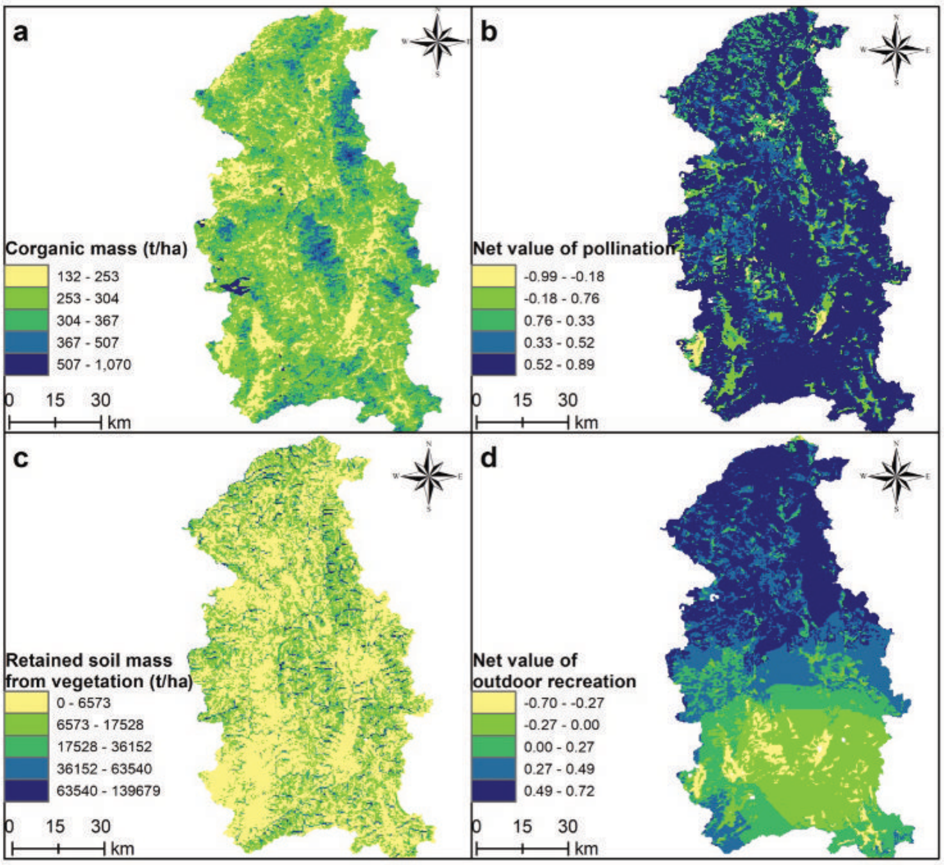



**Figure 4.6. Maps of the values of (a) carbon sequestration (corganic mass: the carbon stored in vegetation and soil), (b) pollination services (net value of pollination: the surplus or deficit of pollination service), (c) soil conservation (retained soil mass: avoided soil erosion attributable to vegetation) and (d) outdoor recreation (the normalized use value) in Mengla County, China.**

Figure 4.6a shows the amount of carbon stored in the soil and vegetation (above-ground and below-ground biomass). The highest value of carbon sequestration was likely to be provided by a complex ecosystem including cropland, forest and shrubland in the middle-left area of Mengla County, with 1,070 tons per hectare of carbon stored in soil and vegetation. The normalized surplus or deficiency of pollination in each landscape parcel is shown in Figure 4.6b. The net value of pollination indicates the balance of supply and demand in the studied Mengla County. The areas with balanced pollination services showed scatter distribution in croplands. Yellow areas (mainly shrublands) are those where pollination services are required but there is inadequate supply to meet the need. Navy areas (forests) can provide pollinators, but no pollinator-dependent crops are grown to benefit from the diversity of pollinators. Green or near-green regions indicate a balance between the provision of pollination services and their utilization (in the case of Mengla, these areas are mainly croplands).

Figure 4.6c depicts the biophysical estimates of soil loss if all land cover were replaced to bare soil, with the findings differentiated to estimate the averted soil erosion attributable to vegetation. Similar to the provision of carbon sequestration, the results showed that the highest value of soil conservation appeared in diversified agroforestry systems, which were distributed sporadically. Compared with the case study of PKNP in the lower LMB, Mengla has relatively higher capacity to provide carbon sequestration and soil conservation, mainly due to the large scale of forests (both natural tropical forests and rubber forests). Meanwhile, challenges also exist. For example, most of the forest zones were not able to benefit from the range of pollinators. The complex ecosystem including cropland, forest and shrubland in the middle-left area is a good example of the provision of all identified key ecosystem services.

Figure 4.6d shows the net normalized use value of outdoor recreation in Mengla County. According to the results, the upper forests have the highest potential to provide outdoor recreation opportunities. Unlike PKNP, which is located on a plateau, Mengla County is closely connected to adjoining counties. The convenience of travel has highly influenced the balance of supply and demand, resulting in the large green region in the lower left. In addition to the provision of outdoor recreation opportunities, the rich ethnic and cultural resources have also supported local livelihoods for a very long time in many ways, such as by attracting tourists and enabling the sale of special local products (Yang and Wall 2008).

# Anthropogenic impacts on local livelihoods of the Tonle Sap Lake Area (TSLA)[5]

## 4.1.7. Tonle Sap Lake

Tonle Sap Lake in Cambodia is part of the Mekong River and an exceptional lake-floodplain system (Figure 4.7). The lake's water surface has a seasonal cycle. It increases from May to September, reaching the maximum in the wet season, and decreases from October to April, hitting the minimum in the dry season, the so-called flood pulse (Junk, Bayley and Sparks 1989; Kummu and Sarkkula 2008). This flood pulse propels the seasonally inundated floodplains, cultivating particularly fertile inland wetlands in South-East Asia and serving as a haven for several threatened and endangered species (Campbell *et al.* 2006; Lamberts 2006; Ziv *et al.* 2012). The lake provides various ecosystem services and economic values for Cambodia (Keskinen 2003; Kummu *et al.* 2006; Chadwick, Juntopas and Sithirith 2008), involves supplying water supplies for home use, agriculture, aquaculture, transportation, and adjusting or controlling the climate locally (Chadwick, Juntopas and Sithirith 2008; Johnstone *et al.* 2013).

About 1.7 million people rely on the lake for their livelihoods, in areas such as fishing, rice cultivation and the collection of medicinal herbs (Salmivaara *et al.* 2016). It is essential for the local ecology, economy, and society in Cambodia (Bonheur and Lane 2002; Uk *et al.* 2018).

[5] This section is mainly based on a paper by Chen *et al.* (2022), the contents of which are reused under the Creative Commons Attribution 4.0 International licence.

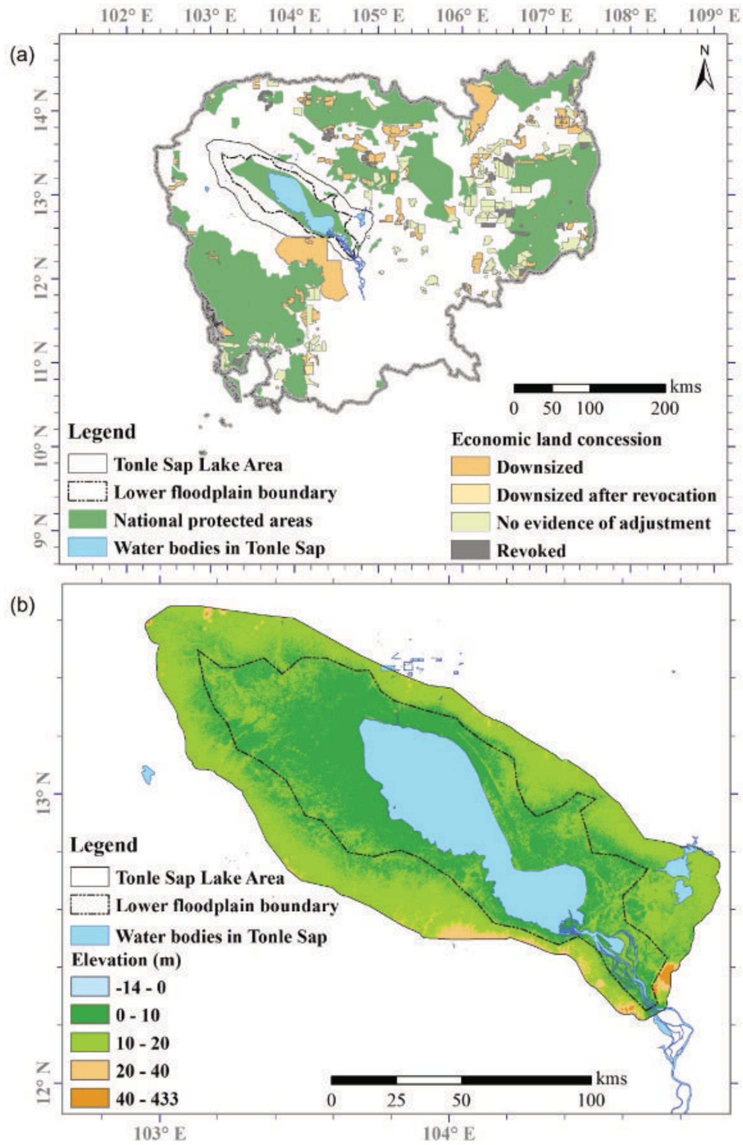



**Figure 4.7. Cambodia and the Tonle Sap Lake Area (TSLA) (a) Natural protected areas and economic land concessions in Cambodia; (b) The TSLA, comprising the lake-floodplain area between National Roads 5 and 6 and an additional 3 km farther from the National Roads. The solid black line is the boundary of the TSLA, and the boundary of the lower floodplains is shown by the dashed black line. Natural protected areas and economic land concessions in Cambodia have been obtained from Open Development Cambodia. (This figure has been adapted from Chen *et al.* (2022) under the Creative Commons Attribution licence).**

Over the past decades, land-cover practices have led to forest loss and altered the ecosystem and environment in the TSLA. To address forest management issues, the Cambodian Government launched reforms such as implementing the Forest Sector Policy Statement and enacting the Forestry Law (in 2002) and the Protected Area Law (in 2008) (McKenney and Tola 2002; Forest Trends 2015). The impacts of the reforms on the forest cover in the TSLA are, however, unclear.

The new Google Earth Engine was used to analyze land use and cover change (LUCC), with a specific focus on forest cover change, in the TSLA between 2001 and 2017. It has been applied to various high-impact societal issues, for instance generating global forest cover change products (Hansen *et al.* 2013) and water surface change (Pekel *et al.* 2016). By investigating LUCC and forest cover change in the TSLA, this study will provide insights to inform future forest policies and their implementation in South-East Asia and in other tropical areas facing similar challenges.

Cambodia. Photo credit @saltonnz

## 4.1.8. Forest fragmentation in the TSLA

On average, forests, shrubs and croplands occupied 78.6 per cent of the TSLA from 2001 to 2017, with other types of cover (water bodies, wetlands, urban and barren) accounting for the remaining 21.4 per cent. Typically, shrubs and forests were more prevalent in the upper floodplain than croplands and shrubs were in the lower floodplain.

Across the whole TSLA, there has been substantial forest loss since 2001 (2,833.8 $km^2$, see Figure 4.8). Meanwhile, an area of about 91.3 $km^2$ area has been converted to forests. The net forest loss was about 2,742.5 $km^2$ from 2001 to 2017, and both shrubs (2,550 $km^2$) and croplands (286.5 $km^2$) have considerably expanded.

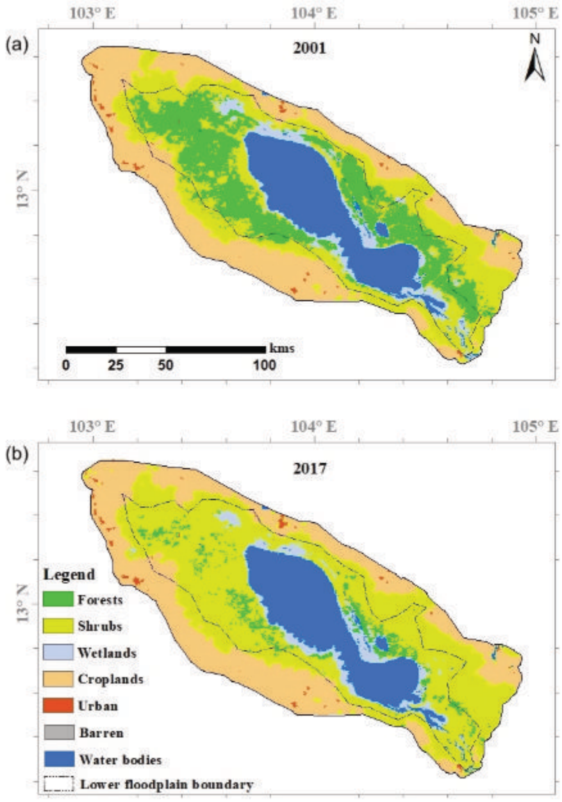



**Figure 4.8. Status of land cover in the TSLA in (a) 2001 and (b) 2017. Forests, shrubs and croplands occupied 78.6 per cent of the TSLA from 2001 to 2017, with other types of cover (water bodies, wetlands, urban and barren) accounting for the remaining 21.4 per cent. (This figure has been adapted from Chen *et al.* (2022) under the Creative Commons Attribution licence).**

LUCC in the two subzones, however, varied during the research period. A tendency of forest loss expanding towards the lake is suggested by Figure 4.9a, which indicates that the region of forest loss encroached towards the lower floodplain year after year. Areas converted to forests, primarily from shrubland, were mainly scattered around the lower floodplain. At the same time, farmland conversion was concentrated mostly at the junction of the lower and higher floodplains (Figure 4.9b). The majority of these new croplands were converted from shrubs.

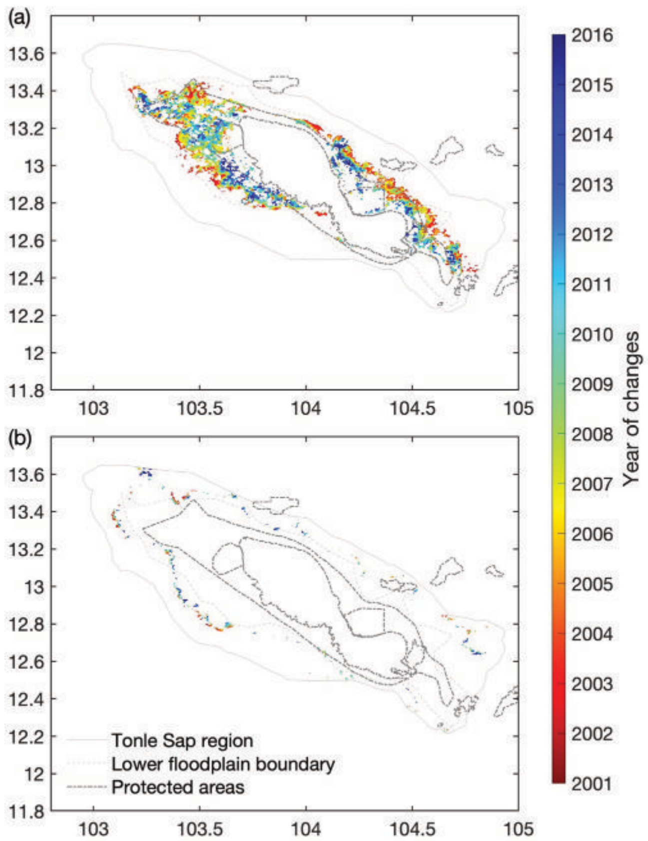



**Figure 4.9. Spatial patterns of annual LUCC in the TSLA from 2001 to 2017. (a) Net forest loss, (b) cropland expansion. The year in which the changes occurred is indicated by the colour bar. Forest loss area encroached into the lower floodplain year after year, and areas that converted to croplands were primarily located at the intersection area of the lower and upper floodplains. (This figure has been adapted from Chen *et al.* (2022) under the Creative Commons Attribution licence).**

Further investigation demonstrated the occurrence of rapid forest fragmentation between 2001 and 2017 in the TSLA (Figure 4.10). The results show that the "interior" forest area, representing the lowest levels of fragmentation or intact forest, declined from 4.5 per cent of the TSLA in 2001 to 0.0 per cent in 2017, meaning that hardly any forest blocks greater than 3.5×3.5 $km^2$ remained by 2017. At the same time, the "patch" forest area, representing the highest levels of fragmentation, increased from 80.8 per cent in 2001 to 99.3 per cent in 2017. This forest fragmentation chiefly took place in the lower floodplain.

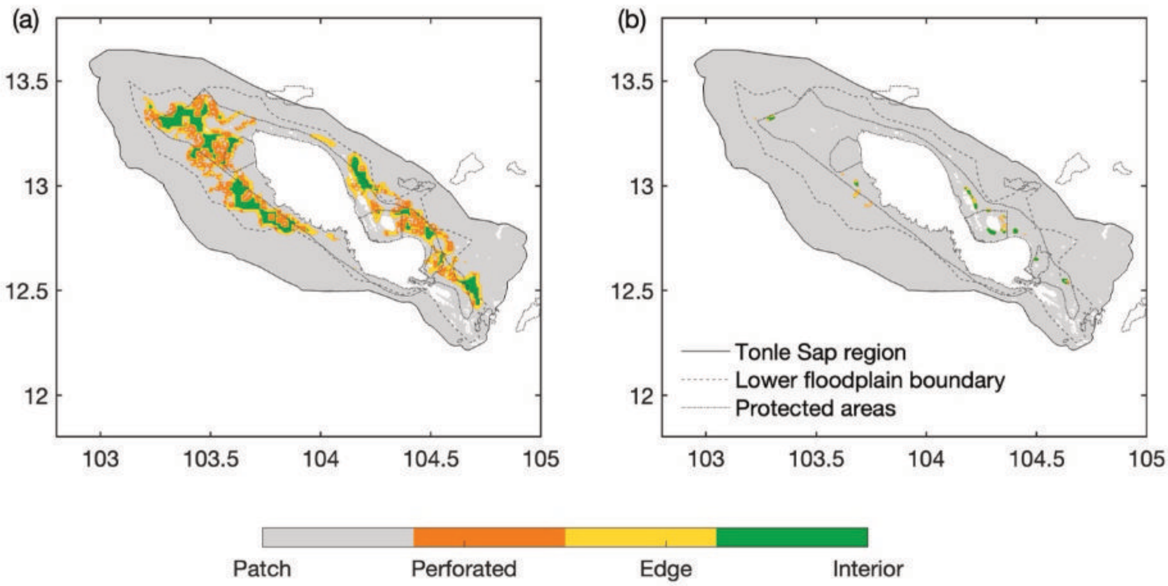



**Figure 4.10. Spatial patterns of forest fragmentation in the TSLA in (a) 2001 and (b) 2017 with 7×7 pixels window. The "patch" areas represent the highest levels of forest fragmentation, while the "interior" areas represent the lowest levels of fragmentation. (This figure has been adapted from Chen *et al.* (2022) under the Creative Commons Attribution licence).**

Despite forest reforms that have been in place since the early 2000s, a significant decrease of forest cover in the TSLA can be observed. The woods were found to be fragmented, with scarcely any intact forest remaining; major forest loss hotspots were identified in the lower floodplain, and forests were degraded to shrubs, resulting in a large rise in shrub coverage. Significant farmland extension occurred mostly at the junction of the lower and higher floodplains, where shrubs were converted to croplands.

This evidence shows that the forest reforms have not halted the deforestation trend in the TSLA. This study provides scientific evidence to help understand human interference in forests and may be helpful for future sustainable forest management aimed at achieving a healthy ecosystem in the TSLA. The challenge is to meet people's expectations in terms of livelihoods and living standards while maintaining the functional capacity of the ecosystem in the TSLA over time.

Family living along the river. Photo credit @Moni Rathnak

CHAPTER 5

# *Conclusions and recommendations*

Flower village in Viet Nam. Photo credit @Tran Le Tuan

# 5. Conclusions and recommendations

The LMB is home to incomparable treasures, including villages with unique cultural histories and uncommon fauna in breathtaking natural settings. It contains some of the most biologically diverse habitats in the world. More than 60 million people depend on natural and cultural resources in the LMB. Yet the LMB is also one of the most vulnerable places on the planet to the impacts of deforestation and forest degradation. These issues affect local people, biodiversity and natural resources, and have cascading effects. The study of the TSLA has suggested that to achieve land-system sustainability, much work remains to be done on how best to approach the complex food, biodiversity and land cover nexus.

Population increase, inappropriate land-use planning, and economic policies have all contributed to deforestation and biodiversity loss throughout the Greater Mekong area. These factors have a significant negative impact on the poorest and most vulnerable members of society, the majority of whom are women. The land-cover change analysis (Chapter 2) indicated that cropland expansion is also a key reason for forest loss (across the whole region and in the case study area, PKNP). The cropland area increased from 261.39×103 $km^2$ to 279.86×103 $km^2$ in the LMB. Tree cover and shrubland areas decreased, especially in Thailand and Cambodia. Due to the expansion of cash crops (such as rubber in the upper basin case study and cashew nut in the lower basin case study), the natural ecosystems and biodiversity of both case study areas are threatened. The high biodiversity of the rainforests in south-western China is being lost due to the need for rubber, and plantations have taken the place of traditional swidden-fallow agroecosystems.

The traditional practice of shifting cultivation for growing rain-fed upland rice and other crops is quickly being replaced by permanent cashew plantations, with additional forested areas being converted to agricultural use in PKNP. Furthermore, according to the PKNP case study, agriculture typically leads to the construction of infrastructure projects like roads, bridges, and dams, which has a detrimental impact on the environment through forest degradation, habitat fragmentation, and increased poaching. The construction of dams has altered the natural flow regime of the mainstream Mekong River in the upper Mekong River basin and on tributaries in the lower LMB. The decreased natural resources in PKNP may have a severe impact on the provision of ecosystem services, the cultural heritage in and near the PKNP and, most importantly, the human right to a clean, healthy and sustainable environment. These adverse environmental impacts also have gender-differentiated outcomes.

Significant adverse effects are experienced by women who have lesser access to credit and whose gender roles are heavily linked to natural resource use at the domestic and community level. These women are thus left to engage with diminished resources and thus use more effort and time in undertaking their roles to the detriment of pursuing more productive activities including capacity building or education, further widening the gender gap. The situation becomes further amplified due to seasonal migration where men may leave the community to find jobs and this means that these women then take on the extra roles previously undertaken by men.

The LMB is currently facing several interventions impacting the environment, with specific feedback on the population and its well-being. Regarding sustainable development requirements, there are also recommendations from the perspectives of both the case study level and the LMB regional level to comprehensively promote the improvement of ecosystem health, natural resource management and sustainable livelihoods.

**Involving multilevel stakeholders**

Communities and ecosystems are closely related. Communities are often distributed in complex ecosystems. Ecosystems provide communities with resources for survival. Ecosystem protection cannot therefore be separated from the participation of surrounding communities. In addition, the effectiveness of public participation in conserving natural resources has been proven. For example, community-based natural resource management has succeeded in planning and protecting small-scale natural areas, promoting good decisions taking local opinions into account and providing extra employment to local communities. The local communities are the sources of both voices that should be listened to in the decision-making process and participants who have great potential to contribute to ecosystem protection and natural resource management. In addition to community-level stakeholders, special attention should be paid to other stakeholder groups (such as women and ethnic minorities) who are at risk of being marginalized. The involvement of multilevel stakeholders has great potential to foster sustainable local livelihoods with local equality and public engagement, and to address the complex problems at the intersection of society and the environment.

**Coordinating the relationship between cultural customs, local awareness and ecological protection**

Most countries along the LMB have solid religious backgrounds and complex ethnic compositions. Religion may attach importance to spiritual cultivation and respect for all living things, and this objectively plays a vital role in the protection of forest resources. However, with changes in modern lifestyles and values, the influence of religion and culture is gradually becoming weaker. National economic development plans could consider coordinating the relationship between culture and customs on environmental protection, advocating new culture-benefited ways of life and living and contributing to sustainable livelihoods.

The importance of ecosystem management should be communicated to enterprises, local communities and the general public to help fully engage them in local and regional ecological protection. To fully involve companies, local communities, and the general public in local and regional ecological protection, awareness of the importance of ecosystem management must be developed among enterprises, local communities, and the general public. Corporate social responsibility is a critical component of ecosystem management. Communities' capacity to participate in ecosystem management should be strengthened, especially through public and school education.

**Exploring limited land for more agroforestry production**

One of the most serious threats to biodiversity comes from the LMB's shift from subsistence farming to commercial agriculture. In the case of both the upper and lower LMB, the health of the ecosystem and its capacity to provide ecosystem services have been negatively influenced by the expansion of single economy agricultural products. Forest habitats are converted by agricultural enterprises into farmland for crops like cashew in the lower LMB and rubber in the upper LMB. Fortunately, both areas have tried exploring more complex ecosystem alternatives. Recognizing that men and women have different roles to play in society and that women are significantly impacted by environmental stressors helps in finding more effective and sustainable solutions that benefit everyone in society, including the most vulnerable populations. In Mengla County, planting shrubs and herbal cash crops or raising poultry in the rubber forest are methods used to improve the approach of planting a single rubber forest and promote sustainable development of the rubber industry. This leads to a larger range of crops being grown, provides more flexibility, and improves the region's ability to adapt to market changes.

**Incorporating stepwise ecological restoration to reverse the trend towards degradation of natural ecosystems**

Natural forest degradation is one of the critical constraints holding back the sustainable development of the pilot areas in both Cambodia and China, as well as the entire LMB. New ecological restoration initiatives and programmes should be planned at the international level and implemented in different regions of the LMB. The management of natural forest ecosystems must be improved in order to increase production without sacrificing other functions including regulating, cultural, and sustaining services. In order to do this, management of the LMB's forest ecosystems should focus on improving the quality of the forest as well as increasing forest cover. It is essential to combine environmental distribution patterns, inter-species relationships, niche, community succession and other principles to construct a systematic ecological restoration technology.

Stepwise ecological restorations (STERE) have been suggested to improve the ecological conditions of natural ecosystems according to different degradation levels, and in different social and economic contexts. STERE is a comprehensive ecological restoration framework that uses a cross-ecosystem theory to enhance the application of the international standards for promoting higher ecological benefits. It aims to implement restorative activities by considering the degree of ecosystem degradation and financial, ecological and institutional feasibility, and by selecting appropriate restorative modes and paths to progressively recover ecological processes, functions, services and biodiversity. For example, fragile regions of the LMB, where natural forest has been severely degraded or fragmented – but is essential for biodiversity conservation, carbon sequestration and so on – should be strictly protected from conversion into other land-use types. In moderately degraded natural forests, intensive management should be implemented to restore the natural ecosystems that provide regulating services, such as soil erosion control and carbon sequestration, while allowing reasonable development of agroforestry. Slightly degraded forests should be improved to near-natural forest by natural regeneration, with more forest products, if management for biodiversity and ecosystem services allows.

**Increasing eco-compensation and financial support**

Enhancing ecosystem health and sustainable livelihoods along the entire LMB requires significant investment, and this is dependent on sustained and stable policies, financial support and public participation. Multilevel, multichannel, gender-responsive and diversified financing methods should be explored. When the time is right, it will be vital to try to ensure the smooth implementation of livelihood-based ecological restoration by prioritizing the input of farmers, society and enterprises, as well as appropriate subsidies from the government.

To increase the ecosystem services financed by their beneficiaries, eco-compensation policies should be established and pilot activities should be carried out. The idea that "whoever utilizes the services should pay the expenses" should be used wherever beneficiaries can be identified explicitly (such as for provisioning and cultural services) while also protecting the requirements of the local people who depend on the ecosystem services for their livelihoods. A non-commercial compensation fund for the persons responsible for preserving the relevant wetlands and forests should be established when beneficiaries cannot be readily identified (i.e., for regulating and supporting services such as pollination).

In the process of executing programs to convert farmland to forest (or grassland), as well as water and soil conservation programs, a variety of investment and funding models have arisen. To increase the impact of money from the private sector, pilot activities on investment and finance methods as well as preferential policies should be established.

Payments and compensation should be created for the provision of services that are not presently market-based, such as carbon storage, water and climate regulation, pollination, and cultural services, in order to promote better fairness between impoverished rural regions delivering services and metropolitan customers. This would allow those who supply these services to get some financial compensation as an incentive to protect the source ecosystems from those who benefit from these services, so contributing to the "win-win" outcomes of conservation, service provision, and poverty alleviation. Gender-responsive financial approaches should also be promoted. As many women do not own property, they have restricted access to credit and loans. Therefore, ensuring that women are also considered in financing mechanisms is a critical step toward eradicating poverty. Through cooperation among countries, departments and industries in the Lancang-Mekong region, limited resources should be invested in ecological improvement to jointly promote the sustainable development of the ecosystem.

# References


Aires, F., Venot, J.P., Massuel, S., Gratiot, N., Pham-Duc, B., and Prigent C. (2020). Surface water evolution (2001–2017) at the Cambodia/Viet Nam border in the Upper Mekong Delta using sat100lite MODIS observations. *Remote Sensing* 12(5), 800. https://doi.org/10.3390/rs12050800.

Arias, M.E., Cochrane, T. A., Piman, T., Kummu, M., Caruso, B. S., and Killeen, T.J. (2012). Quantifying changes in flooding and habitats in the Tonle Sap Lake (Cambodia) caused by water infrastructure development and climate change in the Mekong Basin. *Journal of Environmental Management*, 112, 53-66. https://doi.org/10.1016/j.jenvman.2012.07.003

Asian Development Bank (2015). *Investing in Natural Capital for a Sustainable Future in the Greater Mekong Subregion*. Mandaluyong City, Philippines.

Berg, M., Stengel, C., Trang, P.T.K, Viet, P.H, Sampson, M.L., Leng, M. *et al.* (2007). Magnitude of arsenic pollution in the Mekong and Red River Deltas – Cambodia and Viet Nam. *Science of the Total Environment* 372(2–2), 413–425. https://doi.org/10.1016/j.scitotenv.2006.09.010.

Bonheur, N. and Lane, B.D. (2002). Natural resources management for human security in Cambodia's Tonle Sap Biosphere Reserve. *Environmental Science & Policy* 5(1), 33–41. https://doi.org/10.1016/S1462-9011(02)00024-2.

Bontemps, S., Herold, M., Kooistra, L., Van Groenestijn, A., Hartley, A., Arino, O. *et al.* (2012). Revisiting land cover observation to address the needs of the climate modeling community. *Biogeosciences*, 9(6), 2145–2157. https://doi.org/10.5194/bg-9-2145-2012.

Brewer, J., Langston, J.D., Ferretti-Gallon, K., Innes, J.L., Xin, S., Zhai, H. *et al.* (2020). Alleviating forest degradation in the Lancang-Mekong Region requires closing management-measurement gaps. *Journal of Forestry Research* 31(8), 1–19. https://doi.org/10.1007/s11676-020-01111-z.

Bui, T.K.L., Do-Hong, L.C., Dao, T.S., and Hoang, T.C. (2016). Copper toxicity and the influence of water quality of Dongnai River and Mekong River waters on copper bioavailability and toxicity to three tropical species. *Chemosphere* 144, 872–878. https://doi.org/10.1016/j.chemosphere.2015.09.058.

Campbell, I.C., Poole, C., Giesen, W., and Valbo-Jorgensen, J. (2006). Species diversity and ecology of Tonle Sap Great Lake, Cambodia. *Aquatic Sciences*, 68(3), 355–373. https://doi.org/10.1007/s00027-006-0855-0.

Campbell, I.C. (2009). Development scenarios and Mekong River flows. In The Mekong. *Biophysical Environment of an International River Basin*. Campbell, I.C. (ed.). Amsterdam. Elsevier. Chapter 16. 389–402.

Campbell, I.C. (2012). Biodiversity of the Mekong Delta. In *The Mekong Delta System. Interdisciplinary Analyses of a River Delta*. Renaud, F.G. and Kuenzer, C. (eds.). Springer Dordrecht. 293–313.

Chadwick, M.T., Juntopas, M., and Sithirith, M. (2008). Change of hydrology and fishery impacts in the Tonle Sap. The Sustainable Mekong Research Network (Sumernet). Bangkok. Retrieved from www.sumernet.org

Chea, R., Grenouillet, G. and Lek, S. (2016). Evidence of water quality degradation in Lower Mekong Basin revealed by self-organizing map. *PLOS ONE* 11(1), e0145527. https://doi.org/10.1371/journal.pone.0145527.

Chen, A., Chen, D. and Azorin-Molina, C. (2018). Assessing reliability of precipitation data over the Mekong River Basin: A comparison of ground-based, satellite, and reanalysis datasets. *International Journal of Climatology*, 38(11), 4314–4334. https://doi.org/10.1002/joc.5670.

Chen, A., Ho, C.H., Chen, D., and Azorin-Molina, C. (2019). Tropical cyclone rainfall in the Mekong River Basin for 1983–2016. *Atmospheric Research* 226, 66–75. https://doi.org/10.1016/j.atmosres.2019.04.012.

Chen, A., Liu, J., Kummu, M., Varis, O., Tang, Q., Mao, G., and Chen, D. (2021). Multidecadal variability of the Tonle Sap Lake flood pulse regime. *Hydrological Processes*, 35(9), e14327. https://doi.org/10.1002/hyp.14327

Chen, A., Chen, A., Varis, O., and Chen, D. (2022). Large net forest loss in Cambodia's Tonle Sap Lake protected areas during 1992–2019. *Ambio*, 1-15. https://doi.org/10.1007/s13280-022-01704-4

Chen, Y., Marino, J., Chen, Y., Tao, Q., Sullivan, C.D., Shi, K. *et al.* (2016). Predicting hotspots of human-elephant conflict to inform mitigation strategies in Xishuangbanna, Southwest China. *PLOS ONE* 11, e0162035. https://doi.org/10.1371/journal.pone.0162035.

Cochrane, T.A., Arias, M.E., and Piman, T. (2014). Historical impact of water infrastructure on water levels of the Mekong River and the Tonle Sap system. *Hydrology and Earth System Sciences*, 18(11), 4529-4541. https://doi.org/10.5194/hess-18-4529-2014.

Dang, T.D., Cochrane, T., and Arias, M.E. (2018). Future hydrological alterations in the Mekong Delta under the impact of water resources development, land subsidence and sea level rise. *Journal of Hydrology: Regional Studies* 15, 119–133. https://doi.org/10.1016/j.ejrh.2017.12.002.

Davies, K. (2013). *Mapping Changes in Vegetation Cover Using Multiple Satellite Sensors: A Case Study of the Phnom Kulen National Park, Cambodia.*

Delgado, J.M., Apel, H., and Merz, B. (2010). Flood trends and variability in the Mekong River. *Hydrology and Earth System Sciences* 14, 407–418. https://doi.org/10.5194/hess-14-407-2010.

Desmet, P.J.J. and Govers, G. (1996). A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *Journal of soil and water conservation*, 51(5), 427-433.

Dou, Y., Zhen, L., Yu, X., Bakker, M., Carsjens, G.J., and Xue, Z. (2019). Assessing the influences of ecological restoration on perceptions of cultural ecosystem services by residents of agricultural landscapes of western China. *Science of the Total Environment*, 646, 685-695. https://doi.org/10.1016/j.scitotenv.2018.07.205.

Dou, Y., Liu, M., Bakker, M., Yu, X., Carsjens, G.J., de Groot, R. *et al.* (2021). Influence of human interventions on local perceptions of cultural ecosystem services provided by coastal landscapes: Case study of the Huiwen wetland, southern China. *Ecosystem Services* 50, 101311. https://doi.org/10.1016/j.ecoser.2021.101311.

Dou, Y., Yu, X. and Liu, Y. (2021). Rethinking non-material links between people and drylands from a cultural ecosystem services perspective. *Current Opinion in Environmental Sustainability*, 48, 110-114. https://doi.org/10.1016/j.cosust.2020.12.007.

Dugan, P.J., Barlow, C., Agostinho, A.A., Baran, E., Cada, G.F., Chen, D. *et al.* (2010). Fish migration, dams, and loss of ecosystem services in the Mekong Basin. *AMBIO* 39(4), 344–348. https://doi.org/10.1007/s13280-010-0036-1.

Eastham, J., Mpelasoka, F., Mainuddin, M., Ticehurst, C., Dyce, P., Hodgson, G. *et al.* (2008). Mekong River basin water resources assessment: impacts of climate change. *CSIRO*. https://doi.org/10.25919/z6mm-z569.

Erban, L.E., Gorelick, S.M., and Zebker, H.A. (2014). Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Viet Nam. *Environmental Research Letters* 9(8), 084010. http://dx.doi.org/10.1088/1748-9326/9/8/084010.

Erban, L.E., Gorelick, S.M., Zebker, H.A., and Fendorf, S. (2013). Release of arsenic to deep groundwater in the Mekong Delta, Viet Nam, linked to pumping-induced land subsidence. *Proceedings of the National Academy of Sciences* 110(34), 13751–13756. https://doi.org/10.1073/pnas.1300503110.

Felfelani, F., Wada, Y., L. Longuevergne, L., and Pokhrel, Y.N. (2017). Natural and human-induced terrestrial water storage change: A global analysis using hydrological models and GRACE. *Journal of Hydrology* 553, 105–118. https://doi.org/10.1016/j.jhydrol.2017.07.048.

Fendorf, S., Michael, H.A., and van Geen, A. (2010). Spatial and temporal variations of groundwater arsenic in South and Southeast Asia. *Science* 328(5982), 1123–1127. https://doi.org/10.1126/science.1172974.

Food and Agriculture Organization of the United Nations (2011). *FAO AQUASTAT Reports. Transboundary River Basin Overview – Mekong*. Rome.

Forest Trends (2015). *Conversion Timber, Forest Monitoring, and Land-Use Governance in Cambodia*. Forest Trends Report Series: Forest Trade and Finance. Retrieved from www.forest-trends.org.

Frenken, K. (2012). *Irrigation in Southern and Eastern Asia in Figures: Aquastat Survey, 2011*. Rome. Food and Agriculture Organization of the United Nations.

Friederich, H. (2004). *The biodiversity of the wetlands in the Lower Mekong River Basin*. The World Commission on Dams, Cape Town, South Africa. Retrieved August.

Fu, Y., Brookfield, H., Guo, H., Chen, J., Chen, A., and Cui, J. (2009). Smallholder rubber plantation expansion and its impact on local livelihoods, land use and agrobiodiversity, a case study from Daka, Xishuangbanna, southwestern China. *International Journal of Sustainable Development and World Ecology* 16(1), 22–29. https://doi.org/10.1080/13504500902753246.

Gao, J., Yao, T., Masson-Delmotte, V., Steen-Larsen, H.C., and Wang, W. (2019). Collapsing glaciers threaten Asia's water supplies. *Nature* 565(7737), 19–21. https://doi.org/10.1038/d41586-018-07838-4.

Geurs, K.T. and Ritsema van Eck, J.R. (2001). *Accessibility measures: review and applications. Evaluation of accessibility impacts of land-use transportation scenarios, and related social and economic impact*. RIVM rapport 408505006.

Gibbs, H.K. and Ruesch, A. (2008). New IPCC Tier-1 *Global Biomass Carbon Map for the Year 2000*. Available online from the Carbon Dioxide Information Analysis Center [http://cdiac.ess-dive.lbl.gov], Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Grumbine, R.E., Dore, J., and Xu, J. (2012). Mekong hydropower: drivers of change and governance challenges. *Frontiers in Ecology and the Environment* 10(2), 91–98. https://doi.org/10.1890/110146.

Ha, K., Ngoc, N., Lee, E., and Jayakumar, R. (2015). *Current status and issues of groundwater in the Mekong River basin*. Korea Institute of Geoscience and Mineral Resources (KIGAM), CCOP Technical Secretariat, UNESCO Bangkok Office.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A. *et al.* (2013). High-resolution global maps of 21st century forest cover change. Science 850: 850–854. https://doi.org/10.1126/science.1244693.

He, D. and Chen, L. (2002). *The impact of hydropower cascade development in the Lancang–Mekong Basin, Yunnan*. Mekong Update and Dialogue, 5(3), 2-4.

Hecht, J.S., Lacombe, G., Arias, M.E., Dang, D.T., and Piman, T. (2019). Hydropower dams of the Mekong River basin: A review of their hydrological impacts. *Journal of Hydrology* 568, 285–300. https://doi.org/10.1016/j.jhydrol.2018.10.045.

Hoang, L.P., Lauri, H., Kummu, M., Koponen, J., van Vliet, M.T.H., Supit, I. *et al.* (2016). Mekong River flow and hydrological extremes under climate change. *Hydrology and Earth System Sciences*, 20(7), 3027–3041. https://doi.org/10.5194/hess-20-3027-2016.

Hoang, L.P., van Vliet, M.T.H., Kummu, M., Lauri, H., Koponen, J., Supit, I. *et al.* (2019). The Mekong's future flows under multiple drivers: How climate change, hydropower developments and irrigation expansions drive hydrological changes. *Science of the Total Environment* 649, 601–609. https://doi.org/10.1016/j.scitotenv.2018.08.160.

International Union for Conservation of Nature (2011). *Groundwater in the Mekong Delta*. Helsinki.

Xu, J. (2006). The political, social, and ecological transformation of a landscape. *Mountain Research and Development* 26(3), 254–262. https://doi.org/10.1659/0276-4741(2006)26[254:TPSAET]2.0.CO;2.

Jin, Y. and Fan, H. (2018). Land use/land cover change and its impacts on protected areas in Mengla County, Xishuangbanna, Southwest China. *Environmental Monitoring and Assessment* 190(9), 1–16. https://doi.org/ 10.1007/s10661-018-6891-0. PMID: 30094764.

Johnston, R. and Kummu, M. (2012). Water resource models in the Mekong Basin: A review. *Water Resources Management* 26, 429–455. https://doi.org/10.1007/s11269-011-9925-8

Johnstone, G.J., Puskur, R., Declerck, F., Mam, K., Oeur, I., Sithirith, M. *et al.* (2013). Tonle Sap Scoping Report. CGIAR Research Program on Aquatic Agricultural Systems. CGIAR. Penang, Project Report: AAS-2013-28. Retrieved from aas.cgiar.org

Junk, W., Bayley, P.B., and Sparks, R.E. (1989). The flood pulse concept in river-floodplain systems. *Canadian Journal of Fisheries and Aquatic Sciences* 106, 110–127. Retrieved from http://www.dfo-mpo.gc.ca/Library/111846.pdf

Kent, W. (2022). *Scientists discover 224 new species in the Greater Mekong*. 3 February 2022. Retrieved from https://www.worldwildlife.org/stories/scientists-discover-224-new-species-in-the-greater-mekong.

Keskinen, M. (2003). *Socio-economic survey of the Tonle Sap Lake, Cambodia*. Helsinki University of Technology.

Kiem, A.S., Ishidaira, H., Hapuarachchi, H.P., Zhou, M.C., Hirabayashi, Y., and Takeuchi, K. (2008). Future hydroclimatology of the Mekong River basin simulated using the high-resolution Japan Meteorological Agency (JMA) AGCM. *Hydrological Processes* 22, 1382–1394. https://doi.org/10.1002/hyp.6947.

Kingston, D.G., Thompson, J.R., and Kite, G. (2011). Uncertainty in climate change projections of discharge for the Mekong River Basin. Hydrology and Earth System Sciences, 15(5), 1459-1471. https://doi.org/10.5194/hess-15-1459-2011.

Koerper, K. (2019). *Participation in community protected area management: Lessons from Phnom Kulen National Park, Cambodia*.

Kummu, M., Sarkkula, J., Koponen, J., and Nikula, J. (2006). Ecosystem management of the Tonle Sap Lake: An integrated modelling approach. *International Journal of Water Resources Development*, 22(3), 497–519. https://doi.org/10.1080/07900620500482915.

Kummu, M. and Varis, O. (2007). Sediment-related impacts due to upstream reservoir trapping, the Lower Mekong River. *Geomorphology*, 85(3-4), 275-293. https://doi.org/10.1016/j.geomorph.2006.03.024

Kummu, M. and Sarkkula, J. (2008). Impact of the Mekong River flow alteration on the Tonle Sap flood pulse. *Ambio*, 37(3), 185–192. https://doi.org/10.1579/0044-7447(2008)37[185:iotmrf]2.0.co;2.

Lamberts, D. (2006). The Tonle Sap Lake as a productive ecosystem. *International Journal of Water Resources Development*, 22(3), 481–495. https://doi.org/10.1080/07900620500482592.

Lauri, H., de Moel, H., Ward, P.J., Räsänen, T.A., Keskinen, M., and Kummu, M. (2012). Future changes in Mekong River hydrology: impact of climate change and reservoir operation on discharge. *Hydrology and Earth System Sciences* 16, 4603–4619. https://doi.org/10.5194/hess-16-4603-2012.

Li, D., Long, D., Zhao, J., Lu, H., and Hong, Y. (2017). Observed changes in flow regimes in the Mekong River basin. *Journal of Hydrology* 551, 217–232. http://doi.org/ 10.1016/j.jhydrol.2017.05.061.

Li, S. and He, D. (2008). Water level response to hydropower development in the Upper Mekong River. *Ambio* 37(3), 170–177. https://doi.org/10.1579/0044-7447(2008)37[170:wlrthd]2.0.co;2.

Li, X., Liu, J.P., Saito, Y., and Nguyen, V.L. (2017). Recent evolution of the Mekong Delta and the impacts of dams. *Earth-Science Reviews* 175(5), 1–17. https://doi.org/ 10.1016/j.earscirev.2017.10.008.

Liu, J., Bawa, K.S., Seager, T.P., Mao, G., Ding, D., Lee, J.S.H. et al. (2019). On knowledge generation and use for sustainability. *Nature Sustainability* 2, 80–82. https://doi.org/10.1038/s41893-019-0229-y

Liu, J., Chen, D., Mao, G., Irannezhad, M., and Pokhrel, Y. (2022). Past and future changes in climate and water resources in the Lancang–Mekong River Basin: Current understanding and future research directions. *Engineering* 13, 144–152. https://doi.org/10.1016/j.eng.2021.06.026.

Lutz A., Terink, W., Droogers, P., Immerzeel, W.W., and Piman, T. (2014). Development of baseline climate data set and trend analysis in the Mekong Basin. Wageningen. Future Water.

McKenney, B. and Tola, P. (2002). *Natural Resources and Rural Livelihoods in Cambodia: A Baseline Assessment (Working Paper 23)*. Phnom Penh. Cambodia Development Resource Institute.

Mekong River Commission (2005). *Overview of the Hydrology of the Mekong Basin*. Vientiane.

Mekong River Commission (2010). *State of the Basin Report 2010*. Vientiane.

Mekong River Commission (2016). *Integrated Water Resources Management-Based Basin Development Strategy 2016–2020*. Vientiane.

Mekong River Commission (2018a). *Macro-economic Assessment Report*. Vientiane.

Mekong River Commission (2018b). *State of the Basin Report 2018*. Vientiane.

Merola, R.B., Hien, T.T., Quyen, D.T.T., and Vengosh, A. (2015). Arsenic exposure to drinking water in the Mekong Delta. *Science of the Total Environment* 511, 544–552. https://doi.org/10.1016/j.scitotenv.2014.12.091.

Meur, M.L., Phu, V.L., and Gratiot, N. (2021). What is the future of the Lower Mekong Basin struggling against human activities? A review. In *River Deltas Research. Recent Advances*. Manning, A.J. (ed.). London. IntechOpen. https://doi.org/10.5772/intechopen.95010.

Minderhoud, P.S.J., Erkens, G., Pham, V.H., Bui, V.T., Erban, L., Kooi, H. *et al.* (2017). Impacts of 25 years of groundwater extraction on subsidence in the Mekong delta, Viet Nam. *Environmental Research Letters* 12(6), 064006. https://doi.org/10.1088/1748-9326/aa7146.

Mohammed, I.N., Bolten, J.D., Srinivasan, R., and Lakshmi, V. (2018). Satellite observations and modeling to understand the Lower Mekong River Basin streamflow variability. *Journal of Hydrology* 564, 559–573. https://doi.org/10.1016/j.jhydrol.2018.07.030.

Myers, N., Mittermeler, R.A., Mittermeler, C.G., da Fonseca, G.A.B., and Kent, J. (2000). *Biodiversity hotspots for conservation priorities*. *Nature* 403, 853–858.

Nesbitt, H., Johnston, R., and Solieng, M. (2004). Mekong River water: Will river flows meet future agriculture needs in the Lower Mekong Basin? *Water in Agriculture* 116, 86–104.

Nhan, N.H. and Cao, N.B. (2019). Damming the Mekong: Impacts in Viet Nam and solutions. *In Coasts and Estuaries: The Future*. Wolanski, E., Day, J., Elliott, M. and Ramachandran, R. (eds.). Amsterdam. Elsevier. Chapter 19, 321–340.

Nie, J., Ruetenik, G., Gallagher, K., Hoke, G., Garzione, C.N., Wang, W. *et al.* (2018). Rapid incision of the Mekong River in the middle Miocene linked to monsoonal precipitation. *Nature Geoscience* 11(12), 944–948. https://doi.org/10.1038/s41561-018-0244-z.

Paracchini, M.L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J.P., *et al.* (2014). Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU. *Ecological indicators*, 45, 371-385. https://doi.org/10.1016/j.ecolind.2014.04.018

Pekel, J.F., Cottam, A., Gorelick, N., and Belward, AS. (2016). High-resolution mapping of global surface water and its long-term changes. *Nature*, 540(7633), 418-422. https://doi.org/10.1038/nature20584

Piman, T., Cochrane, T.A., and Arias, M.E. (2016). Effect of proposed large dams on water flows and hydropower production in the Sekong, Sesan and Srepok Rivers of the Mekong Basin. *River Research and Applications* 32(10), 2095–2108. https://doi.org/10.1002/rra.3045.

Podgorski, J. and Berg, M. (2020). Global threat of arsenic in groundwater. Science 368(6493), 845–850. https://doi.org/10.1126/science.aba1510.

Pokhrel, Y.N., Hanasaki, N., Yeh, P.J.F., Yamada T.J., Kanae, S., and Oki, T. (2012). Model estimates of sea-level change due to anthropogenic impacts on terrestrial water storage. *Nature Geoscience* 5(6), 389–392. https://doi.org/10.1038/ngeo1476.

Pokhrel, Y.N., Hanasaki, N., Wada, Y., and Kim, H. (2016). Recent progresses in incorporating human land–water management into global land surface models toward their integration into Earth system models. *Wiley Interdisciplinary Reviews: Water* 3, 548–574. https://doi.org/10.1002/wat2.1150.

Pokhrel, Y., Burbano, M., Roush, J., Kang, H., Sridhar, V., and Hyndman, D.W. (2018a). A review of the integrated effects of changing climate, land use, and dams on Mekong River Hydrology. *Water* 10(3), 266. https://doi.org/10.3390/w10030266.

Pokhrel, Y., Shin, S., Lin, Z., Yamazaki, D., and Qi, J. (2018b). Potential disruption of flood dynamics in the Lower Mekong River Basin due to upstream flow regulation. *Scientific Reports* 8, 17767. https://doi.org/10.1038/s41598-018-35823-4.

Räsänen, T.A., Koponen, J., Lauri, H., and Kummu, M. (2012). Downstream hydrological impacts of hydropower development in the Upper Mekong Basin. *Water Resources Management* 26, 3495–3513. https://doi.org/10.1007/s11269-012-0087-0.

Räsänen, T.A., Someth, P., Lauri, H., Koponen, J., Sarkkula, J., and Kummu, M. (2017). Observed river discharge changes due to hydropower operations in the Upper Mekong Basin. *Journal of Hydrology*, 545, 28-41. https://doi.org/10.1016/j.jhydrol.2016.12.023.

Reinecke, R., Müller Schmied, H., Trautmann, T., Andersen, L.S., Burek, P., Flörke, M. *et al.* (2021). Uncertainty of simulated groundwater recharge at different global warming levels: a global-scale multi-model ensemble study. *Hydrology and Earth System Sciences* 25, 787–810. https://doi.org/10.5194/hess-25-787-2021.

Ruiz-Barradas, A. and Nigam, S. (2018). Hydroclimate variability and change over the Mekong River Basin: Modeling and predictability and policy implications. *Journal of Hydrometeorology* 19(5), 849–869. https://doi.org/10.1175/JHM-D-17-0195.1.

Salmivaara, A., Kummu, M., Varis, O., and Keskinen, M. (2016). Socio-economic changes in Cambodia's unique Tonle Sap Lake Area: A spatial approach. *Applied Spatial Analysis and Policy*, 9(3), 413–432. https://doi.org/10.1007/s12061-015-9157-z.

Schmitt, R.J., Bizzi, S., Castelletti, A., Opperman, J.J., and Kondolf, G.M. (2019). Planning dam portfolios for low sediment trapping shows limits for sustainable hydropower in the Mekong. *Science advances*, 5(10), eaaw2175. https://doi.org/10.1126/sciadv.aaw2175

Shin, S., Pokhrel, Y., Yamazaki, D., Huang, X., Torbick, N., Qi, J. et al. (2020). High resolution modeling of river-floodplain-reservoir inundation dynamics in the Mekong River Basin. *Water Resources Research* 56(5). https://doi.org/10.1029/2019WR026449.

Shrestha, S., Anal, A., Salam, P., and van der Valk, M. (2016). *Managing Water Resources Under Climate Uncertainty: Examples from Asia, Europe, Latin America and Australia*. Springer.

Shrestha, S., Bach, T.V., and Pandey, V.P. (2016). Climate change impacts on groundwater resources in Mekong Delta under representative concentration pathways (RCPs) scenarios. *Environmental Science & Policy* 61(C), 1–13. https://doi.org/10.1016/j.envsci.2016.03.010.

Singh, M., Evans, D., Chevance, J.B., Tan, B.S., Wiggins, N., Kong, L., *et al.* (2019). Evaluating remote sensing datasets and machine learning algorithms for mapping plantations and successional forests in Phnom Kulen National Park of Cambodia. *PeerJ*, 7, e7841. https://doi.org/10.7717/peerj.7841

Smajgl, A., Toan, T.Q., Nhan, D.K., Ward, J., Trung, N.H., Tri, L.Q. *et al.* (2015). Responding to rising sea levels in the Mekong Delta. *Nature Climate Change* 5, 167–174. https://doi.org/10.1038/nclimate2469.

Sodhi, N.S., Posa, M.R.C., Lee, T.M., Bickford, D., Koh, L.P., and Brook, B.W. (2010). The state and conservation of Southeast Asian biodiversity. *Biodiversity and Conservation* 19(2), 317–328. https://doi.org/10.1007/s10531-009-9607-5.

Sothearith, Y., Appiah, K.S., Motobayashi, T., Watanabe, I., Somaly, C., Sugiyama, A., *et al.* (2020). Evaluation of Allelopathic Potentials from Medicinal Plant Species in Phnom Kulen National Park, Cambodia by the Sandwich Method. *Sustainability*, 13(1), 264. https://doi.org/10.3390/su13010264

Spruce, J., Bolten, J., Mohammed, I.N., Srinivasan, R., and Lakshmi, V. (2020). Mapping land use land cover change in the Lower Mekong Basin from 1997 to 2010. *Frontiers in environmental science*, 8, 21. https://doi.org/10.3389/fenvs.2020.00021

Tang, J., Yin, X., Yang, P., and Yang, Z. (2015). Climate-induced flow regime alterations and their implications for the Lancang River, China. *River Research and Applications* 31(4), 422–432. https://doi.org/10.1002/rra.2819.

Thilakarathne, M. and Sridhar, V. (2017). Characterization of future drought conditions in the Lower Mekong River Basin. *Weather and Climate Extremes* 17, 47–58. https://doi.org/10.1016/j.wace.2017.07.004.

Trang, N.T.T., Shrestha, S., Shrestha, M., Datta, A., and Kawasaki, A. (2017). Evaluating the impacts of climate and land-use change on the hydrology and nutrient yield in a transboundary river basin: A case study in the 3S River Basin (Sekong, Sesan, and Srepok). *Science of the Total Environment* 576, 586–598. https://doi.org/10.1016/j.scitotenv.2016.10.138.

Tweed, S., Massuel, S., Seidel, J.L., Chhuon, K., Lun, S., Eang, K.E. *et al.* (2020). Seasonal influences on groundwater arsenic concentrations in the irrigated region of the Cambodian Mekong Delta. *Science of the Total Environment* 728, 138598. https://doi.org/ 10.1016/j.scitotenv.2020.138598.

Uk, S., Yoshimura, C., Siev, S., Try, S., Yang, H., Oeurng, C., *et al.* (2018). Tonle Sap Lake: Current status and important research directions for environmental management. *Lakes and Reservoirs: Science, Policy and Management for Sustainable Use*, 23(3), 177–189. https://doi.org/10.1111/lre.12222.

United Nations Educational, Scientific and Cultural Organization (2020). Phnom Kulen: Archeological Site/Ancient Site of Mahendraparvata. Retrieved from https://whc.unesco.org/en/tentativelists/6460/.

United Nations Environment Programme (2006). *Mekong River, GIWA Regional Assessment 55*. Kalmar, Sweden.

Valbo-Jørgensen, J., Coates, D., and Hortle, K. (2009). Fish Diversity in the Mekong River Basin. In *The Mekong. Biophysical Environment of an International River Basin*. Campbell, I.C. (ed.). Chapter 8, 161–196. https://doi.org/10.1016/B978-0-12-374026-7.00008-5.

Västilä, K., Kummu, M., Sangmanee, C., and Chinvanno, S. (2010). Modelling climate change impacts on the flood pulse in the Lower Mekong floodplains. *Journal of Water and Climate Change* 1(1), 67–86. https://doi.org/10.2166/wcc.2010.008

Veldkamp, T.I.E., Wada, Y., Aerts, J.C.J.H., Döll, P., Gosling, S.N., Liu, J., *et al.* (2017). Water scarcity hotspots travel downstream due to human interventions in the 20th and 21$^{st}$ century. *Nature communications*, 8(1), 1-12. https://doi.org/10.1038/ncomms15697.

Wada, Y., van Beek, L.P.H., van Kempen, C.M., Reckman, J.W.T.M., Vasak, S., and Bierkens, M.F.P. (2010). Global depletion of groundwater resources. *Geophysical Research Letters* 37(20). https://doi.org/10.1029/2010GL044571

Wagner, F., Tran, V.B., and Renaud, F.G. (2012). *Groundwater resources in the Mekong Delta: availability, utilization and risks*. In The Mekong Delta System (pp. 201-220). Springer, Dordrecht.

Wang, Y., Feng, L., Liu, J., Hou, X., and Chen, D. (2020). Changes of inundation area and water turbidity of Tonle Sap Lake: responses to climate changes or upstream dam construction? *Environmental Research Letters* 15, 0940a1. https://doi.org/10.1088/1748-9326/abac79.

Water Environment Partnership in Asia (2010). *State of Water Environmental Issues: Cambodia*. Retrieved from http://www.wepa-db.net/policies/state/cambodia/

White, I. (2002). *Water Management in the Mekong Delta: Changes, Conflicts and Opportunities*. Canberra. Centre for Resource and Environmental Studies.

Whitehead, P.G., Jin, L., Bussi, G., Voepel, H.E., Darby, S.E., Vasilopoulos, G., and Hung, N.N. (2019). Water quality modelling of the Mekong River basin: Climate change and socioeconomics drive flow and nutrient flux changes to the Mekong Delta. *Science of the total environment*, 673, 218-229. https://doi.org/10.1016/j.scitotenv.2019.03.315

World Wide Fund for Nature (2013). *Ecosystems in the Greater Mekong: Past trends, current status, possible futures*.

World Wide Fund for Nature (2014). *Mysterious Mekong. New Species Discoveries 2012–2013*.

Xi, L.X., Jian-Jun, W., and Grundy-Warr, C. (2008). Are the Chinese dams to be blamed for the lower water levels in the Lower Mekong? *Modern Myths of the Mekong*, 39-51.

Yang, L. and Wall, G. (2008). Ethnic tourism and entrepreneurship: Xishuangbanna, Yunnan, China. *Tourism Geographies*, 10(4), 522–544. https://doi.org/10.1080/14616680802434130.

Yao, T., Wu, G., Xu, B., Wang, W., Gao, J., and An, B. (2019). Asian water tower change and its impacts. *Bulletin of Chinese Academy of Sciences* 11, 1203–1209. https://doi.org/10.16418/j.issn.1000-3045.2019.11.003.

Fu, Y., Guo, H., Chen, A., and Cui, J. (2006). Household differentiation and on-farm conservation of biodiversity by indigenous households in Xishuangbanna, China. *Biodiversity and Conservation* 15(8), 2678-2703. https://doi.org/10.1007/978-1-4020-5283-5_19.

Zeng, Z., Estes, L., Ziegler, A.D., Chen, A., Searchinger, T., Hua, F. et al. (2018). Highland cropland expansion and forest loss in Southeast Asia in the twenty-first century. *Nature Geoscience* 11, 556–562. https://doi.org/10.1038/s41561-018-0166-9.

Zheng, Y. (2020). Global solutions to a silent poison. *Science* 368(6493), 818–819. https://doi.org/10.1126/science.abb9746.

Ziegler A.D., Fox, J.M., and Xu, J. (2009). The rubber juggernaut. *Science* 324(5930), 1024–1025. https://doi.org/10.1126/science.1173833.

Ziv, G., Baran, E., Nam, S., Rodriguez-Iturbe, I., and Levin, S.A. (2012). Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin. *Proceedings of the National Academy of Sciences* 109(15), 5609–5614. https://doi.org/10.1073/pnas.1201423109.

# Appendix A Information about the interviewees for the upper and lower LMB case studies

| Interviewee | Affiliation and brief description |
| --- | --- |
| Mr. Ratt Reouy | Head of Phnom Kulen CPAs network, lives on this mountain, used to work with other CPAs as well as the Siem Reap Provincial Department of Environment and non-governmental organizations to improve local livelihoods. |
| Mr. Sakoern Sakada | Director of Phnom Kulen National Park, used to work with the Archaeology and Development Foundation and the Ministry of the Environment to establish the CPA.<br>Has worked in Kulen for more than 10 years. |
| Mr. Chou Radina | Deputy Director, Department of Water System and Heritage, Authority for the Protection of the Site and the Management of the Region of Angkor (APSARA National Authority), has worked in Siem Reap and Kulen for more than 15 years. |
| Mr. Sun Kong | Director of Siem Reap Provincial Department of Environment, moved to this position about three years ago; used to work at Kulen Promtep Wildlife Sanctuary (the protected area next to PKNP). |
| Mr. Chheam Taing | Khnorn Phnom Commune chief, born here and has been in this position for about five years. |
| Mr. Xiaodong Yang | Professor at Xishuangbanna Tropical Botanical Garden (XTBG) of the Chinese Academy of Sciences (CAS), expert in ecological management and sustainable livelihoods in the upper LMB. |

# Appendix B Summarized interview scripts for the pilot study in the lower LMB, Phnom Kulen National Park[6]

## Group one

1. **What do you think are the essential local economic-related resources in the national park?**

   Answer: *Cashew nut plantation is the main income for almost everyone living on this mountain; then non-timber forest products such as Kulen (lychee) and Khunmear (Ancistrocladus tectorius)) but those are seasonal only. In addition to non-timber forest products, there are lot of cultural sites located inside the park, so these sites also contribute to local earnings.*

   **A. Could you please help with the changes in local income from 2010 to 2021?**

   Answer: *The income of the people living here depends on the price of cashew nuts. Over the last 10 years, a lot of new plantations have been developed. The people with larger farms earn more and more; however, people who depend on natural products are faring worse and worse.*

2. **Could you please rank the mentioned resources according to their importance to local livelihoods and explain why?**

   Answer: *Kulen provides the main income for local people, followed by Khunmear, Kuy, mushroom. Those products can create additional income during the harvest season; however, the Kulen bears fruit every two years.*

3. **Could you please describe the changes in the resources mentioned above over recent decades?**

   Answer: *The natural area is being disturbed. Most of the natural forest has been converted into chamkar (farm), so people have been able to collect fewer non-timber forest products from year to year.*
   **Are there any milestones or highlighted moments related to these changes?**
   Answer: *When the cashew nut become popular in the area (about 10 year ago)*

4. **How do you think those resources influence the income of residents?**

   Answer: *They affected some families who depend on natural resources; however, the families who shifted to farming earn a much higher income.*

[6] All transcripts are anonymous and have been translated from local languages.

5. **Do you think the changes are related to the increase in the local population? Why?**

   Answer: *The increasing number of people in the park is also part of the reason, because now we see there are lot of newcomers buying land and starting plantations.*

6. **How do the mentioned changes or resources influence the life of your own family and your own work? Could you please give some examples?**

   Answer: *My family cannot depend only on natural resources, so my son and daughter migrated to Thailand and Siem Reap, but during COVID they lost their jobs and returned home.*

## Group two

1. **What is the share of threatened species (vulnerable, endangered and critically endangered) among the total number of species within the national park? (e.g. what are the proportions?)**

   Answer: *There is no up-to-date study on biodiversity here. A full biodiversity assessment was conducted in Phnom Kulen in 2013. Recent information based on reports from rangers and the local village shows that gibbon, banteng and gaur are still present here, but there is no population data available.*

2. **To what level do you think biodiversity protection would be necessary for regional and local governance? Could you please explain why with some examples?**

   Answer: *As it is a national park and part of a protected area system, biodiversity protection would be most important at the local level to connect with the regional level, because only proper protection at the local level or in each protected area will make a good contribution to the regional level.*

3. **Are there any policy or management regulations already in place or in progress to protect or enhance biodiversity in the PKNP?**

   **A. If so, please explain.**

   Answer: *Yes. Law enforcement in this park is now based on the Protected Area Law 2008.*

   **B. If not, could you please comment on why?**

4. **Are there any invasive species?**

    **A. If so, could you explain which species and how serious the problem is?**

    Answer: *We don't know much about this.*

    **B. Have any measures been taken to control their expansion?**

    Answer: The Ministry of Environment used to produce a strategy to control Mimosa pigra, but I don't know what the situation is in Phnom Kulen.

5. **Is there any fragmentation in the PKNP? Could you please estimate the non-fragmented natural areas based on your knowledge or expertise?**

    Answer: *The natural forest here has been fragmented a lot, especially due to cashew nut plantations and new road construction.*

6. **What do you think, in general, about biodiversity in relation to local livelihoods? Could you please give some examples?**

    Answer: *This is a national park and is soon to be the heritage park. Biodiversity plays a very important role in this area, especially in relation to traditional medicine. There are a lot of traditional healers here, who earn a lot of money from selling traditional medicine, especially plants. In addition, the flowers, birds and gibbon here are the key to attracting the tourists.*

## Group three

1. **To what extent does the national park lie in a water stress area? (e.g. 10–20 per cent of the whole park)**

   Answer: *PKNP is the source of water for the Stueng (river) in Siem Reap, which is the main river that connects to Siem Reap and provides the groundwater to the temples in Siem Reap Province. Water from Phnom Kulen is recognized as holy water (Khmer beliefs). Because some forest areas have been converted into cashew nut plantations, most of the streams have experienced drought during the dry season. I think around 15 per cent of the national park lies in a water stress area.*

2. **Are any measures under consideration to relieve the water stress?**

   Answer: *Work is beginning on preparations for the PES [payment for ecosystems services] pilot in in PKNP and a few studies have been undertaken; especially on water availability and sediment in Phnom Kulen, as well as willingness to pay, but the policy document is still under consultation and being reviewed by the relevant stakeholders.*

3. **How do you think water stress in the PKNP will influence local livelihoods?**

   Answer: *There is very often drought during the dry season; more pipes have been installed to pump the water from the stream. Local people are reducing cultivation of plants (vegetables) that need more water. People in the city are digging or drilling wells much deeper from year to year. The people are no longer planting rice but cashew nut instead because it needs less water and effort.*

4. **How do you think water stress in the PKNP will influence biodiversity and local livelihoods?**

   Answer: *Some animals will move out to better places and some may disappear from this area; people whose livelihoods depend on the natural resources will switch their occupations or migrate somewhere too.*

## Group four

1. **Are there any infrastructure or large projects under construction or consideration? Could you please describe in more detail?**

   Answer: *Yes, a new concrete road is under construction from Svay Loue to Banteaysrey district and this road will provide better transportation for local people and tourists.*

2. **How do you think these construction projects will influence the condition of the local environment?**

   Answer: *Save more time, improve the connection with others, improve livelihoods. However, this construction has cleared a lot of natural forest, also there have been a lot of accidents.*

3. **How do you think these construction projects will influence current local livelihoods?**

   Answer: *Yes, people are able to transport their products more easily and save more money.*

4. **Is there any forest governance policy or practice? Could you please describe in more detail?**

   Answer: *Yes, we try to manage this area following the management that already prepared for this park. Based on this, the community here is also encouraging others to zone their communities and prepare management for these areas.*

5. **How do you think the forest governance policy will influence the condition of the local environment?**

   Answer: *Some people are not happy with the enforcement that we are doing; especially those who want to expand their plantation and grab the new natural areas. Those who love nature, on the other hand, understand the importance of happy nature and participate in our activities.*

6. **Are there any projects that reinforce forest governance and address illegal logging?**

   **A. If so, could you please describe in a little more detail? e.g. the approximate level of investment?**

   Answer: *Law enforcement here were dependent on government funding. Sometimes we got additional support for projects, but this was very limited.*

7. **How do you think the forest governance policy will influence current local livelihoods?**

   Answer: *Yes, this policy will help to ensure the future natural resources of this area and will also ensure their livelihoods too.*

## Group five

1. **How many inhabitants live in the region of PKNP, approximately?**

   **A. Could you please roughly describe the population changes in the past decade from your perspective?**

   Answer: *The population has almost doubled compared to 10 years ago; there are a lot of new houses, new farms, new roads, and those new people also come from outside too, they are buying the land here.*

   **B. Could you please further comment on what you think led to the changes?**

   Answer: *There will be more and more people in this area because the land here is good and also here is a good place for tourists, so local people can earn money too.*

2. **What are the main occupations of the inhabitants in/among the national park?**

   **A. How are they related to the resources mentioned above?**

   Answer: *Selling their labour in the cashew nut plantation.*

3. **Is there any conservation culture or activities?**

   **A. If so, how much is/will be the investment? When? By which stakeholder?**

   Answer: *Yes, mostly traditional medicinal plants, but those are just for use at the local level. We've now heard about the Strengthening Access and Benefit Sharing (ABS) project that wants to help local people to have their own traditional home garden, but I am not sure what they will support.*

4. **Is there any human-wildlife conflict?**

   Answer: *No.*

5. **Is there any project that promotes crop diversification, intercropping or crop rotation practices?**

   Answer: *No.*

6. **Is there any project that promotes a mixed farming system?**

   **A. If so, could you please describe it in more detail? e.g. the number of investments approximately?**

   Answer: *Agrisud used to train and introduce local people to the new techniques for planting organic vegetation, but we are not sure how much they invested. BBP trained us to plant and harvest the black ginger.*

7. **Is there any project that promotes conservation agriculture?**

   **A. If so, could you please describe it in more detail? e.g. the number of investments approximately?**

   Answer: *There is no project that is just working on this but we heard the government will establish one in this area soon.*

# Appendix C Basic demographic information about the respondents in Phnom Kulen National Park

| Demographic factor | Classification | Proportion ( per cent) |
|---|---|---|
| Year of birth | 1950s | 9.1 |
| | 1960s | 8.1 |
| | 1970s | 26.3 |
| | 1980s | 27.3 |
| | 1990s | 24.2 |
| | 2000s | 5.1 |
| Gender | Male | 51.5 |
| | Female | 48.5 |
| Education | No education | 24.2 |
| | Primary school | 54.5 |
| | Middle school | 15.2 |
| | High school | 6.1 |
| Village of residence | Phum Ta Han | 7.1 |
| | Phum Po Pel | 6.1 |
| | Phum Preah Anthum | 25.3 |
| | Phum TA Penh | 2 |
| | Phum Kia Khmums | 2 |
| | Phum Tmei | 8.1 |
| | Phum Aniong Thum | 34.3 |
| | Phum Tima Chhouh | 11.1 |
| | Chab Ta Sok | 2 |
| | Prey Phnom Kduoch | 2 |

# Appendix D Survey questions used in Lower LMB, Phnom Kulen National Park[7]

1. **When were you born?**
   ☐ 1950s ☐ 1960s ☐ 1970s ☐ 1980s ☐ 1990s ☐ 2000s

2. **At which level did you finish your education?**
   ☐ Primary school ☐ Middle school ☐ High school ☐ College and above

3. **What do you think your gender is?**
   ☐ Male ☐ Female ☐ Not sure

4. **What do you do for living?**
   ☐ Logging ☐ Rice farming ☐ Crops farming ☐ Cashew nut farming
   ☐ Orchard farming ☐ Fish collecting ☐ Traditional medicine collecting
   ☐ Tourism-related jobs
   ☐ Other, please indicate________

5. **Do you think gender has any influences on your choice of occupation?**
   ☐ Yes ☐ No If yes, how________

6. **Have you changed your job in the last decade?**
   ☐ Yes ☐ No If yes, from________to________

7. **Which do you think is the most important resource in your surrounding area related to your choice above?**
   ☐ Forest/ trees ☐ Other plants (except for forest) ☐ River/lakes/waterfall ☐ Farmlands
   ☐ Temples ☐ Animals ☐ Other, please indicate________

8. **Is it easy for you to afford your house?**
   ☐ Easy ☐ Neutral ☐ Hard

9. **Is it easy for you to afford your electricity?**
   ☐ Easy ☐ Neutral ☐ Hard

[7] The survey was translated into local languages for convenience.

**10. Do you know the "Phnom Kulen National Park"?**

☐ Yes ☐ No

**If yes, do you think the establishment of the "Phnom Kulen National Park" has influenced your life?**

☐ Yes ☐ No

**If yes, from which perspective (choose the most relevant option)?**

☐ Changed types of crops for farming
☐ Changed living places
☐ Increased opportunities of earning money
☐ Decreased opportunities of earning money
☐ Less use of natural sources
☐ More use of natural sources
☐ Other, please indicate________

**11. Do you live inside the "Phnom Kulen National Park"?**

☐ Yes ☐ No

**If yes, in which village/community protected area do you live?**

☐ Phum Ta Han ☐ Phum Po Pel ☐ Phum Preah Anthum ☐ Phum Sang Ke Lak
☐ Phum TA Penh ☐ Phum Kia Khmum s ☐ Phum Tmei ☐ Phum Aniong Thum
☐ Phum Tima Chhouh ☐ Chab Ta Sok ☐ Prey Thom Popel ☐ Prey Phnom Kduoch
☐ Prey Phnom Mneas ☐ Prey Thom

**12. How many years have you been living there? ________**

**13. Is there any issue with illegal immigrants in your village?**

☐ Yes ☐ No

**If yes, from which year approximately? ________**

**14. How many species (including fish, plants, animals) do you think that you can identify from the surrounding area where you live?**

☐ None ☐ Less than 10 species ☐ 10-50 species ☐ More than 50 species

**15. Have you ever experienced conflict with wild animals?**

☐ None ☐ Only a few times ☐ Several times ☐ Very often

**16. Have you ever experienced water stress in your life?**

☐ None ☐ Only a few times ☐ Several times ☐ Very often

**17. Did you notice the forest governance of "Phnom Kulen National Park"?**

☐ No ☐ Yes

**If yes, from which perspective (choose the most relevant option)?**

☐ Logging forbidden ☐ Reforestation ☐ Collection of natural resources forbidden

☐ Hunting forbidden ☐ Other, please indicate________

**18. Did you notice any infrastructure being developed over the last decade?**

☐ No ☐ Yes

**If yes, what do you think it is being/was developed for?**

☐ Tourism ☐ Road or other traffic uses ☐ Factories ☐ Residence

☐ Other, please indicate________

**19. What do you think about the income of your household compared with five years ago?**

☐ Increased ☐ Decreased ☐ No change

**If it has increased, by how much approximately?**

☐ Less than 10 per cent ☐ 10-50 per cent ☐ 50-100 per cent ☐ Doubled or more

**If decreased, by how much approximately?**

☐ Less than 10 per cent ☐ 10-50 per cent ☐ 50-100 per cent

**If appropriate, what do you think is the reason for the increase or decrease?**

☐ Tourism ☐ More labour in household ☐ Changing jobs from farming to other employment ☐ Shifting cultivation from rice/crops to cashew nut/orchard

☐ Ban on logging, hunting or collecting ☐ Other, please indicate________

**20. I am now going to offer some statements about your living areas. Please tell me how much you agree with me (1: Strongly disagree; 2: Disagree; 3: Not sure; 4: Agree; 5: Strongly agree)**

**A) These places have made me learn more about nature.**
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**B) These places make me feel more connected to nature.**
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**C) I have felt touched by the beauty of these places.**
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**D) I feel like I can contribute to taking care of these places.**
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**E) These places inspire me.**
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Have these perceptions changed since the establishment of Phnom Kulen National Park?**
☐ Yes ☐ No
**If yes,** ☐ Increased ☐ Decreased

**21.**

**A) These places are almost like a part of me.**
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**B) I feel a sense of belonging in these places.**
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**C) I miss these places when I have been away from them for a long time.**
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Have these perceptions changed since the establishment of Phnom Kulen National Park?**
☐ Yes ☐ No
**If yes,** ☐ Increased ☐ Decreased

22.

**A) These places clear my head.**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**B) These places give me a sense of freedom.**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Have these perceptions changed since the establishment of Phnom Kulen National Park?**

☐ Yes ☐ No

**If yes,** ☐ Increased ☐ Decreased

**23. At these places I feel part of something that is greater than myself.**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Has this perception changed since the establishment of Phnom Kulen National Park?**

☐ Yes ☐ No

**If yes,** ☐ Increased ☐ Decreased

**24. I've had a lot of memorable experiences in these places.**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Has this perception changed since the establishment of Phnom Kulen National Park?**

☐ Yes ☐ No

**If yes,** ☐ Increased ☐ Decreased

**25. I have made or strengthened bonds with others through these places.**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Has this perception changed since the establishment of Phnom Kulen National Park?**

☐ Yes ☐ No

**If yes,** ☐ Increased ☐ Decreased

**26. I believe that these places have high cultural or historical values.**

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

**Has this perception changed since the establishment of Phnom Kulen National Park?**

☐ Yes ☐ No

**If yes,** ☐ Increased ☐ Decreased

**27. Would you like your children to keep living here?**

☐ Yes ☐ No

# Appendix E Basic local living conditions in Phnom Kulen National Park

| Villages/ (per cent of respondents) | Life influenced by PKNP | | Housing affordability | | | Electricity affordability | | | Conflict with wild animals | | | Water stress | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | Easy | Neu-tral | Hard | Easy | Neu-tral | Hard | None | Few | Seve-ral | None | Few | Seve-ral |
| Phum Ta Han | 7.1 | 0.0 | 0.0 | 7.1 | 0.0 | 6.1 | 1.0 | 0.0 | 1.0 | 6.1 | 0.0 | 1.0 | 5.1 | 1.0 |
| Phum Po Pel | 5.1 | 1.0 | 2.0 | 4.0 | 0.0 | 3.0 | 3.0 | 0.0 | 0.0 | 6.1 | 0.0 | 0.0 | 4.0 | 2.0 |
| Phum Preah Anthum | 24.2 | 1.0 | 2.0 | 21.2 | 2.0 | 24.2 | 1.0 | 0.0 | 11.1 | 13.1 | 1.0 | 14.1 | 10.1 | 1.0 |
| Phum TA Penh | 1.0 | 1.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 |
| Phum Kia Khmums | 1.0 | 1.0 | 0.0 | 2.0 | 0.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 |
| Phum Tmei | 8.1 | 1.0 | 1.0 | 6.1 | 1.0 | 5.1 | 3.0 | 0.0 | 2.0 | 6.1 | 0.0 | 5.1 | 3.0 | 0.0 |
| Phum Aniong Thum | 32.3 | 1.0 | 4.0 | 24.2 | 5.1 | 19.2 | 15.2 | 0.0 | 15.2 | 18.2 | 1.0 | 9.1 | 25.3 | 0.0 |
| Phum Tima Chhouh | 8.1 | 1.0 | 2.0 | 9.1 | 0.0 | 4.0 | 7.1 | 0.0 | 3.0 | 8.1 | 0.0 | 4.0 | 6.1 | 1.0 |
| Chab Ta Sok | 2.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 |
| Prey Phnom Kduoch | 2.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 0.0 | 0.0 | 2.0 | 0.0 | 1.0 | 1.0 | 0.0 |
| **Total** | **90.9** | **1.0** | **14.1** | **75.8** | **10.1** | **65.7** | **34.3** | **0.0** | **35.4** | **62.6** | **2.0** | **37.4** | **57.6** | **5.1** |

# Appendix F Detailed methods of ecosystem services assessment[8]

## 1. Carbon sequestration

The ecosystem service of carbon sequestration is quantified as the sum of carbon mass stored in above-ground and below-ground vegetation, plus the amount of carbon stored in the first 200 cm of soil.

- Land-cover type
- Ecofloristic region according to FAO classification
- Continental region
- The presence of frontier forests (a proxy for the degree of forest degradation)
- The recent occurrence of fires.

## 2. Pollination

The value of pollination is estimated by the net value, representing the surplus or deficit of pollination services at each point. Climatic factors (solar radiation and temperature) are used to compute the weather-related component of insect occurrence. Nesting suitability, computed as the suitability of each landscape parcel for pollinator nesting, and flower availability, which describes the occurrence of flowers suitable to serve as food for pollinators, are based on expert opinion and published literature. Table F.1 is used to map land-cover types to the probability of nesting suitability and flower availability occurring at each point. Distance from streams, nesting probability and flower occurrence are used to compute the landscape-related component of pollinator insect occurrence. The pollinator occurrence map, which is displayed in the results section, is created by combining elements of insect occurrence linked to meteorological variables and landscape structure.

8 All the methods are provided by and computed under the K. Lab platform (https://integratedmodelling.org).

### Table F.1 Land-cover types and their nesting suitability and flower availability

| Land-cover type | Nesting suitability | Flower availability |
|---|---|---|
| Artificial surface | 0.1 | 0.05 |
| Arable land | 0.2 | 0.05 |
| Permanent cropland | 0.4 | 0.6 |
| Pasture land | 0.3 | 0.2 |
| Annual cropland | 0.4 | 0.5 |
| Complex cultivation patterned land | 0.4 | 0.4 |
| Agricultural land with natural vegetation | 0.7 | 0.75 |
| Agroforestry land | 1 | 0.5 |
| Broadleaf forest | 0.8 | 0.9 |
| Coniferous forest | 0.8 | 0.3 |
| Mixed forest | 0.8 | 0.6 |
| Grassland | 0.8 | 1 |
| Shrubland | 0.9 | 1 |
| Sclerophyllous vegetation | X | 0.75 |
| Transitional wood and scrub | 1 | 0.85 |
| Beach, dune and sand | 0.3 | 0.1 |
| Bare rock | 0 | 1 |
| Lichen moss | 0 | 1 |
| Sparse vegetation | 0.7 | 0.35 |
| Burned land | 0.3 | 0.2 |
| Glacier and perpetual snow | 0 | 0 |
| Wetland | 0.3 | 0.75 |
| Water body | 0 | 0 |

### 3. Soil conservation

In order to assess the prevented soil erosion owing to vegetation, the RUSLE is calculated twice, first using the best land cover data available and then with all area covered by vegetation removed.

$$A = R * K * LS * C * P$$

where A represents soil loss, R – rainfall run-off erosivity, K – soil erodibility, LS – slope steepness and length, C – cover management and P – conservation practice. These appear in the results as observations of the corresponding concepts.

In this RUSLE implementation, the LS, K, and C and P factors are calculated using worldwide research for C and P factors based on land-cover type and methods from Desmet and Govers (1996) for LS, based on contributing area, grid cell size, aspect, and slope length exponents. Although it has the limitation of only applying to rill erosion, the method used to calculate sediment regulation has been applied widely in ecosystem services assessment and global applications.

### 4. Outdoor recreation

The travel efficiency function specifies how far a person is likely to travel for recreation on a single day trip. This function, adapted from the mobility function, simulates the likelihood of going to a place as a function of distance, assuming a high probability of trips within 30 kilometers and a very low probability of travels beyond 80 kilometers:

$$f(d) = (i + K) / (K + exp(a*d))$$

where d is the distance from a site and K and a are parameters describing the shape (S- shape) and scale of the log-logistic function (Geurs and Ritsema van Eck 2001). We modified the original function by including a dependency on estimated travel time:

- d is the distance to main cities; when travel time is > 20 min, then d = d + 30 km. This creates a 30 km buffer for short trips around main cities, where the likelihood of high recreation demand is much greater.
- The mobility function parameter values are set to K = 450 and a = 1.12E − 04, which combine the long-distance (80 km) and short-distance (8 km) functions (Paracchini et al. 2014).

Recreation demand considers the possibility of taking a day trip to a certain site as well as the population density in the areas acting as a source of visitors for that destination, describing the relative number of trips made from each grid cell within the context. In this manner, the model calculates the flow of recreation demand from population centers to a recreational destination using estimated travel time. The proportion of naturalness impacted by human activities (so-called "hemeroby") is computed as a reclassification of land-cover type, shown in Table F.2. The theoretical potential for the outdoor recreational attractiveness of each point in the landscape is modelled by classifying the landscape in terms of Euclidean distance to protected areas, water bodies and sites of relevance for tourism. This value does not take into consideration the ability of people to reach the areas (hence the theoretical attribute).

**Table F.2 Land-cover types and the proportion of naturalness impacted by human activities**

| Land-cover type | Hemeroby |
|---|---|
| Artificial surface | 7 |
| Vineyard | 4 |
| Fruit and berry plantation | 4 |
| Olive grove | 4 |
| Rice filed | 4.5 |
| Agricultural land with natural vegetation | 4.5 |
| Agroforestry land | 4 |
| Annual cropland | 6 |
| Complex cultivation patterned land | 5 |
| Pasture land | 4 |
| Non-irrigated arable Land | 6 |
| Permanently irrigated arable land | 6 |
| Permanent cropland | 6 |
| Arable land | 6 |
| Mixed forest | 3 |
| Broadleaf forest | 3.5 |
| Coniferous forest | 3.5 |
| Beach, dune and sand | 1 |
| Bare area | 2 |
| Bare rock | 0 |
| Lichen moss | 1 |
| Sparse vegetation | 2 |
| Transitional wood and scrub | 3 |

(Table continues on the next page)

(Continuation of table from previous page)

| Land-cover type | Hemeroby |
|---|---|
| Shrubland | 3 |
| Grassland | 3.5 |
| Burned land | 7 |
| Glacier and perpetual snow | 0 |
| Mangrove | 0 |
| Inland marsh | 2 |
| Peat bog | 2 |
| Salt marsh | 2 |
| Saline | 2 |
| Intertidal flat | 2 |
| Wetland | 2 |
| Water body | 7 |

**Special thanks to UNEP's funding partners.** For more than 50 years, UNEP has served as the leading global authority on the environment, mobilizing action through scientific evidence, raising awareness, building capacity and convening stakeholders. UNEP's core programme of work is made possible by flexible contributions from Member States and other partners to the Environment Fund and UNEP Planetary Funds. These funds enable agile, innovative solutions for climate change, nature and biodiversity loss, and pollution and waste.

**Support UNEP. Invest in people and planet.**
www.unep.org/funding

UN environment programme

www.unep.org
unep-communication-director@un.org