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Faculty of Environmental Sciences

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Master's Thesis

Riverine ecosystem conservation in Vietnam national parks system

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Engineering Ecology
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Riverine ecosystem conservation in Vietnam national parks system

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Objectives of thesis

1] How well can the current NPs in Vietnam, Cambodia and Laos protect the riverine ecosystem?
2] Is it needed to expand protected area system for FWPAs effective protection?
3] Set of simple indicators for long-term monitoring of tropical Asia freshwater protected area: review and suggestions.

Methodology

Worldwide, the decline of freshwater biodiversity has become a fundamental environmental issue. Vietnam has a long existing system of national parks and harbour biodiversity with worldwide importance (Hoang et al. 2001). The designation of protected areas is a principal strategy for the conservation of biodiversity (Abell et al. 2017; Acreman et al. 2019). However, freshwater protected areas (FWPAs), as defined by (Saunders et al. 2002), constitute only a minor proportion of the world's protected areas (Abell et al. 2007). Effective complex approach how to spatial design FWPAs defined by Abell et al. (2007) distinguished freshwater focal areas (for example valuable habitat or territory of endangered species), critical management zonas and catchment management zone. Those zonas are areas without occurrence of endangered species or habitats, but need to be protected in order to manage processes like water quality or river net connectivity in complex open riverine ecosystem. But in many protected areas they are still absent. Without the possibility to manage limiting critical processes in all catchment many of these FPAs can protect only physical stage of some kilometres of river channel or bank vegetation but not water quality, sediment processes or river continuum (Abell et. al 2007) essentially needed for long time sustainable river ecosystem function (Grill et al. 2019).

Some of the world's databases will be used to make our own maps of protected areas in Vietnam. National parks in estuaries and coastal ecosystems will be excluded from the basic dataset. The river network will be analyzed using the available layer of the river network and with respect to the system according to Saunders et al. (2002). The design of parameters for the aquatic environment monitoring system will take into account local parameters used in the state monitoring network in Vietnam (Thi Minh Hanh et. Al 2011).

The proposed extent of the thesis

45

Keywords

Vietnam, Freshwater protected areas, Riverine ecosystem conservation, National parks

Recommended information sources

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Declaration

I declare that I have worked on my master's thesis titled "Riverine ecosystem conservation in Vietnam national parks system" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the master's thesis, I declare that the thesis does not break any copyrights.

In Prague on 31/3/2022.

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I would like to thank my family, Professor Ondřej Simon, and my uncle and for their advice and support during my work on this thesis.

Riverine ecosystem conservation in Vietnam national parks system

Abstract

Worldwide, the decline of freshwater biodiversity has become a fundamental environmental issue. With Vietnam's dense and complex river system, protected areas (PAs) are an effective tool for riverine ecosystem conservation. This thesis assesses the conservation of the riverine ecosystem in Vietnam's protected areas through the criteria of a freshwater protection area (FWPA). River system maps in protected areas of three countries in the Indochina Peninsula, including Vietnam, Lao PDR, and Cambodia, were made and screened. The percentage of PAs meeting the criteria of an FWPA in Vietnam is much smaller when compared to the two neighboring countries and the total number of terrestrial PAs in the country. The expansion of the protected area system to enhance the ability to preserve the riverine ecosystem in Vietnam is necessary. In addition, a simple and inexpensive set of indicators including continually measurable parameters (pH, EC, turbidity) and bioindicators (benthic macroinvertebrates, fishes) is suggested for long-time monitoring of water quality in countries in the study area and areas with similar natural conditions.

Keywords: Vietnam, Freshwater protected areas, Riverine ecosystem conservation, National parks

Ochrana říčních ekosystémů v systému národních parků Vietnamu

Abstrakt

Pokles biodiversity sladkovodních ekosystému je v současnosti jedním ze zásadních témat ochrany přírody v celosvětovém kontextu. Ve Vietnamu s jeho hustou a komplexní říční sítí jsou chráněná území (CHÚ) jedním z účinných nástrojů ochrany říčních ekosystémů. Tato práce hodnotí ochranu říčních ekosystémů ve Vietnamu podle standardů pro sladkovodní chráněná území (SVCHÚ). V práci byly zhotoveny a analyzovány originální mapy říční sítě ve všech velkoplošných chráněných územích typu SVCHÚ ve Vietnamu, Laosu a Kambodži. Ve Vietnamu je oproti těmto dvěma zemím výrazně menší procento chráněných území, který splňují kritéria pro SVCHÚ přesto, že celkový počet terestrických CHÚ je zde vysoký. Je proto potřebné rozšířit systém CHÚ ve Vietnamu tak, aby byl vhodný ve větším měřítku i pro ochranu říčních ekosystémů. V diplomové práci byl také navržen seznam levných a jednoduše měřitelných indikátorů vhodných pro dlouhodobý monitoring kvality vody v CHÚ ve studované oblasti nebo oblastech s obdobnými přírodními podmínkami. Jde zejména o bioindikaci s využitím bentosu a ryb jako signálních organismů a parametry jakosti vody snadno měřitelné kontinuálními sondami (pH, vodivost, zákal).

Klíčová slova: Vietnam, sladkovodní chráněné oblasti, ochrana říčních ekosystémů, národní parky

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List of abbreviations

PAs: Protection areas
FWPA: Fresh water protection areas

Lao PDR: Lao People's Democratic Republic
IUCN: International Union for Conservation of Nature
WQI: Water quality index
MCR: Mekong River Commission
CITES: The Convention on International Trade in Endangered Species of Wild Fauna and Flora

Introduction

1. Background

Rivers have been an important factor in supporting humanity in its development. The river net not only provides water for human activities and production, but also provides transportation corridors and is an important source of electricity production for mankind.

Human activities, on the other hand, have resulted in habitat loss and degradation. Globally, the spread of invasive species, overexploitation, and polluting wastes have had a negative impact on the status of freshwater ecosystems and their dependent species (Revenga et al., 2005). Freshwater bodies are losing biodiversity at a significantly faster rate than terrestrial ecosystems. On a worldwide basis, freshwater biodiversity continues to deteriorate fast, with the freshwater wildlife population index declining by 83% since 1970, more than double the pace at which marine and terrestrial species fall (Grooten et al., 2018). This reduction appears to be very severe in some tropical latitudes, affecting large fish and other vertebrates (Dudgeon et al., 2006).

Protected areas (PAs) are designated with the function of a management tool to balance the conservation and use of natural resources (Roux et al., 2008). Research by Acreman et al. points to evidence that PAs can be effective in conserving and restoring biodiversity in freshwater ecosystems (Acreman et al., 2019). However, PAs do not appear to be as effective in conserving aquatic populations as they are with terrestrial populations (Virgilio et al., 2016). For PAs to contribute to the conservation of riparian ecosystems, decision-makers need to change both the way PAs are designated and the strategy for managing rivers in the region (Roux et al., 2008).

This study focuses on assessing the status of the PA system in Vietnam by comparing it with two countries that share a border and are in the Indochina region: Lao People's Democratic Republic (Lao PDR) and Cambodia. It also examines the freshwater conservation capacity of this system in the three countries by classifying and rating PAs according to the criteria for becoming a Fresh Water Protected Area (FWPA). Finally, the study also introduces a suitable set of indicators to be used for long-time monitoring of water quality in countries in the study area and other places with similar natural conditions.

2. Thesis objectives and hypothesis

2.1 Research's Aim

- To understand the ability of riverine ecosystem protects of PAs in Vietnam
- Provide suggestions on cheap and simple indicators for long-term monitoring for areas of Vietnam and tropical Asia.

2.2 Research's Objectives

- How well can the current protected areas (PAs) in Vietnam, Cambodia, and Laos protect the riverine ecosystem?

- Is it needed to expand the protected area system for fresh water protected areas (FWPAs) for effective protection?

- Review and suggest a set of simple indicators for long-term monitoring of tropical Asia freshwater protected area: review and suggestions.

2.3 Research's hypothesis

- How good can current state PAs in Viet Nam protect riverine ecosystem? Is it need to expand?
  H0: The current state PAs in Vietnam is not good enough to protect riverine ecosystem and need to expand.
  H1: The current state PAs in Vietnam is good enough to protect riverine ecosystem and do not need to expand.

Literature Review

1. Overview of the riverine and freshwater biodiversity

1.1 Riverine and Freshwater biodiversity protection

- Riverine ecosystem and it‘s anthropogenic threats:

Water is an essential component for life. Surface water bodies are the most suitable places to settle for life. The human civilizations that emerged alongside the major rivers were also the first ones. According to Gerard Van der Velde et al (2008), river connects shore, inland and coastal marine ecosystems via an open transport and migration path (Velde et al., 2008). The most obvious feature of riverine ecosystems is that of gravity driven unidirectional flow. There are six riverine ecosystem characteristics, they are:

- Flow
- Stream order
- Stream size
- Land-water interface and other characteristics
- Influx and retention of organic matter
- Natural disturbance regime

In 2018 WWF report, Grooten et al., showed that the extent of wetlands has declined by over 50 percent since 1900 and the number of free flowing river in the world has decreased dramatically due to human development, especially with more than 50,000 large and small dams in the world (Grooten et al., 2018). Only 37% of rivers longer than 1,000 km remain free-flowing throughout their entire length, and 23% flow uninterrupted to the ocean (Grooten et al., 2018). Very long FFR are mainly limited to isolated parts of the Arctic and the Amazonian and Congo Basins. Few very long rivers, including the Irrawaddy and Salween, remain accessible in densely populated areas (Grill et al., 2019). Rivers are increasingly disconnected because of dams and other infrastructure, with reservoirs changing natural flow regimes and trapping around 25 percent of the global total sediment charge previously reached the ocean (Grooten et al., 2018).

• Mekong riverine ecosystem

The river systems of Vietnam, Lao PDR, and Cambodia are all heavily influenced by the Mekong River. The Mekong River is the world's 12th longest river, at 4345 km long, with heavy influences on the Indo-China Peninsula. It flows through

China, Myanmar, Lao PDR, Cambodia, and Thailand before ending in a delta in Vietnam, where it distributes influences to farmers, particularly in paddy fields, before entering the South China Sea (MRC © 1997; Sagar et al., 2016).Average annual discharge of the Mekong River is 475 km3, or 13 000 m3/s, into the South China Sea, which is eighth in the world's river basins (Botkosal et al., 2009).

According to Sagar 2016, The Mekong River basin can be divided into two parts (Sagar 2016):

- The Upper Basin located in Tibet plateau, Myanmar, and China (where the river is called the Lancang Jiang)

- The Lower Mekong Basin located in Lao PDR, Thailand, Vietnam and Cambodia .

Therefore, the river systems of three countries: Vietnam, Lao PDR and Cambodia share common points. By comparing the possibilities to protect and conserve river ecosystems in three different countries that have the same waterways, one can exchange strengths and weaknesses in conservation. From there, the lesson learns are tailored to suit with each country.

- Red river ecosystem:

The Red River originates in the mountainous region of Yunnan Province in China, and flows 1200 km south-eastward before discharging through 4 delta arms into the Gulf of Tonkin in the South China Sea (Thi Nguyet Minh Luu et al., 2010). The Red River originates from three main tributaries; the Da, Lo and Thao rivers. In the upper parts of the Delta, two important tributaries (the Da and the Lo Rivers) join the main stream at Son Tay, and flow into the Tonkin Bay (Thi Nguyet Minh Luu et al., 2010).

The upstream portion of the Red River in China is dominated by various kinds of soil types compared to the upstream section of the Red River in Vietnam. The upstream portion of the Red River in China is a tectonically active region with unstable geological formations. Due to heavy rainfall, this caused significant erosion (Thi Phuong Quynh Le et al., 2007). There are two contrasting seasonal climates that exist in the Red River basin: a dry season lasting from November to April, and a rainy (tropical monsoon) season from May to October. The annual rainfall here is approximately 1900 mm, and it is between 85–95 percent of this figure that occurs during the rainy season (Thi Thuy Duong et al. 2019).

- Small river in Vietnam that ends in South China Sea:

Vietnam is landscape made up of tropical hills and heavily forested highlands. Vietnam's lowland is located in the Red River Delta and Mekong Delta (Cuu Long delta). The vast majority of water resources, more than 90 percent, are concentrated in these basins while other parts of the country, that occupy more than 75 percent of the total area of Vietnam, receive just over 35 percent of the national total river-run off (Viet Nguyen Tien et al., 2018). Vietnam's rich water supplies are 2,360 rivers over 10km in length and 16 river basin over 2,500km^2 each. The annual run-off volume is approximately 847 km^3 (VMNRE © 2012).

- Small river in Cambodia that ends in Gulf of Thailand

This river system, which originates in the Cardamom and Elephant mountain chains and empties into the Gulf of Thailand. In Cambodia, this system is not as significant as the other three river systems, which include the Mekong River systems, Tonle Sap Lake, and the tributaries of the Tonle Sap Great Lake. However, because of the abundance of rain and steep slopes in this location, this system retains its potential for the development of water resources in the future (WEPA © 2021).

- Indochina Peninsula

Vietnam, Lao PDR, and Cambodia are in the Indochina Peninsula, inside the Indo-Burma hotspot region, one of the 25 bidodiversity hotspots in the world (Norman et al., 2000). According to CEPF (2022), the Indo-Burma Biodiversity Hotspot, which includes non-marine areas of Cambodia, the Lao People's Democratic Republic, Myanmar, Thailand, and Vietnam, as well as portions of China, is one of the southern planet's most biologically important regions.

Since 1992, the hotspot has continued to reveal its biological treasures, with six new large animal species having been discovered. There is also a tremendous diversity of tortoise and freshwater turtle species here, as well as about 1,200 bird species (CEPF © 2022).

The Mekong giant catfish is the best-known endangered fish in the Indochina region. Besides, this area also has some important fish species, such as the endangered Mekong freshwater stingray (Dasyatis laosensis), the critically endangered giant carp (Catlocarpio siamensis) and the endangered Jullien's golden carp (Probarbus jullieni) (Kottelat 1989, CEPF © 2022). Significant progress is being made with dragonflies and other aquatic mollusks in Indo-Burma, but there aren't any global threat assessments of the invertebrates there. However, other groups that might have species that are quickly disappearing haven't been looked at. These include large specimen beetles, which sell for a lot in the pet and specimen markets (CEPF © 2022).

- Freshwater biodiversity:

Freshwater systems are created through precipitation in the terrestrial environment and flow to the sea both above and below the ground. These systems cover a variety of habitats, including rivers, lakes and wetlands, and their riparian areas. With the seasonality in the hydrological cycle, their boundaries change constantly (Revenga et al., 2000). Freshwater habitats have essential resources and are the sole refuge for an incredibly diverse, endemic and vulnerable biota.

Freshwater biodiversitys cover just less than 1% of the surface of the Earth, but host more than 10% of known animals and around 1/3% of all known vertebrate organisms. They also provide the primary source of protein for hundreds of millions of people worldwide (Grooten et al., 2018) But freshwater biodiversitys are suffering a significantly greater loss in species than those in the impacted terrestrial habitats. Human pressures on freshwater habitats have grown sharply over the last century, leading to significant and increasing challenges to biodiversity around the world (Dudgeon et al., 2006). Revenga (2005) showed also in the 2000 Pilot Analysis of Global Ecosystem report that the quality of the freshwater biodiversity and its dependent organisms declines in strength and are far worse than the other bio-ecological systems, such as forests, grasslands or coastal ecosystems (Revenga et al., 2005).

The decline of freshwater biodiversitys affects the lives of many different species. Revenga, 2005 refer to Asian fresh water turtle and tortoise, Chinese alligator as examples of how ecosystem loss can affect organisms that depend on it (Revenga et al., 2005). The human race is also not out of this influence. Vörösmarty (2010) indicate that about 80 percent of the human population lives in areas at risk of water resources (Vörösmarty et al., 2010). Decreases in water quality and land-use fluid reliability not only affect the composition, distribution and abundance of species but can significantly affect human health and economic activities which rely upon safe sources of adequate clean water (Abell et al., 2019).

Abell et al., (2019) demonstrated the degree to which water conservation can provide biodiversity benefits for freshwater and how these benefits are realized. However, water protection investments were very limited compared with water industry sector investments. Alexandra, 2012 shows that there is still no extensive, up-to-date, or equivalent water quality database in Asia, with national data obtained through systematic monitoring and project-based evaluations indicating that the situation remains serious but with many positive improvements and signs of hope (Alexandra et al., 2012). However, there are still many challenges. For states, the immediate problem is domestic sanitation due to health risks. While many Asian countries are making substantial steps towards the Millennium Development Goals, their activities to take care of freshwater biodiversity are still limited (Abell et al., 2019).

- Important terms:

3 important terms explained in the research of Abell et al (2007) were used to PAs in this study.

- Freshwater focal area: The Freshwater focal area designates the location of a particular freshwater feature that requires protection. Management interventions may or may not occur directly in a freshwater focus region, but if they do, they will almost certainly be quite limiting in nature in order to avoid direct disruption of the characteristic of concern. Freshwater focus areas are not always tiny or limited; for example, an unbroken river may be maintained over its whole length as an exceptional example of a functionally integrated system (Abell et al., 2007).

- Critical management zone: Critical management zones are locations where management is vital to the continued operation of a focus region. Restrictions would be tailored to the zone's unique use and would very certainly not prohibit all usage. For instance, a wetland region vital for managing downstream water flows may be designated as a key management zone for a drought-prone freshwater focus area, with development in or draining of the wetland forbidden. Use limits in critical management zones may also be temporal in nature, timed to correspond with seasonal spawning movements. Riparian zones next to and maybe immediately upstream of freshwater focus regions may potentially qualify as key management zones. (Abell et al., 2007).

- Catchment management zone: The term refers to the whole upstream catchment area of a crucial management zone. Along with surface catchments, these zones may be defined to safeguard subsurface focus regions' ground watersheds. Basic catchment management concepts would be used inside a watershed management zone. Technically, catchment management zones might be considered multiple-use PAs. Along with biodiversity conservation, these areas would help maintain ecosystem services; PAs established to safeguard water-related services have a long history (Abell et al., 2007).

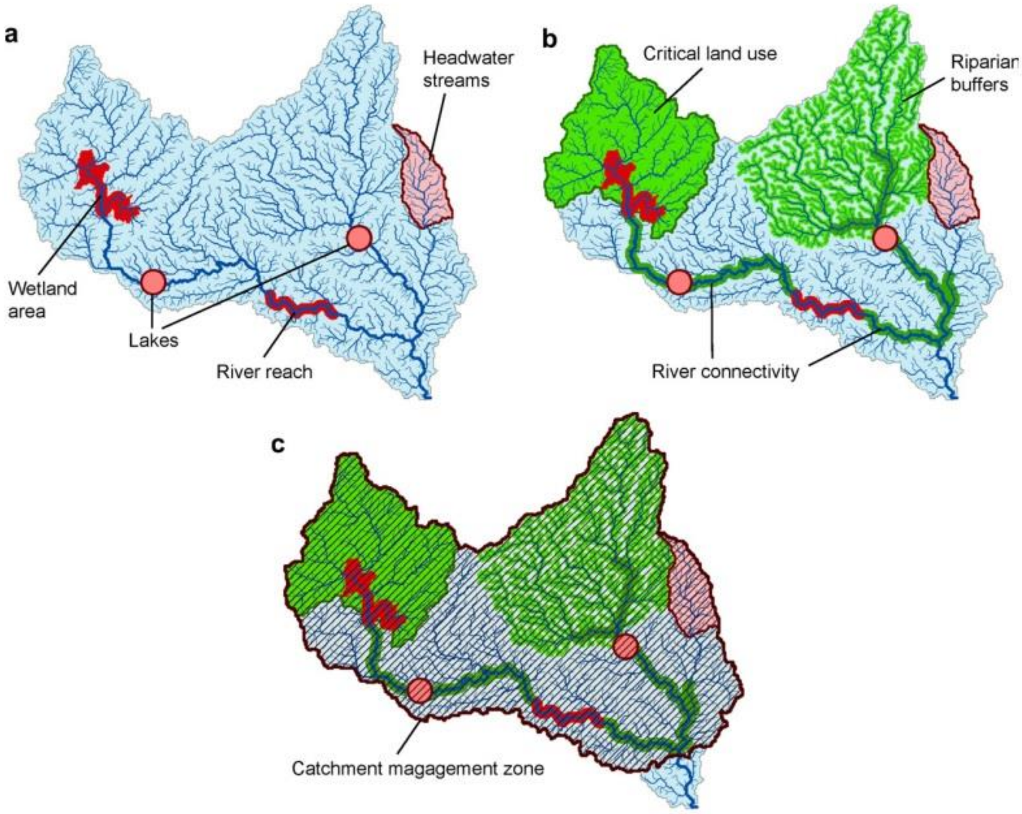

Figure 1: The diagram depicts the planned zones of freshwater PAs. (a) freshwater focal regions, which may include river segments, lakes, headwater streams, or wetland habitats that support focal species, populations, or communities. (b) crucial management zones, such as river segments connecting critical habitats or upstream riparian areas, whose integrity is necessary for the freshwater focus areas to function successfully. (c) A watershed management zone that spans the entire catchment upstream of the most downstream freshwater focus region or critical management zone is subject to the principles of integrated catchment management (Abell et al., 2007).

1.2 Protected areas

A protected area is an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means (Stolton et al., 2008). The designation of PAs is a crucial biodiversity conservation strategy (Abell et al., 2007).

The IUCN divides PAs into six categories as follows:

	Description
Category I	Strict nature reserve/wilderness protection area managed mainly for science or wilderness protection - Areas of land and/or sea with certain habitats, geological or physiological characteristics and/or organisms that are remarkably or symbolic, available primarily for scientific study or environmental monitoring.
Category Ib	Wilderness area: protected area managed mainly for wilderness protection - Large unmodified area of land and/or sea with slightly modified areas, maintaining their natural characteristics and impact without permanent or substantial dwelling that is covered and maintained in their natural state.

Category II	National park: protected area managed mainly for ecosystem protection and recreation - Natural land and/or sea areas planned for three key tasks: protecting the ecological integrity of one or more present and future generations eco-systems, excluding exploitation or occupation which is inimical to the area designation and providing the basis for spiritual, research, educative, recreational and visitor opportunities all to be environmentally and culturally relevant.
Category III	Natural monument: protected area managed mainly for conservation of specific natural features - Area with specific natural or natural/cultural characteristics of excellent or special value due to their intrinsic rarity, representative characteristics or esthetic characteristics or cultural context.
Category IV	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention - Area of land and/or sea subject to active management action with a view to ensuring the conservation of ecosystems to meet particular species requirements.
Category V	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation or recreation - Area of land, where the relationships of people and nature have been formed with time, with a major aesthetic, ecological and/or cultural value and often with high biological diversity, with coast or sea interaction. Protection, preservation and growth of this region depends on safeguarding the dignity of this conventional relationship.
Category VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural resources - Area comprising primarily unmodified natural systems, ensure the long-term conservation and sustainability of biodiversity while ensuring safe flows of natural resources and services to fulfill community needs.

Table 1: Categories of PAs by International Union for Conservation of Nature (IUCN © 2021).

PAs are one partial solution to habitat degradation, but few such areas have been created specifically for fresh waters (Saunders et al., 2002). In the 2007 study, Abell et al. showed similar results (Abell et al., 2007).

In addition, the documents on active Freshwater P\protected areas (FWPAs) are few and far between, according to an exhaustive analysis by Acreman et al. (Acreman et al., 2019). This lack of evidence impedes our perception of PAs' efficacy and leads to the study gap in case studies (Sunderland et al., 2009).

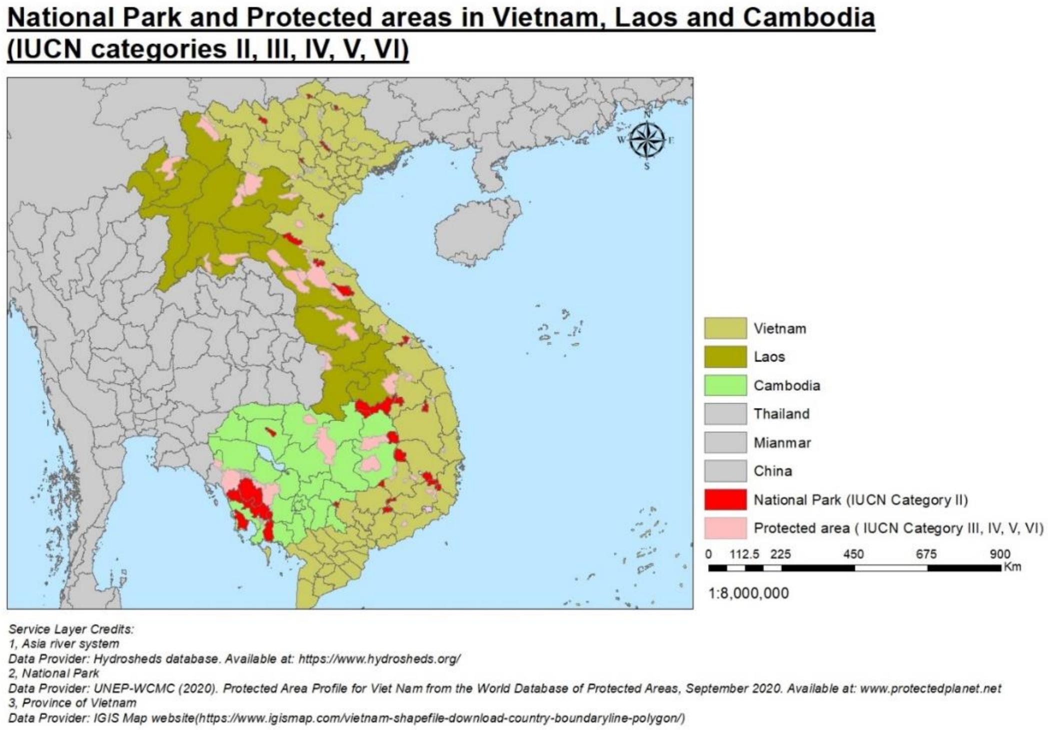

Figure 2: National park and PAs in Vietnam, Lao PDR and Cambodia (original map).

However, PAs is one of the rational conservation approaches for the prevention of threats to freshwater resources. The watershed PAs plays an important role in the environment with the right characteristics for conservation. According to ICEM © 2003, Vietnam's water sources have been handling rice and preventing flood damage for thousands of years. Water-protection projects, which often serve various mandates and sometimes deal with complex trade-offs between conservation of biodiversity and ecosystem services, may help understand the actions of local actors at catchment level (Abell et al., 2019). Watershed management of PAs clearly not only offers the environment ecological benefit, but it also delivers other human and economic services.

Table 1 – Threats to freshwater ecosystems and the possibility of prevention by PAs

Threat to freshwater ecosystems	Description/cause	Origin: local	Origin: catchment	Origin: extra-catchment	Place-based solution for proactive protection?
Direct habitat alteration	Degradation and loss	X	X		Local-to-catchment management
	Fragmentation by dams and inhospitable habitat segments	X			Protected rivers or river reaches
Flow alteration	Alteration by dams	X	X		Protected rivers or river reaches
	Alteration by land-use change		X		Catchment management
	Alteration by water abstraction	X	X		Abstraction prohibited or managed for priority systems
Overharvest	Commercial, subsistence, recreational, poaching	X	X		Fishery reserves
Contaminants	Agricultural runoff (nutrients, sediments, pesticides)		X		Catchment management
	Toxic chemicals including metals, organic compounds, endocrine disruptors	X	X		Catchment management; local prohibitions against point-source discharges
	Acidification due to atmospheric deposition and mining			X	None
Invasive species	Altered species interactions and habitat conditions resulting from accidental and purposeful introductions	X	X		Preventing introductions to systems with natural or constructed barriers to invasion
Climate change	Results in changes to hydrologic cycle and adjacent vegetation, affects species ranges and system productivity			X	None (except maintaining dispersal opportunities and thermal refugia)

In nearly all cases where both local and catchment origins are listed, local stresses are transferred downstream to become catchment impacts elsewhere. (Information drawn from Brinson and Malvarez (2002), Bronmark and Hansson (2002), Malmqvist and Rundle (2002), and Tockner and Stanford (2002).)

Table 2: Threats to freshwater biodiversity and the possibility of prevention by PAs (Abell et al., 2007)

2. Vietnam riverine system, water industry, freshwater biodiversity and protected areas

The total area of the river basins in the country is more than 1,167,000 km^2, of which 72 per cent is the catchment area outside the territory. Due to many reasons, the decline in water sources in the downstream of most river basins leads to water scarcity, water scarcity is not sufficient to supply for daily life, and production is increasingly occurring on a large scale. Every year, rivers discharge about 880 billion m3 of water into the coast of Vietnam and between 200 million and 250 million tons of sediment suspended in the Mekong and Red estuaries (Thanh et al., 2000).

With a dense river network, Vietnam is an ideal place to develop hydroelectric dams. With nine large hydropower reservoirs with an area of 1267 km^2, dams have been built to create many reservoirs in the watershed and coastal plains for irrigation and hydropower. Every year, 48 million tons of sediments, equal to 83% of all suspended sediments, are transported into the reservoir and deposited. (Thanh et al., 2000). It is very necessary to ensure the quality of river habitats, at least in the protected region.

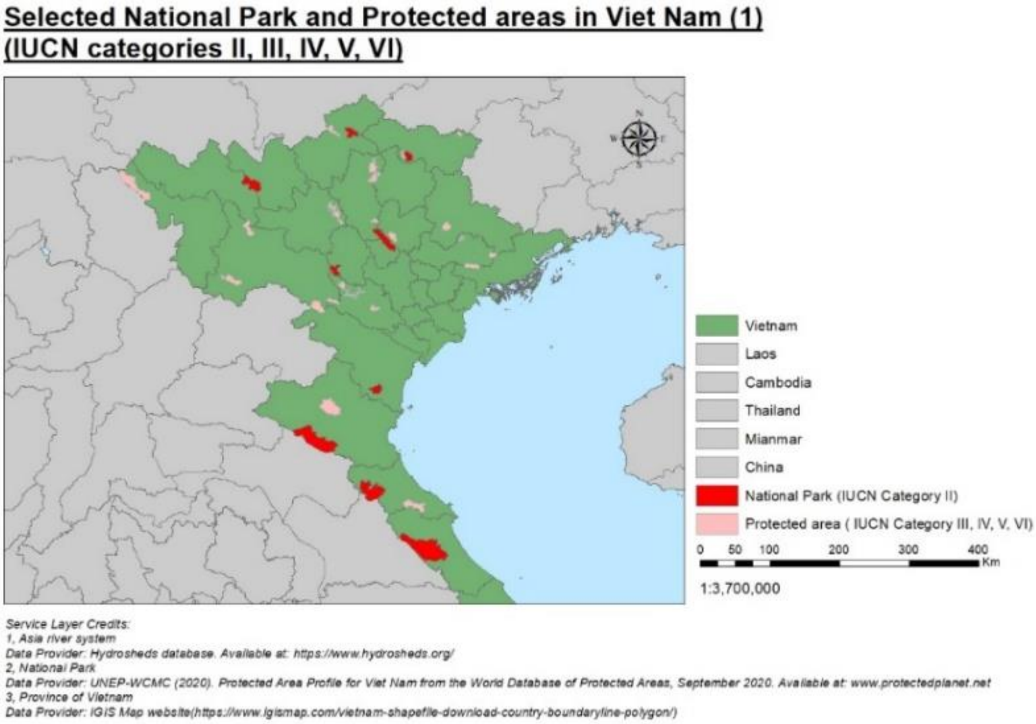

Figure 3: National park and PAs in northern of Vietnam (Original map)

Currently there are 209 PAs in Vietnam, including 32 national parks, 2 national park buffer zones with a total area of 24,994 km^2, accounting for 7 percent of the total geographical area (IUCN © 2020) (Figure 3). IUCN's data indicates that the area of PAs in Vietnam has increased significantly compared to the 2001 study by JH Clarkes: a total of 102 PAs, including 10 national parks, with a total area of 2547 km^2 accounting for 0.8% of the total national area (Clarke et al., 2003), National parks in Vietnam are PAs under the national special-use forest program established to protect natural resources and biodiversity (An et al., 2018).

According to Stolton (2008), out of a total of 30 national parks, six are under the control of the Vietnam Forestry Administration and the other 24 are managed by the provincial authorities (Stolton et al., 2008). The capacity to maintain the park is still limited, however. Significant causes of reduced management capability of national parks include human population growth and resource demand, lack of resources, reduced human and institutional capability, and land use conflict or land grab. Illegal hunting, trapping, smuggling, fishing, illegal trade in wildlife, illegal deforestation, and harvesting of firewood tend to pose the most significant threat to the conservation and management of natural resources (An et al., 2018).

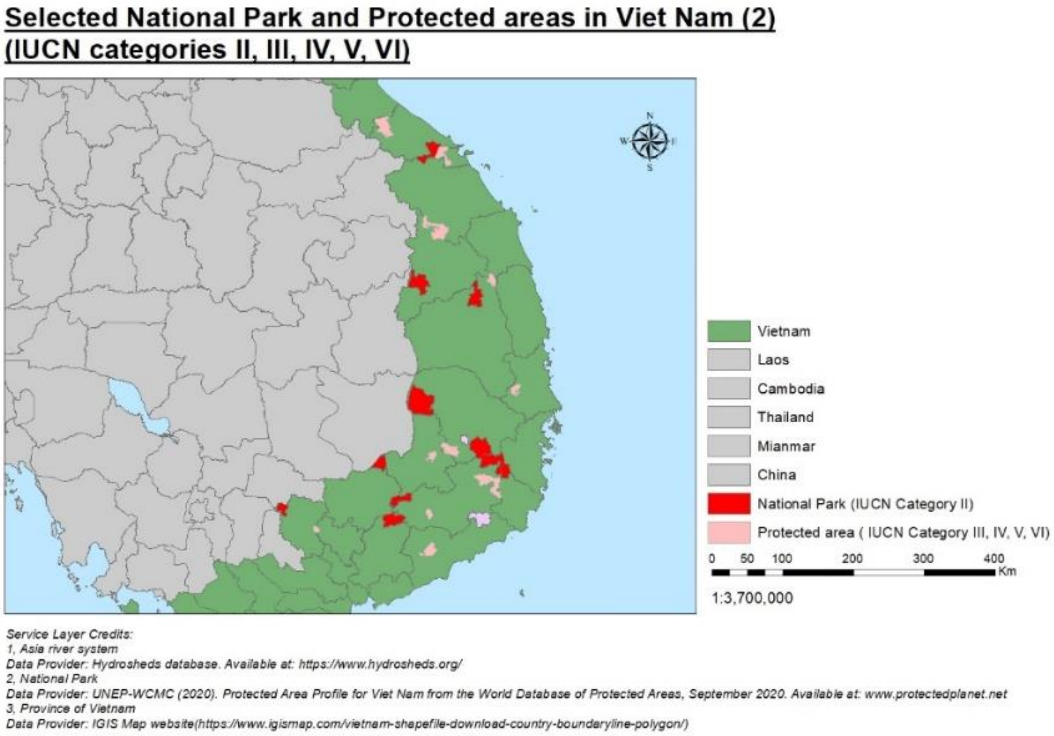

Figure 4: National park and PAs in southern of Vietnam (Original map)

For thousands of years, Vietnam has been handling its water supplies to irrigate rice and stop flood damage. Around 80% of Vietnam's existing special-use forests are located above 500 meters above sea level. These PAs are important for the protection of watersheds and flood damage (ICEM © 2003). Some PAs help to sustain water flows throughout the dry season. They supply rice fields with water, especially during the dry season. U Minh Thuong is an example of a protected area providing a water flow control system through sluice gates, as referred to in Vietnam's National Protected and Development Areas Report.

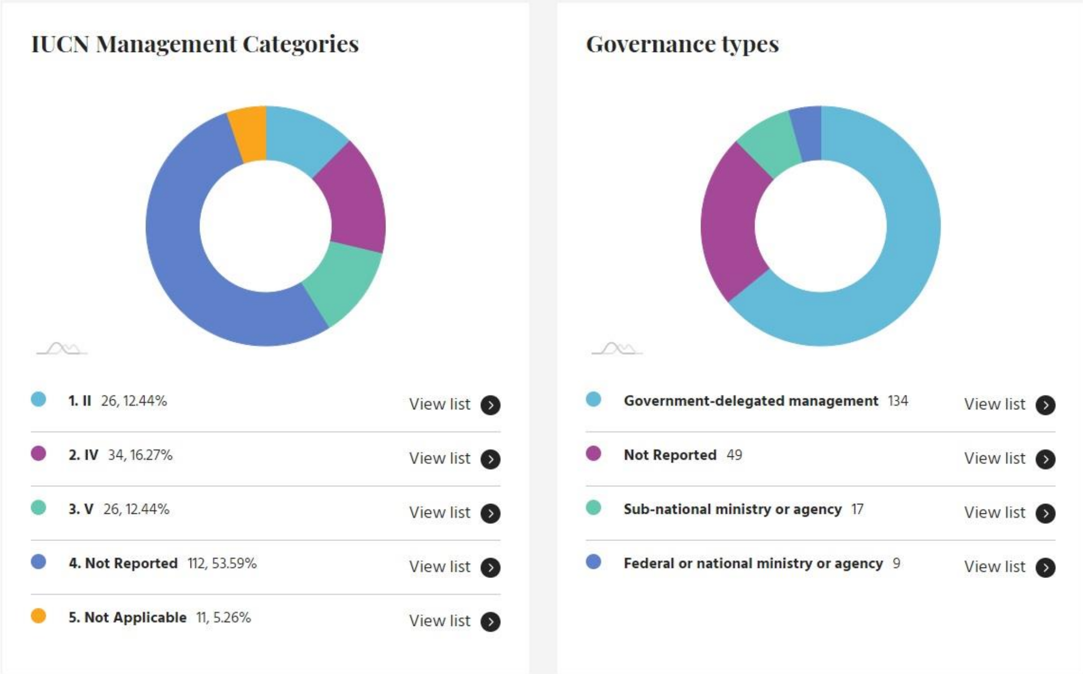

Figure 5: Percentage of PAs in Vietnam by IUCN categories (IUCN © 2020)

3. Lao PDR riverine ecosystem, freshwater biodiversity and protected areas

According to IUCN © 2020, there are currently 31 PAs in Laos, accounting for 43,220 km^2, or 18.69% of the national area. Lao PDR is a mountainous country, with mountains covering 80% of its territory or having a mountainous climate. This is rich in water resources. The total surface water available (including the flow of the Mekong River and its affluents) is 55,000 m^3 per capita annually, the highest in Asia. However, there has been little development in the national water supply. The total storage capacity of a large pond is less than 3% of the annual surface flow (Komany et al., 2008).

The Mekong River, one of the world's largest rivers (eighth largest in terms of flow), measures 1.898 km and attracts 80 % of the Lao People's Republic. The annual moonsoon season affects the Lao PDR climate greatly, while from April to October the rainy SW moonsoon accounts for around 90% of the annual rainfall. During the dry season from November to March, rainfall can be entirely absent a few months in many parts of the world. Mekong Plain is one of three physiographical areas - the Mekong Plain River and its wider resources. Tropical mountain climate similar to the Louang Saiphou but numerous precipitations. Generally flat upper levas with acidic and superficial recent alluvial deposits are productive, but also likely to flood during the wet season (ICEM © 2003).

Lao PDR is not a member of many main international conventions and organisations. Also under consideration is the Ramsar Convention GoL (Government of Lao PDR). It seems that the meaning and the benefit of this convention are not clear for Lao yet (Phittayaphone et al., 2003). The absence of Lao PDR from CITES (the

Convention on International Trade in Endangered Species of Wild Fauna and Flora) is especially important, since the trade in wildlife is a major concern of the country and PAs in particular. According to ICEM © 2003, however the status of the Lao government is practical and will be integrated into the Convention when it is able to enforce it. However, as with CITES, adherence to the convention of Ramsar appears useful, given the importance and size of its wetlands, the failure to enforce it for the time being is a legitimate reason not to accede, even though the international community urges Lao PDR to accede to it.

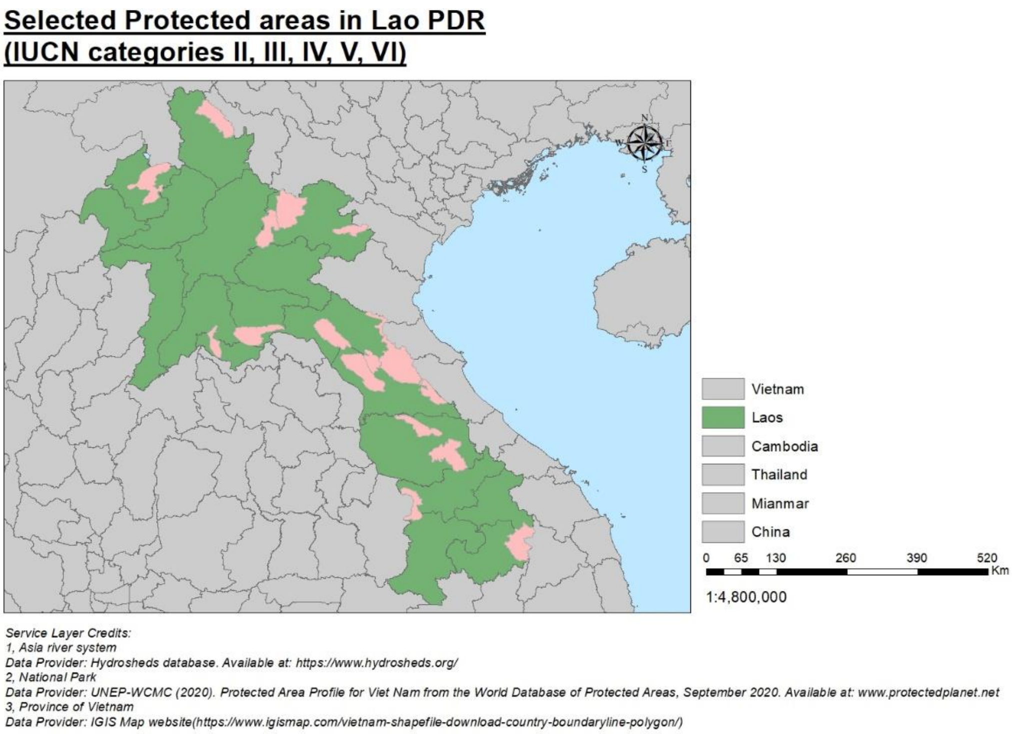

Figure 6: PAs in Lao PDR (original map)

According to the IUCN classification, currently in Lao PDR there are only PAs of Categories II, III and VI (Figure 8). The amount of information on the current state of Pas in Lao PDR is rather small, prompting questions about the quality of freshwater conservation in the country.

Figure 7: Percentage of PAs in Lao PDR by IUCN categories. (IUCN © 2020)

4. Cambodia riverine ecosystem, freshwater biodiversity, and protected areas

Cambodia has many important characteristics of international conservation. Indochina and Thailand were home to vast instances of ecosystems that previously covered much of the region. More than 45 habitat types have been identified and mapped for the region (ICEM © 2003). The foundation of Cambodian society are the freshwater biodiversity. Although they constitute the minority of the territory, they provide home and help to most Cambodians whose farming traditions (rice and fish production) revolve around annual flooding. Cambodian freshwater humidity ecosystems – streams, pools, lakes and swamps that house high fish and many other freshwater species and are noted for their high productivity, with yearly harvests exceeding 100,000 tons of fish over several decades (Vathana et al., 2003).

The Mekong River enters Cambodia from Lao PDR to the north-east and flows to Phnom Penh south (Vathana et al., 2003). During the flow of the river between PDR Laos and Phnom Penh, it splits into channels, forming large islands and sand banks. The Mekong Delta starts from Kampong Cham downstream and enters Vietnam. It is a large and fertile plain of 49,520 km^2, of which the city is 16,000 km^2. The Mekong River connects with Cambodia's largest lake, Tonle Sap Lake, for the time being Below Phnom Penh, the Mekong Delta is formed by both Rivers Mekong and Basac. But the Mekong is swelling in the wet season (April to October) to the point that its water forces the Tonle Sap River into its path and re-flows into the Tonle Sap Lake. By the end of October, the water deposited on the Tonla Sap Lake flows back into the sea through the Tonle Sap River and into the Mekong and Bassac Rivers (Vathana et al., 2003).

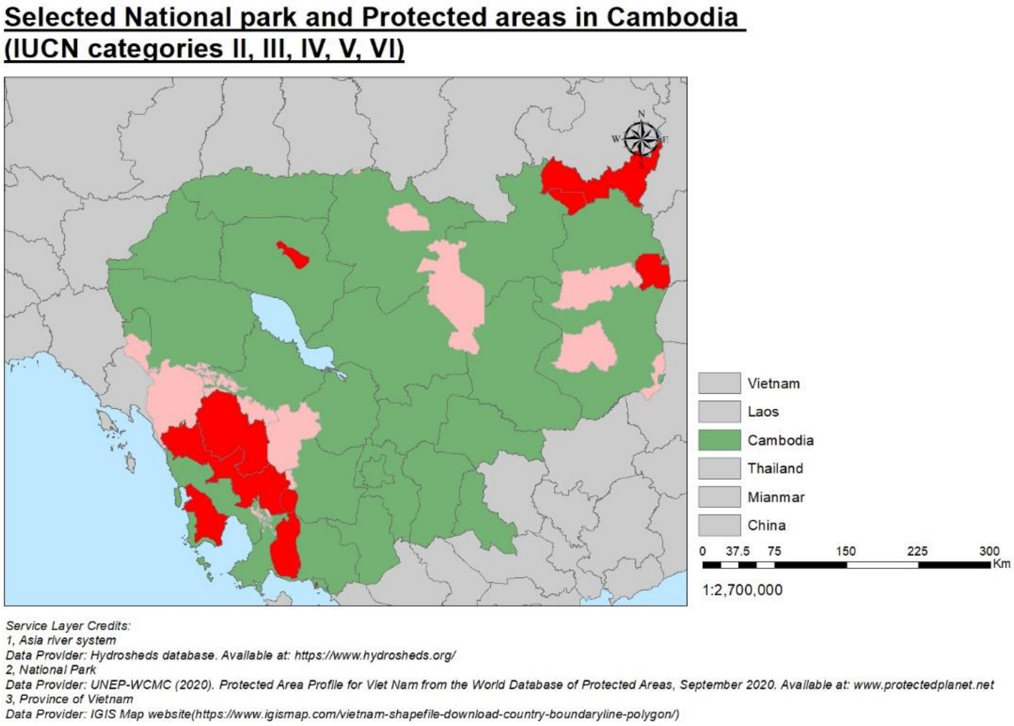

Figure 8: National parks and PAs in Cambodia (Original map)

Cambodia was the first country in South-East Asia to establish PAs. According to ICEM © 2003, there are 23 PAs covering 3.3 million hectares - more than 18 percent of the country. According to IUCN © 2020 data, there are currently 69 PAs in Cambodia, accounting for 72,527 km2, equivalent to 39.74% of the total national area (excluding Marine PAs). PAs in Cambodia are very diverse and there are 6 out of 7 categories of the IUCN (except categorie IIa) (Figure 10).

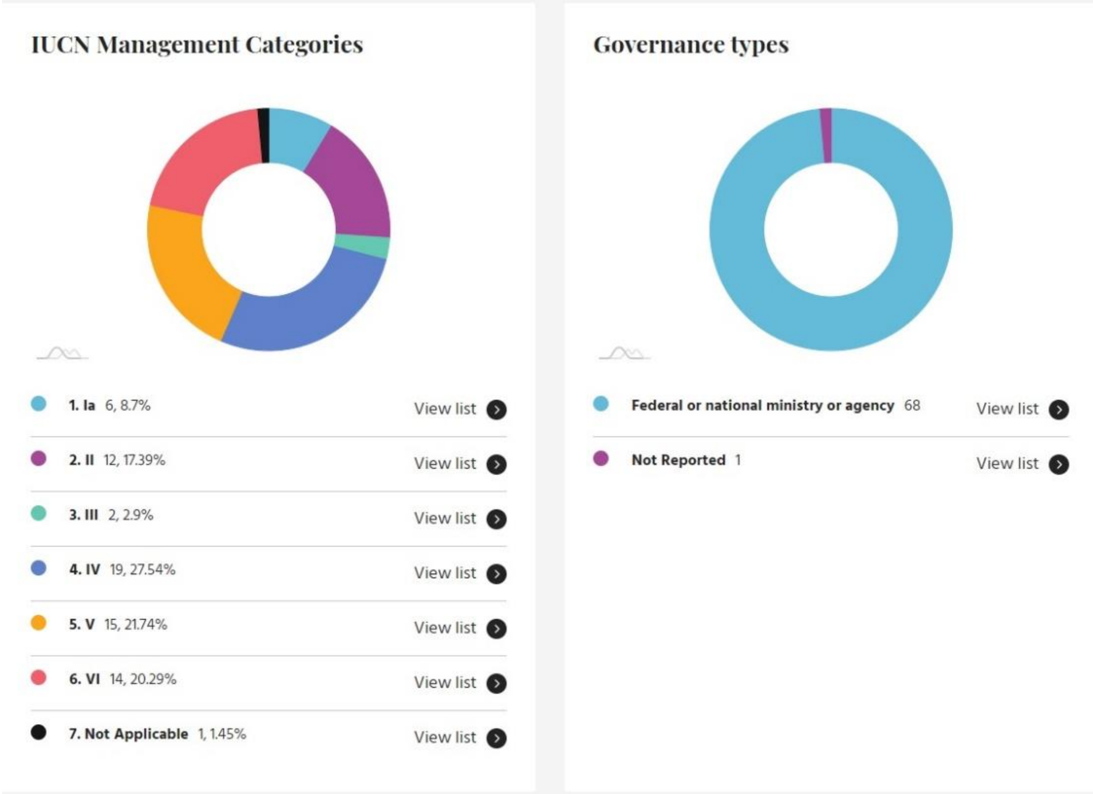

Figure 9: Percentage of PAs in Cambodia by IUCN categories. (IUCN © 2020)

5. Water quality monitoring indices and indicators

Remotely sensed data is in increasing rate used for assessment of ecosystem services (Kibria et al., 2017) or ecosystem protection in South Asia region protected area. For riverine ecosystems these methods in limiting in use, but see (Grill et al., 2019) for some exceptions e.g., riverine ecosystem quality. Water quality is important not only for riverine biodiversity protection but is vital for protect costal and estuarine ecosystems too (Li et al., 2014; Yang et al., 2018). Monitoring of chemical and physicochemical parameters using good choice indicators in frame of monitoring program is essentially needed. In region is still only very rare long time river water monitoring programs, exception is some big rivers like Jang-Ce (Changjinang) (Liu et al., 2003). For example, in Vietnam, state water quality monitoring net is still in development (Hanh et al., 2011; Thi Phuong Quynh Le et al., 2007). The Mekong River Commission has also measured the water quality in the areas the Mekong passes through with three different sets of WQI indices (see Indices Selection in Methodology), suitable for each area and with different characteristics (MCR © 2021)

5.1 Indicies

The need for monitoring water quality was realised in the 1960s, and water contamination acts were developed to regulate water quality degradation (Barry, 1970). In some coutries the comprehensive system of state river system water quality monitoring start before 1970, for example in Czechoslovakia (150 profiles, since 1963 physicochemical parameters, 1966 radionuclids) (Arrow database MZP 2010). Monitoring water quality is a dynamic process due to the many different variables that must be considered. Indeed, numerous scholars have discussed this issue over the years, handbooks, recommendations and papers have been published on this subject (Behmel et al., 2016).

Zhaoshi Wu shows in his study in 2018 that there are some reasons for the difficulty of building a water monitoring program. One of the reasons is that every watershed has its own constraints, and it is not possible to have a "one-size-fits-all" solution (Wu et al., 2018). Thus, there are differences in the methods of water monitoring in different sizes. When managing a water monitoring procedure, many factors need to be controlled (Wu et al., 2018). They are:

- Identification of monitoring objectives (e.g., the information that needs to be produced)
- Determination of a sampling site network for lakes and rivers;
- Selection of the water quality parameters (wqp);
- Establishment of sampling frequencies and recurrence;
- Estimation of human, technical and financial resources;
- Preparation of the logistics (e.g., fieldwork, laboratory work, quality control and assessment, data handling, data storing, data analysis);
- Identification of information diffusion channels and
- An assessment if the information generated has been put to use.

There is no realistic method for optimally planning and optimizing all facets of WQMP at once (Khalil et al., 2011; Strobl et al., 2008). Furthermore, the information needs for water quality on which WQMPs are based are frequently inaccurate (Bartram et al., 1996). Atilla Akkoyunlu also mentioned in his work: "Water quality indices have to be developed considering the local properties and pollution status of the ecosystems." "Such an initiative would allow the managers, decision makers, or policy makers to appreciate the state of the water body very easily and propose suggestions for managing the water body very effectively" (Akkoyunlu 2012).

Tiyasha mentioned in his research (Tiyasha et al., 2020) that Tchobanoglous (1985) distinguished three distinct water quality groups, including biological, hydro-morphological, and physiochemical (Tchobanoglous and Schroeder, 1985). Other variables, such as physiochemical parameters, are almost all used in river modeling. The physical and chemical variables that produce synergistic effects on WQ along with several other environmental factors may produce unpredictable WQ outcomes (Wilhm et al., 1968).

According to Atilla Akkoyunlu (2012), water quality regulations usually consist of emission criteria and summary statistics of water sources that are ascertainable by scientists but also useful to managers and policy makers in the water sector who want to know about the status of their local water bodies (Nasirian 2007). Therefore, WQIs have become a realistic way to observe and reflect the contamination problem in water bodies. It does not require a great amount of testing of water quality parameters; only a small number of water quality parameters are necessary for the validation process (Akkoyunlu 2012).

Zhaoshi Wu (2018) also shows that the water quality index (WQI) method has been widely used in water quality assessments of both groundwater and surface water, particularly rivers, and it has played an increasingly important role in water resource management (Debels et al., 2005; Lumb et al., 2011; Mohebbi et al., 2013).

In the study of Tirkey Poonam (2013), WQI shows some brief history of WQI. In the mid-twentieth century, water quality was categorized by Horton in 1965 (Horton et al., 1965). Then, in 1970, Brown et al. developed a general water quality index (WQI) (Brown et al., 1970). In 1982, Steinhart et al. applied a novel environmental quality index to sum up technical information on the status and trends of the Great Lakes ecosystem (Steinhart et al., 1982). In the mid-1990s, WQI was introduced in Canada by the water quality guidelines task group of CCME (Dunn et al., 1995, Rocchini et al., 1995).

There are some frequently used WQI (Poonam et al., 2013), they are:

- The US National Sanitation Foundation Water Quality Index
- Canadian Water Quality Index (Canadian Council of Ministers of the Environment Water Quality Index). This index is modified form of original British Columbia Water Quality Index.
- Mekong River Commission

WQI categorises WQ into classes, such as good, poor, and bad, based on the standards set by the research area governing bodies; the results are numerical but are described in a condensed form (Fernández et al., 2004). Research into water quality is key in ensuring that river water is clean, healthy, and safe to use. The number of scientific approaches to WQ data has expanded vastly since its first evaluation in 1980 (Tiyasha 2020).

Tirkey Poonam pointed out in his study in 2013 that indices for determining water quality usually fall into four categories (Poonam et al., 2013):

First, public indices: these indices are derived from general water quality measurements and disregard water quality measurements by form. For example, there is the National Sanitation Foundation Water Quality Index (Ott 1978).

Second, basic consumption indices: the classification of water is based on the type of consumption and use. For example, we have the Oregon and British Columbia indices (ODEQ © 2003).

Third, designing or planning indices: This class is used by water quality managers in making water quality management decisions.

Fourth, statistical indices: These indices are not driven by personal opinion, they are based solely on statistical analysis. Statistical methods are used to evaluate and interpret the results. The central concept of statistical approaches is to use meaningful findings in the field (Poonam et al., 2013).

Tirkey also showed that the first three indices are referred to as "expert opinion" approaches. Due to different amounts being provided for the same reasons by various panels of experts, the EO process becomes subjective. Objectivity and comparability can be undermined by the varied scores provided by the experts. It leads to many alternative indexes having been developed. Using statistical methods eliminates subjectivity by removing assumptions, thereby making the indices more reliable. Statistical methods are helpful in determining parameters and essential characteristics relevant to water quality (Poonam et al., 2013).

5.2 Indicators

Worldwide, indicators are generated and utilized by governmental, business, and civil society organizations for a range of reasons, ranging from knowledge provision to administrative control. As a rule, indicators are thought to help make policy decisions and public debate more rational by providing an objective source of data that is easy to understand, long-lasting, and trustworthy They show a certain state or trend over a certain area and time (Lehtonen 2015).

Indicators can be quantitative or qualitative measures that are used to determine the condition of a process, system, or entity, as well as its performance in comparison to a benchmark (OECD © 2008). Once developed, the indicators may be used to assess the effectiveness of a basin management plan and to guide resource development decisions. People who use a lot of water, like utilities, industries, municipalities, or farmers, may also be active users and use the indicators to look at their effects and how they work together in a basin (Bertule et al., 2017).

5.2.3, Physicochelmical indicators

- **Turbidity:**

It is used to determine the efficiency with which light passes through water. It is produced by clay, silt, organic matter, plankton, and other particles. Particles can conceal lethal infections that are difficult to clear. Suspended material can lower infection resistance, growth rates, egg and larval development, and capture efficiency. Numerous pesticides and hazardous organic pollutants (PCBs, PAHs) could adsorb on suspended particles. Turbidity raises the temperature of the water, thus lowering food availability. In comparison to cold water, warm water has less dissolved oxygen. It is possible use automatic autonomous probes for field measurement of this parameter.

- **pH:**

pH measures the water's hydrogen ion content. The pH of water shows its acidity or alkalinity.

Water with a pH of 6.5-8.5 is generally considered safe to drink. Alkaline water is safer. Waters with a pH exceeding 8.5 tend to taste harsh or carbonated (Omer 2020). The pH of water can affect water treatment and should be considered if water is used for pesticide field application (Omer 2020).

- **EC:**

Conductivity is described in electrical engineering as the resistance of water to an electric current. Umhos/cm is a widely used unit of conductivity measurement (micromhos per centimeter). This is a straightforward measurement that correlates well with the total dissolved solids content of the water at issue. Around 70% of the conductivity (measured in umhos/cm) is accounted for by total dissolved solids (Omer 2020). Automatic autonomous probes for this parameter are cheap, durable, and can work independently for many months. Continuous data from this porbe (EC + temperature) allows for the detection of not only changes in water quality (Benettin and Van Breukelen 2017), but also hydrological episodes such as storms or floods, as well as many types of accident pollution (mining, clearcuts, wastewaters) (Cano-Paoli et al., 2019, Demers et al., 2021).

- **NH3:**

Plants obtain nitrogen from nitrate and ammonia (NH_3). Nitrates and nitrites are created when ammonia is oxidized by nitrifying bacteria. They are converted to various types of nitrogen by denitrification and plant uptake (Omer 2020).

Due to the fact that water contains more nitrogen than phosphorus, nitrogen rarely hinders plant growth in the same way that phosphorous does. Aquatic plants are usually more tolerant of increases in ammonia and nitrate. The atmosphere, sewage treatment plants, agricultural runoff, storm drains, and septic systems are all sources of nitrates (Omer 2020).

5.2.4 Bioindicator:

Biological monitoring, or biomonitoring, is the process of assessing the quality of the environment in which live creatures exist or their reactions. It reflects environmental conditions through the presence or absence of indicator species or indicator communities (Yegon et al. 2021).

To assess a stream or river's health, biologists conduct biological surveys of the aquatic life that inhabits it. It's a means of estimating water quality by looking at the organisms (Ortega et al., 2021). Unlike chemical measures, which give a snapshot of the aquatic ecosystem, biological measurements provide a more comprehensive picture of water quality as represented by the aquatic organism community. It is not needed to measure every month or shorter period (day, hour) like in the case of chemical parameters. Bioindicatos give good information about the quality of the riverine ecosystem if they are taken once per year (especially benthos and fishes) (Lamberti and Hauer 2017).

- **Diatoms:**

In the stream and river ecology, periphytes are key markers of the health of the ecosystem. Periphytes, which are primary producers in river environments, are critical for the establishment of food webs in these ecosystems.

Because of their quick reproduction rates and short life spans, periphytes might be expected to reflect short-term environmental influences and changes. Because assemblages are often linked to the substrate, changes in temperature, nutrition levels, current regimes, and grazing can directly affect their growth and development. Periphytons, especially diatoms, have been advocated for river biomonitoring (Sallenave 2015).

- **Benthos:**

Benthic macroinvertebrates, fish, and/or periphytes can all be used for biomonitoring. Due to their vast size and lengthy longevity, macroinvertebrates are the most frequently used and have the longest history of use in biomonitoring projects (Sallenave 2015). For instance, musells are excellent bioindicators because they maintain a fixed position on the river bottom during their last life stage (Simeone et al., 2021). Bentho can also be used to make a regional stream drying index (Straka et al., 2021).

- **Fishes**:

For pollution evaluation, fish are critical because they are at the top of the aquatic food chain and because they are ingested by people. Due to their importance and vitality in freshwater ecosystems, fish populations have long been used to measure the health of river ecosystems.

They are excellent markers of long-term (multi-year) impacts and habitat conditions due to their extremely long lifetime and mobility. Fish assemblages, which include top predators, provide provide insight into the general health of the aquatic ecosystem. Fish populations, overall, respond strongly and reliably to human disturbances such as eutrophication, acidification, chemical pollution, flow control, and habitat change and fragmentation (Sallenave 2015).

Methodology

The study will acquire information on PAs and national parks from the same source as Protectedplanet.net - the IUCN's protected area information website - for the main system of information and synchronization.

1. Research Area:

The research areas are Vietnam, Lao PDR, and Cambodia, with Vietnam as the research focus. The main regional studies are PAs located in the following areas:

- Red river delta

- Lower Mekong Delta

- Small rivers flow into the South China Sea

- Small rivers flow into the Gulf of Thailand

1.1 Vietnam

Vietnam is a country in Southeast Asia, located on the eastern edge of the Indochina Peninsula, divided into 58 provinces and five centrally-run cities, covering an area of 331,699 square kilometers with a population of more than 96 million people, becoming the 16th most populous country in the world. Vietnam shares a border with China to the north, Laos and Cambodia to the west, while maintaining maritime borders with Thailand across the Gulf of Thailand and the Philippines, Indonesia and Malaysia across the South China Sea.

Vietnam has a dense river network with more than 2360 rivers having a length of more than 10 km. Eight of these are large basins with a catchment area of 10,000 km^2 or more. This river network includes many international rivers that originate in basins in other countries. About two-thirds of Vietnam's water comes from outside sources, which makes Vietnam vulnerable to water resource decisions made by countries upstream (WEPA © 2021).

The entire area of all international basins inside and outside Vietnam is over 1.2 million km^2, which is nearly three times the total area of the country of Vietnam. All the rivers that flow across Vietnam provide a plentiful supply of water (255 billion m^3 per year on average). Due to a lack of suitable physical infrastructure and financial resources, just 53 billion m^3 of water is used every year on average for inhabitants. The unequal distribution of rainfall across Vietnam, along with an average annual rainfall of 1,960 mm and an extended dry season, results in severe water shortages in many parts of the country (WEPA © 2021).

1.2 Cambodia

Cambodia, officially the Kingdom of Cambodia, is a Southeast Asian country located in the southern section of the Indochina Peninsula. It has an area of 181,035 square kilometers and is bounded to the northwest by Thailand, to the north by Laos, to the east by Vietnam, and to the southwest by the Gulf of Thailand. Phnom Penh is the country's capital and largest city. Cambodia is a sovereign nation with a population of around 15 million people. Cambodia's river system is mostly centered on the Mekong River's flow through the country. Cambodia‘s water resources are separated into three systems: the (i) Mekong River System, the (ii) Tonle Sap Lake System, and the (iii) river system that empties into the Gulf of Thailand (WEPA © 2021).

i) The Mekong River Basin

Roughly 480 kilometers long and 1.5 kilometers wide, the Mekong River flows through Cambodia from the northern border with Lao PDR to the southern border with Vietnam. In Cambodian territory, the river's average width is approximately 1.5 kilometers. During its journey to the South China Sea, the river passes through Stung Treng and Kratie provinces, Kampong Charm province, Phnom Penh city (Cambodia's capital), and Kandal province, among other places (WEPA © 2021).

ii) System of Tonle Sap lake

Tonle Sap lake is located in Cambodia's central floodplain and is connected to the Mekong River by the Tonle Sap River, which is around 120 kilometers in length. Tonle Sap lake is the largest permanent freshwater lake in Southeast Asia and is located in Cambodia. The river is a waterway that connects Tonle Sap Lake to the Mekong River in Cambodia.

Tonle Sap Lake's watershed area encompasses a total of 67,600 km^2 (MCR © 1993). Tonle Sap Lake gets its water from a number of rivers, the most important of which is the Tonle Sap River, which supplies up to 62 percent of the total water supply available during the rainy season.Rivers such as the Stung Sen, Stung Sreng, Stung Pursat, Stung Sisophon, Stung Mongkul Borey, and Stung Sang Kae are also important in the region. Furthermore, direct rainfall on the lake and rivers within the watershed accounts for the remaining 38% km^2 (MCR © 1993). This waterway and floodplain begin in the western portion of the country, continue to the areas around the Tonle Sap Lake, and end in Phnom Penh City, which is located near the Mekong River. This wetland has a dry season area of approximately 2,500 km^2 and a wet season area of approximately 13,500 km^2 (WEPA © 2021) (Table 3).

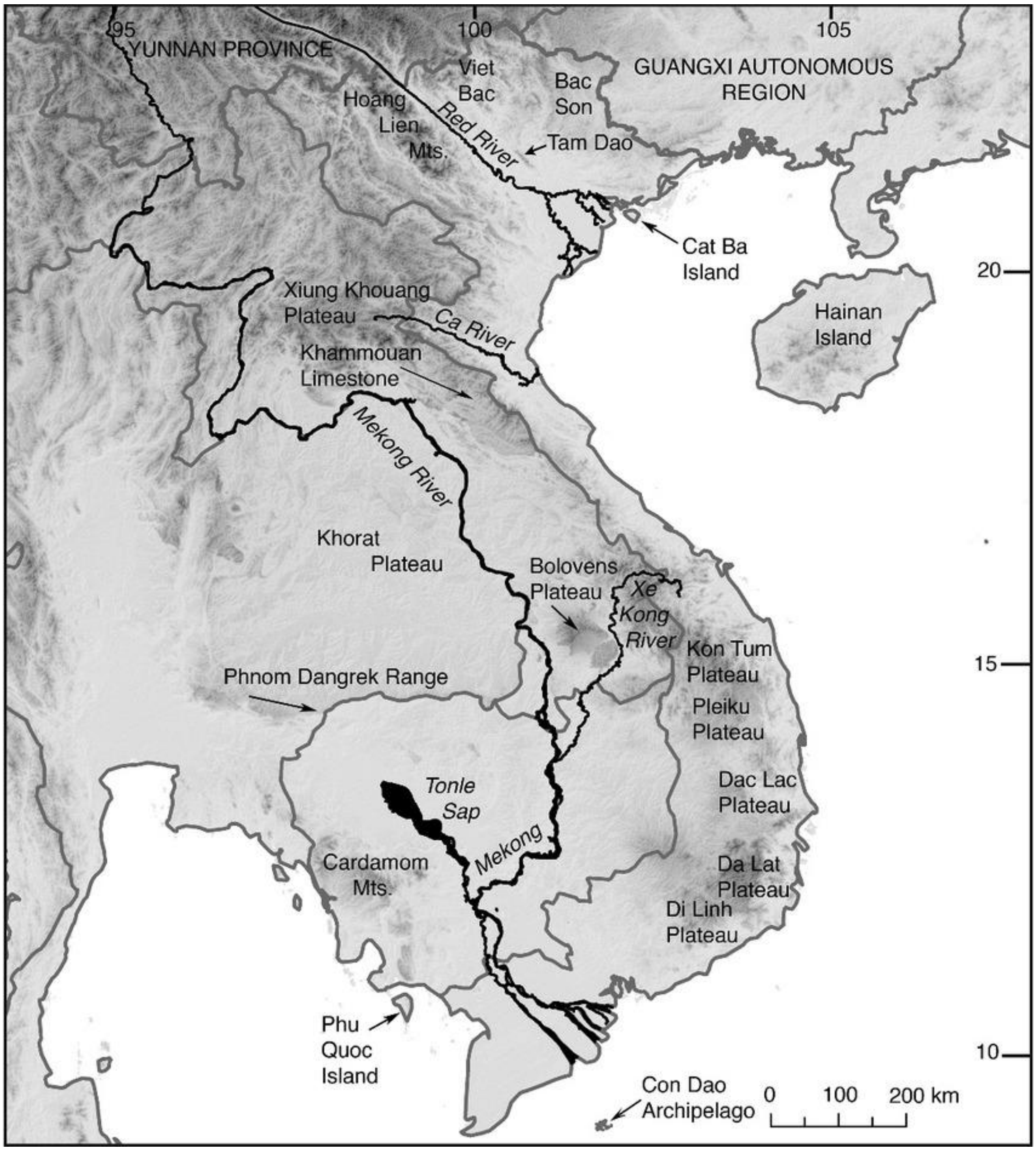

Figure 10: Major geographic features of Indochina with main rivers in Viet Nam, Lao PDR, and Cambodia (Raoul Bain and Martha Hurley, 2011).

iii) <u>River network that flows into the Gulf of Thailand.</u>

This river system, which originates in the Cardamom and Elephant Mountains and flows into the Gulf of Thailand, is not as significant as the Mekong River system, Tonle Sap Lake, and the tributaries of Tonle Sap Lake. However, given the heavy rainfall and steep slopes in this area, this system still has the potential to develop water resources in the future (WEPA © 2021).

Sources of flooded water	Percent %
Mekong River	62
Local Inflow	38
Total	**100**

Table 3: Water sources caused flooding the Tonle Sap Great Lake (WEPA © 2021)

1.3 Lao PDR

The Lao People's Democratic Republic is a socialist republic and Southeast Asia's sole landlocked country. Laos is located in the heart of the Indochina Peninsula, surrounded to the northwest by Myanmar and China, to the east by Vietnam, to the southeast by Cambodia, and to the west and southwest by Thailand. Vientiane is the capital and largest city.

The annual water volume of Lao PDR is predicted to be 270 billion cubic meters, or 35% of the Mekong basin's average annual water volume. Monthly river flow distribution in Lao PDR according to rainfall patterns: approximately 80% during the rainy season (May–October) and 20% during the dry season (November–April). In the Central and Southern regions (particularly Sebang Fai, Sebang Hieng, and Seong), the dry season flow is significantly reduced, at around 10% to 15% of the annual flow. Outside the Mekong Basin, rivers drain into the South China Sea through Vietnam. Nam Ma, Nam Sam, and Nam Neune are the names of these rivers. Due to a lack of information regarding these rivers, it is difficult to estimate their hydropower and irigation potential (WEPA © 2021).

Lao PDR's major rivers are primarily composed of the Mekong's first and second tributaries. The Mekong River Basin contains around 39 significant tributaries. The following 11 rivers have a catchment area of more than 5000 km2: The Nam Ou river basin is located in northern Lao PDR; Nam Suang is located in northern Lao PDR; Nam Khan is located in Lang Prabang province; Nam Ngum is located in the North Central region; Nam Nhiep is located in Xiengkhoung province's Phonesavan; Nam San is located in the province of Bolikhamxay; Nam Theun/Kading is located in the province of Bolikhamxay; and Sebangf (WEPA © 2021).

The combined catchment area of the major tributaries is estimated to be 183,000 km2. On the other hand, there are only two major rivers in the provinces of Houaphan and Xieng Khuang: Nam Ma and Nam Ka. They are located outside the Mekong River basin and stretch into the eastern regions of Houaphan and Xieng Khuang. Both rivers drain directly into the South China Sea through Vietnam. Both rivers have a combined catchment area of approximately 13,000 km^2. (WEPA © 2021).

The study area consists of three countries in the Indochina region that share a border with each other and have many similarities in topography and climate. The river systems of all three countries are large with high flows and flow to the delta areas before reaching the sea. Thanks to the similarity between the above factors, comparing the conservation status of PAs in the three countries provides a perspective on the current situation, limitations, and opportunities to overcome development for the future.

2. Protected area classification

According to the International Union for Conservation of Nature, Vietnam now has 209 PAs, 26 of which are classified as category II and 60 classified as lesser categories. The Lao People's Democratic Republic currently has 31 PAs, but only three of which are classed as category II and twenty-one of which are designated as lower category. Cambodia has a total of 69 protected places, with 18 of them classified as categories I and II and the remaining 62 classified as lesser categories. This data does not include PAs that are not reported or do not meet the criteria for inclusion on the IUCN's list of PAs. From there, I classified the countries' PAs into the following categories:

- Vietnam's national parks (Category II PA of Vietnam)
- Vietnam's PAs (Under category II PA of Vietnam)
- Cambodian national parks (Category II PA of Cambodia)
- Cambodia's PAs (Under category II of Cambodia)
- Lao PDR's nationa parks (Category II PA of Lao PDR)
- Lao PDR's Lao PDR's nationa parks (Under category II PA of Lao PDR)

After categorizing the regions according to the IUCN categories, I began filtering PAs that were ineligible for my study concerned to river nets. PAs from the following areas will be filtered:

- Marine PA (not suitable for freshwater protection)
- Island PA (not suitable for river nets protection)
- PAs located in the delta region. (Delta is where water from the upstream area is consumed. Besides, this is a place with a high concentration of population with high production frequency and many sources of pollution. At the same time, FWPA-eligible areas need to cover the watershed. Thus, the PAs in delta region is not suitable for rivernet protection)
- Lake PA (not suitable for rivernet protection)
- Wetland PA (not suitable for rivernet protection)

While these PAs may qualify as freshwater PAs, they are not eligible to become conservation areas for river networks.

I then whittled down the list of qualified PAs for this study as follows:

Vietnam: 52 PAs in total, with 19 NPs and 33 PAs.

Cambodia: 21 PAs in total, including 9 NPs and 11 PAs.

LaoPDR: 17 Pas in total, including 3 NPs and 14 PAs.

3. Requirements for becoming a valuable for FWPA

To qualify as a valuable PAs for freshwater and river system protection, a PA must have the following characteristics, according to Saunders et al (Saunders et al., 2002):

- Preserved river basin or a single PA that can manage an entire area (a reasonable protected area should be a catchment management zone).
- Capable of sustaining natural flow, and the hydrological mode is in its natural state (connections between freshwater focal areas exist, and no large dams affect the hydrological mode).
- Exclusion of invasive species and rigorous management of them.

To determine the river system's connectedness, I use the Strahler’s model. Strahler's model is a model that was established in 1957 to examine the order of the river system. First-order tributaries do not receive affluents; when two first-order tributaries join, a second-order tributary is formed that gets only first-order lateral affluents. When two second-order rivers meet, a third-order river is formed. (Strahler 1957)

Strahler's ordering is significant because it establishes unambiguous relationships between stream order and a range of physical characteristics within a drainage basin, such as watershed size, tributary length, breadth, slope, and total number of tributaries. (Billen et al., 1994).

In conclusion, a PAs that meet these characteristics will be defined as a valuable PAs:

- Contains an entire the entire upstream catchment in it (Catchment management zone)
- Located outside the delta, wetlands, seas and islands
- Strahler stream order index >= 3

4. Mapping

PAs outside of the areas to be removed will be mapped separately using ArcGIS and shapefiles from the IUCN website for PAs (protectedplanet.net). Shapefiles of countries, including borders and boundaries between regions in that country, are provided by the IGIS map website.

After the geographic maps were completed, I used rivernet shapefiles from riverSHEDS to layer on top of the protected area map. From here, I can clearly see and rate the river according to the Strahler scale. (Example of map see Figure 11, all maps see Appendix)

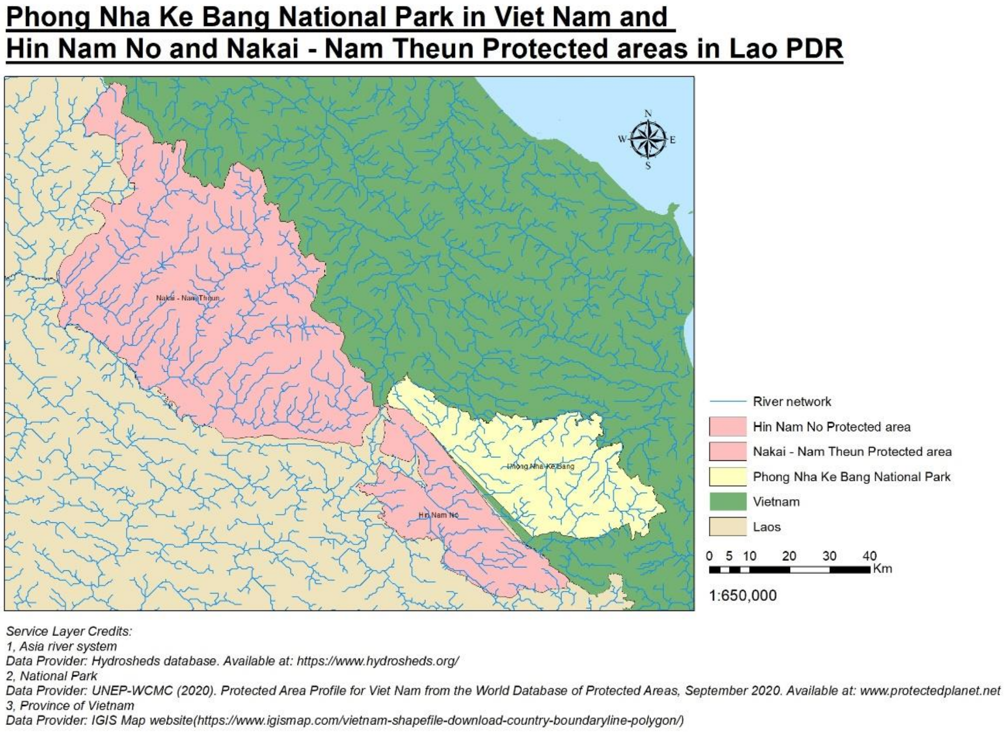

Figure 11: Map of Phong Nha Ke Bang National Park area in Vietnam. On the Eeast part NP border copy catchment (it is optimal for FWPA), but in north part is river channels and floodplain mostly outside of NP. Gap on state border region is only layer inaccuracy. An example of crossborder FWPAs (original map).

With the available data from IUCN, I also made a map of the three countries to get an overall picture of the location of PAs across the country (see maps in Literature Review).

5. Comparison

To answer the first objective question, I use different comparisons:

1. Calculate the ratio of total PA and PA area as defined by the IUCN to the country's total area. With this comparison, I can observe the protected area's proportion to the country's overall land area, which demonstrates the country's commitment to the protected area system.

2, Determine the percentage of PAs eligible for freshwater and river net protection in relation to the total number of national PAs. I can see the ratio of PAs that can be used to conserve freshwater and river systems to the total national PAs using this comparison. From there, it demonstrates the country's capacity for fresh water and river system conservation.

The two ratios will be compared along with the total number of sample sites and the standard of clean water in three nations. From there, one may determine the current state, level of endangere, and capacity of three countries to protect their freshwater and river systems.

6. Indices Selection

The three countries included in the study region share a similar temperature and natural geography, but their primary connection is that they are all members of the Mekong River basin. In other words, the Mekong River and the Mekong River ecosystem are the three target countries' primary points of convergence. I used research and measurements conducted by the Mekong River Commission (MCR) to construct a set of indicators for river ecosystems health in three nations' PAs, thereby further establishing indicators necessary for the index to perform most effectively in these countries' PAs.

The MCR monitoring reports use a variety of indicators to measure water quality for a variety of objectives. Three sets of WQI indicators are utilized in the 2014 and 2016 reports on MCR water quality measurement (MCR © 2021).

- WQI for protection of aqua life.
- WQI for human health.
- WQI for agriculture use.

For the following reasons, I chose to use WQI for protection of aqua life as a foundation to develop a new set of WQI for FWPA:

- The WQI will be used to collect data in FWPA areas with little or no human or agricultural activity.
- The new set of indicators is primarily intended to monitor water quality as well as the elements that influence the quality of the freshwater environment and riverine ecosystems.
- According to MCR 2018 Lower Mekong water quality monitoring report (2021), the WQI index for protection of aqua life is an open set of indicators. This means that I can add the necessary indicators suitable for the purpose of the study without affecting the results or the application of the indicator set.

Therefore, the WQI for protection of aqua life index will be used as a foundation in the development of the new set of indicators in this study.

6.1 WQI for protection of aqua life

Only six parameters are included in the MCR's yearly water quality report. The parameters and their target values are shown in Table 2. The classification method used by the United Nations Environment Programme's Water Quality Index for the Protection of Aquatic Life is summarized in Table 3.

This index is calculated according to the equation:

$$WQI = \frac{\sum_{i=1}^{n} P_i}{M} \text{ x}10$$

With “pi” is the points scored on sample day i. If each parameter listed in Table x meets its respective target value in Table y, one point is scored; otherwise, the score is zero

“n” is the number of samples from the station in the year

“M” is the maximum possible score for the measured parameters in the year

Rating score	Class
$9.5 \leq WQI \leq 10$	A: High Quality
$8 \leq WQI < 9.5$	B: Good Quality
$6.5 \leq WQI < 8$	C: Moderate Quality
$4.5 \leq WQI < 6.5$	D: Poor Quality
$WQI < 4.5$	E: Very Poor Quality

Table 4: Parameters used for calculating the rating score of the Water Quality Index for the Protection of Aquatic Life, together with their target values (MCR © 2016)

Parameters	Target value
pH	6-9
EC (mS/m)	<150
NH_3 (mg/L)	0.1
DO (mg/L)	>5
NO_2^{-3}-N (mg/L)	0.5
T-P (mg/L)	0.13

Table 5: Rating systems for the Water Quality Index for the Protection of Aquatic Life (MCR © 2016)

Results

The PAs in the research area's three nations were screened using the processes mentioned in the Methods section. After filtering away PAs that fall into the unreasonable area, the PAs are remapped to compare and determine which PAs meet the FWPA specifications. The appendix to this paper contains a list and map of PAs. The next section of results often shows comparisons of areas, cumulative percentages, and ratios between FWPA and PA.

The statistics in the results section make it simple to determine the status of PAs in the three nations. Vietnam has a FWPAs rate of 5.26 percent, which is significantly lower than the rates in the other two nations. The largest proportion of PAs fulfilling the objective was 25.8 percent in Lao PDR, followed by 17.39 percent in Cambodia.

In terms of PAs, Vietnam has the most, with a total of 209 PAs matching IUCN criteria. Cambodia is in second place with 69 PAs, followed by Lao PDR with 31 PAs. Although Vietnam has the most PAs, it falls far behind the other two countries in terms of the area covered by mainland PAs. Lao PDR's 31 PAs cover 11,634 Km^2, Cambodia's 68 PAs span 72,527 Km^2, and Vietnam's total area of 209 PAs is just 24,990 Km^2. As a result, while Vietnam has a significant number of PAs, most of them are rather small (Table 6).

In terms of valuable PAs for being FWPAs, Vietnam and Cambodia both own 12 valuable PAs, more than twice of Lao PDR's 6 valuable PAs. Despite their quantitative similarities, the total area covered by valuable PA in the two countries is entirely different. Cambodia's 12 valuable PAs span an area of up to 27,390 Km^2, whereas Vietnam's covers only 6,983 km2, which is even less tha Along with increasing and improving each country's protected area system, cooperation across countries will aid in the more effective preservation of the riparian system. There are several PAs in the region claimed by the three nations that are adjacent to one another and can be fully connected to establish a transnational protected area, as illustrated in map x. In Europe, many countries share protected zones along their borders. The advantage of a shared conservation area is that decisions about the area must be agreed upon by all parties, ensuring that decisions are reviewed from a variety of angles and thoroughly considered to get the greatest results.

Viet Nam and Cambodia both own 12 valuable PAs, more than twice the Lao PDR's 6 valuable for FWPAs. Despite their quantitative similarities, the total area covered by valuable PA in the two countries is entirely different. Cambodia's 12 valuable protected areas span an area of up to 27,390 Km^2, whereas Vietnam's covers only 6,983 Km^2, which is even less than the combined coverage area of Lao PDR's six protected areas, which totals 11,634 Km^2.

	Viet Nam	Cambodia	Lao PDR
Total number of valuable PA	12	12	6
Total PA of the country	209	69	31
Total area valuable PA (Km^2)	6,983.24	27,390.07	11,634
Total terrestrial PA (Km^2) (Source: UICN, 2021)	24,994	72,527	43,220
Total area of the country (Km^2) (Source: UICN, 2021)	329,880	182,511	231,276
Average area of valuable PA (Km^2)	581,9367	2,282.506	1,939
% valuable PA/PA mainland (%)	27.93967	37.76534	26.91809
% area of valuable PA/country area (%)	2.116903	15.00735	5.030353

Table 5: Comparison of results of PAs meeting targets among three countries: Vietnam, Cambodia and Lao PDR.

Vietnam likewise ranks lowest in terms of the coverage ratio of valuable PA to the total area of the country, at 2.11 percent, whereas Lao PDR reaches 5.03 percent and Cambodia covers 15% of the national territory with PAs that match the aim. However, comparing the ratio of total target PA area to total land PA area reveals little difference. Vietnam's rate is 27.93 percent, greater than Lao PDR's rate of 26.91 percent. Cambodia maintains a lead over the other two countries, with a coverage rate of 37.76 percent.

While Vietnam has the greatest total area and number of PAs, it lags behind Lao PDR and Cambodia on valuable PAs. We can clearly observe that Vietnam has not placed a high premium on riparian and freshwater ecosystems, nor has it placed a high premium on their protection in national PAs.

With a large number of PAs located inland and the topography of numerous rivers and streams flowing into the Ton Slap lake area, Cambodia's rate of 17.39 percent of PAs meeting the target does not accurately reflect the country's trend of using PAs to protect freshwater ecosystems via national PAs. Given Cambodia's varied topography, conservation of the country's riparian and freshwater ecosystems will require additional attention and study in the future.

Despite having the highest rate of target achievement, most Lao PDR's PAs failed to reach IUCN targets. The comparison is based solely on data provided by the countries to the IUCN, and so may contain inaccuracies. However, when IUCN data for all three nations is considered, it is evident that Lao PDR is doing an excellent job safeguarding freshwater habitats in its national parks.

1. Vietnam:

Vietnam has 12 PAs reached the target of conserving freshwater and river systems, out of a total of 209 PAs nationwide. The rate of PA reaching the target was 5.26%.

Out of the total coverage area of land PAs in Vietnam is 24,994 Km^2, the covered area of the target PAs accounts for 6455.83 Km^2. The average area of Pa reaching the target in Vietnam is 586.84 Km^2. The percentage of PA area reaching the target with the total national area is 1.95%.

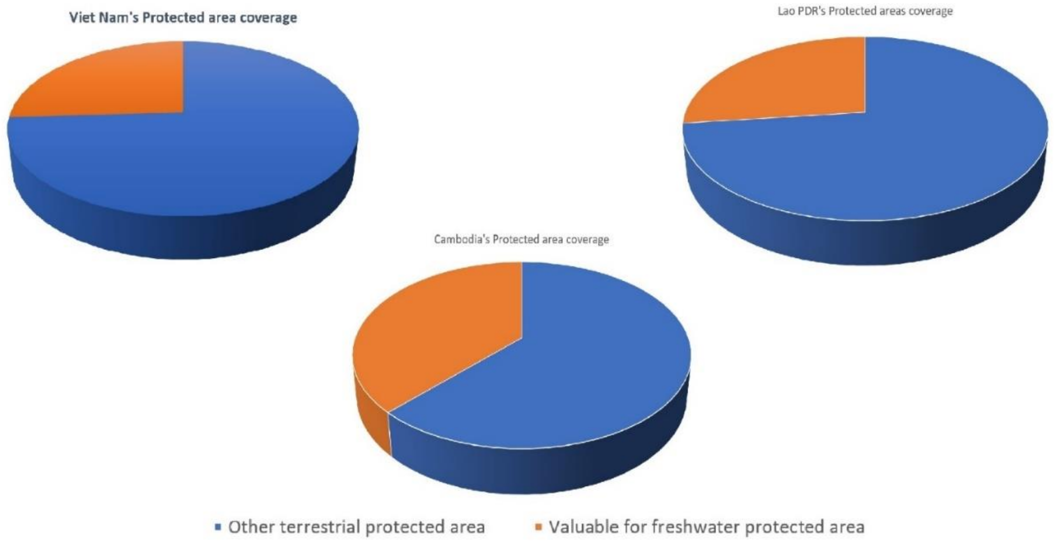

Figure 12: Rate of Valuable for FWPAs with Other terrestrial Pas

1.1 National Park of Vietnam Group (IUCN's categories I and II):

- Bach Ma NP: 374.87 Km^2, Strahler stream order index level 3
- Bidoup - Nui Ba NP: 575.12 Km^2, Strahler stream order index level 3
- Chu Yang Sin NP: 669.8 Km^2, Strahler stream order index level 3
- Hoang Lien NP: 285.09 Km^2, Strahler stream order index level 3
- Kon Ka Kinh NP: 420.57 Km^2, Strahler stream order index level 3
- Phong Nha - Ke Bang NP: 1233.2 Km^2, Strahler stream order index level 3
- Pu Mat NP: 935.24 Km^2, Strahler stream order index level 3
- Yok Don: 1138.54 Km^2, Strahler stream order index level 3
- Vu Quang: 527.41 Km^2, Strahler stream order index level 3

1.2 PAs of Vietnam (under IUCN's Categories II)

- Nam Ka PA: 194.12 Km^2, Strahler stream order index level 3
- Phong Dien: 415.08 Km^2, Strahler stream order index level 3
- Xuan Nha 214.2 Km^2, Strahler stream order index level 3

2. Cambodia:

Cambodia has 12 PAs meeting the targets of freshwater conservation and river connectivity, out of a total of 69 PAs nationwide. The rate of PA reaching the target is 17.39%.

The total area of target PAs in Cambodia is 27,390.07 Km^2, the average area is 2,282.5 Km2. The ratio of PA area reaching the target to the total national area is 15.007%.

Cambodia has many PAs reaching the target with strahler level higher than 3, for example Central Kravanh with an area of 4013.13 Km^2 (Figure 13)

2.1 National Park of Cambodia group (IUCN's categories I and II):

- Botum Sakor NP: 1712.5 Km^2, Strahler stream order index level 3
- Central Kravanh: 4013.13 Km^2, Strahler stream order index higher than level 3

- Preah Jayavaraman: 375 Km^2, Strahler stream order index level 3
- Preah Monivon Bokor: 1544 Km^2, Strahler stream order index higher than level 3
- Virajay: 3325 Km^2, Strahler stream order index higher than level 3

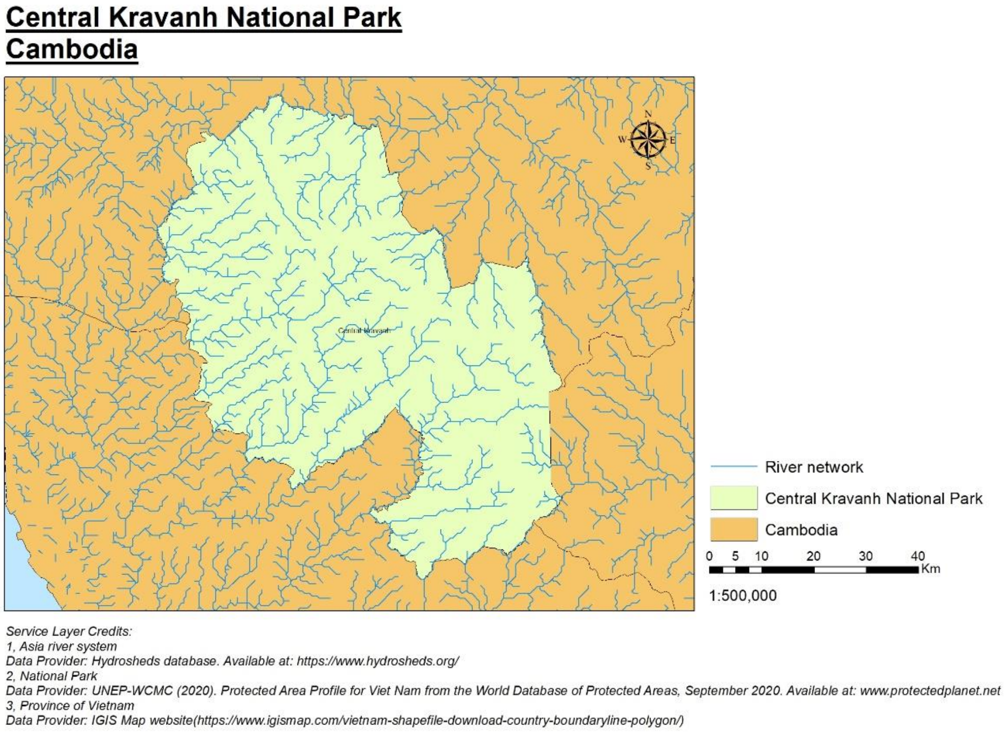

Figure 13: Central Kravanh National Park of Cambodia. The biggest NP in region protect central part of mountains with dense river net. Bigest river system have high level of stream order according Strahler.

2.2 PAs of Cambodia (Under IUCN's Categories II)

- Lumphat: 2500 Km^2, Strahler stream order index higher than level 3
- Phnom Aoral: 2537.5 Km^2, Strahler stream order index level 3
- Phnom Prech: 2225 Km^2, Strahler stream order index higher than level 3
- Phnom Somkos: 3337.5 Km^2, Strahler stream order index higher than level 3
- Preah Roka: 903.61 Km^2, Strahler stream order index level 3
- Prey Lang: 4316.83 Km^2, Strahler stream order index higher than level 3
- Sam Lout: 600 Km^2, Strahler stream order index level 3

3. Lao PDR:

Lao PDR has 7 PAs reaching the targets of freshwater and river linkage conservation, out of a total of 31 PAs nationwide. The rate of PA reaching the target is 22.5%. The total area of target PAs in Lao PDR is 15,741 Km^2, the average area is 1967.6 Km^2. The percentage of PA area reaching the target with the total national area is 6.8%.

Lao PDR has many PAs reaching the target with strahler level higher than 3, for example Nakai – Nam Theun with an area of 2000 Km^2 (Figure 14).

Lao PDR has only one group of PAs, which is IUCN's PA group under category II, the PAs that meet the criteria include:

- Nakai – Nam Theun: 2000 Km^2, Strahler higher than level 3
- Nam Ha: 2224 Km^2, Strahler higher than level 3
- South Kading: 1690 Km^2, Strahler higher than level 3
- Phou Denedin: 2220 Km^2, Strahler level 3
- Phou Hin Poun: 1500 Km^2, Strahler higher than level 3
- Phou Khao Khuy: 2000 Km^2, Strahler higher than level 3
- Nam Et Phouloey: 4107.1 Km^2, Strahler higher than level 3

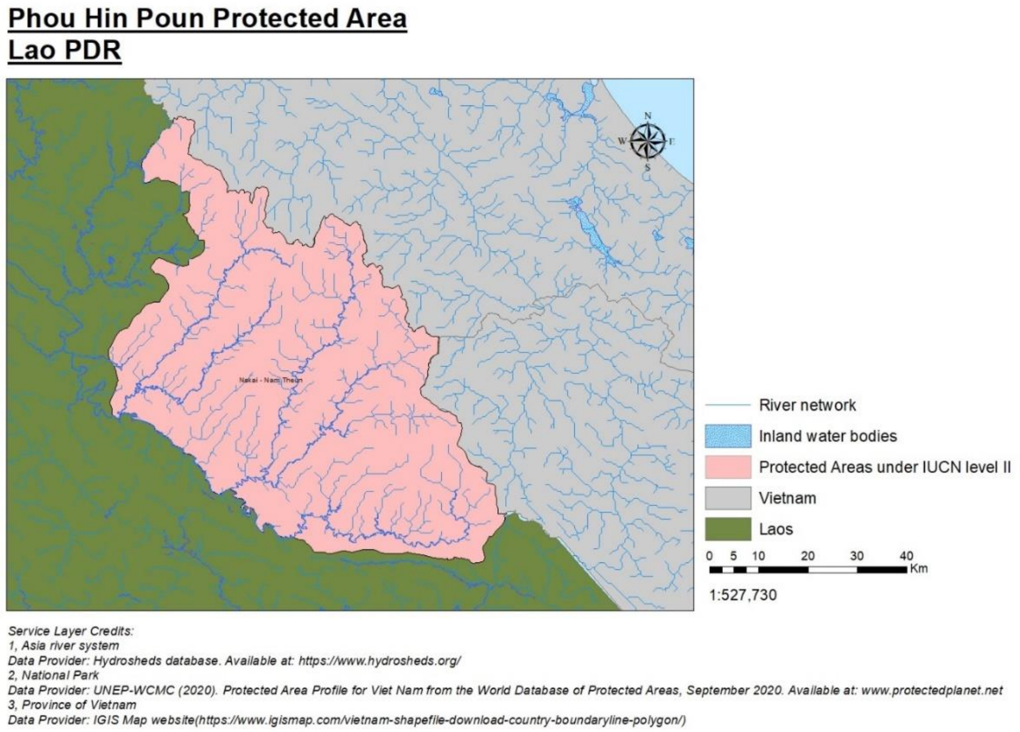

Figure 14: Nakai – Nam Theun Protected area of Lao PDR

Regarding the number of fresh water sampling points, in all three countries there are no access to specific data, this index is excluded from the calculation range.

4, Parameters implement for the new Freshwater WQI

After having the original WQI set, I started removing and adding parameters to create a new WQI set that was suitable for long term monitoring of riverine ecosystems in national parks.

First, I removed the following parameters: T-P, DO. These are important parameters in freshwater monitors, they are mainly used to measure the eutrophication and nutrient levels of water. It is not possible to use cheap automatic devices for measurements unfortunately. Instead of using those parameters, the complex bioindicator, namely fish and benthos, are chosen to measure eutrophication in freshwater systems.

Besides, turbidity is added to the WQI set. These parameters give a complex view of the process in all chambers, and it is possible to measure it by automatic devices. Without this parameter, it would not be possible to monitor excessive anthropogenic erosion or the effect of trapping sediments in reservoirs.

EC and pH are important parameters, and it is possible to use cheap automatic devices to measure them. Important threats to riverine ecosystems like acydificatin, excessive erosion, and dilution of minerals from soil are possible to measure by these parameters.

The final set of parameters for WQI includes:

- pH
- EC
- Turbidity
- Fish
- Benthos

Discussion and recommendation

1, Is it important to protect 100% of catchments of river net?

Catchments are an important area that is the source of water for the entire basin of the river (Abell et al. 2007). River systems are formed by the confluence of numerous tributaries that originate in various catchments. A catchment area is formed by the elements of water, soil, plants, and animals that are linked together in a watershed, and any activity occurring in that one will affect the entire catchment. For chemically reactive parameters, there is a need for focus on some specific parts (like floodplains or riverine corridors), but for chemically stabile parameters, all catchment focus is important (Staponites et al. 2019). Healthy river basins are vital to human survival as they are where the water people drink comes from. Drinking water supply is one of the most important ecosystem services provided by FWPAs in many cases. For example, the value of ecosystem services obtained from the protected forest of Veun Sai-Siem Pang National Park (Cambodia) was calculated in the category of water storage at (US $32.31 million yr1), (Kibria et al. 2017). These arguments can support biodiversity conservation arguments in FWPAs' existence defense in the region.

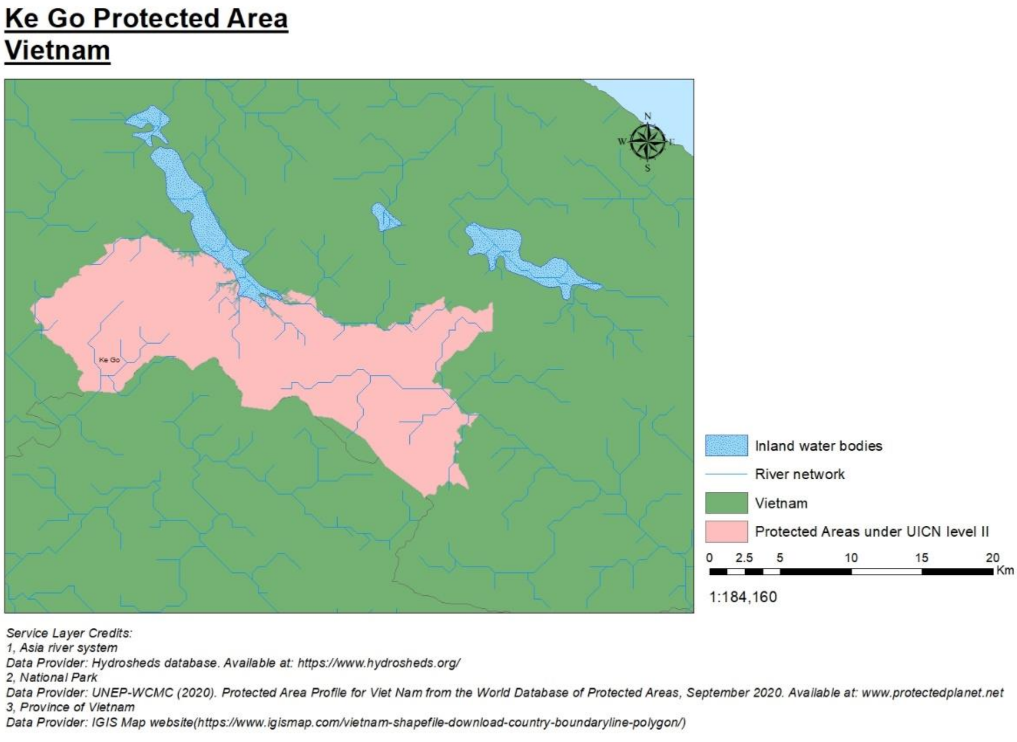

Figure 15: Ke Go protected area in Viet Nam. The protected area does not cover all the catchment area (original map).

Protecting catchments of the river net from pollutants and ecosystem change is an important task to protect the water supply of the river system. However, the idea of 100% protection of catchments is not really feasible. With a dense network of rivers and mountainous terrain like in the 3 countries in the study area, zoning all catchments will consume a lot of time and effort. Instead, resources should be used to protect other important parts of the river system.

Figure 15 is a map of the Ke Go protected area. Within the boundary of the reserve, many tributaries flow through and form the catchment area. However, some of the flows and watersheds that make up the catchment area are located outside the boundary of the reserve. In the case of the Ke Go protected area, the flows forming the catchment area outside the protected area's border can significantly affect water quality and riverine habitat if polluted. Decision-makers may consider developing buffer zones in areas of flow that lie beyond borders rather than changing the boundaries of the entire reserve.

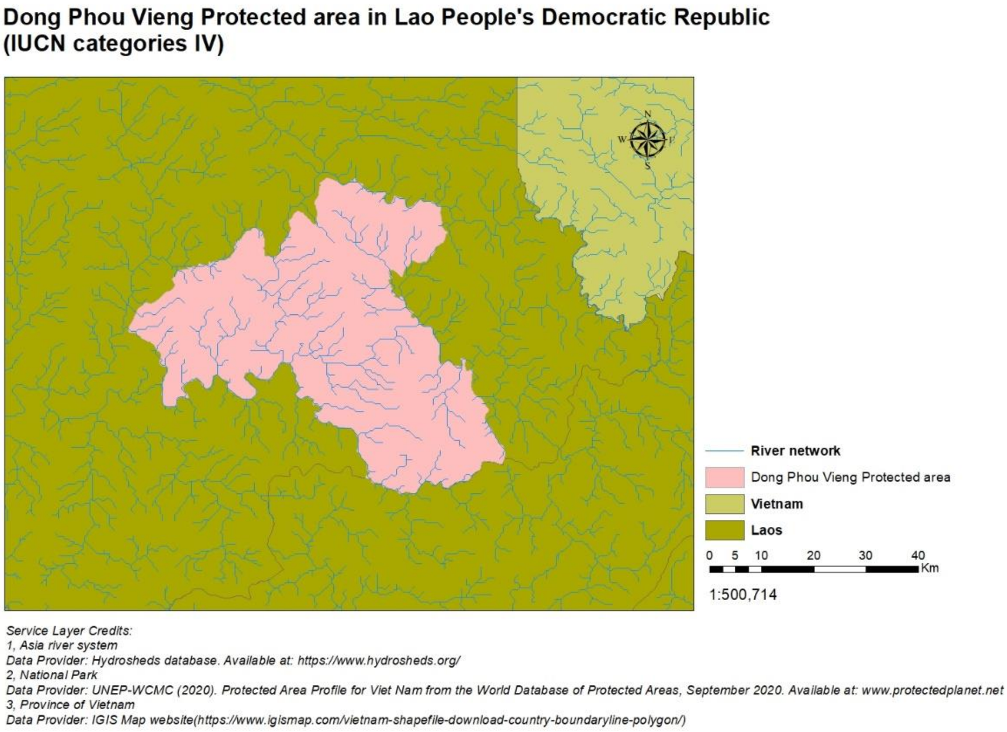

Figure 16: Dong Phou Vieng Protected area in Lao PDR. The protected area does not cover all the catchment area (original map)

In the case of the Dong Phou Vieng protected area in Lao PDR (figure 16), the flows within the border area have merged into small catchments. Streams located outside the border join the main stream once the basin has been formed, without much impact on the conservation quality of catchmen inside the reserve in case of pollution. The Dong Phou Vieng protected area still can well preserve the basin within the border without fear of being affected by flows outside the protected area.

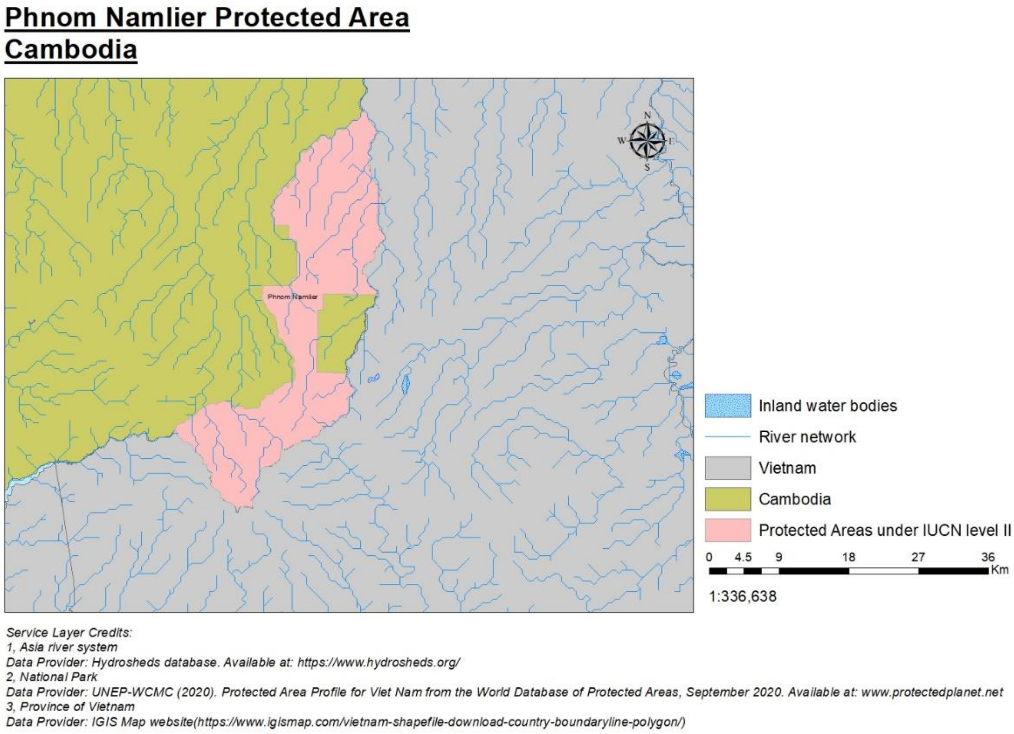

Figure 17: Phnom Namlier protected area in Cambodia. The protected area does not cover all the catchment area (original map).

With the Phnom Namlier protected area in Cambodia (figure 17), the main stream in the basin follows the boundary of the PA. The main flow of the basins here is a combination of flows originating from both inside and outside the conservation area. Therefore, water quality in the basin is highly likely to be affected if the flows and water sources located outside the PA are polluted. Buffer zones are an option that can be used to extend freshwater conservation beyond the main boundaries of the PA. However, this is a PA that located close to the border. To bring the best conservation to the riverine ecosystem in this area, there needs to be a combination of decision-makers and governments between the two countries. country.

Thus, 100% protection of the catchment area is very important to the PA's ability to preserve the river net. However, it is not always possible for a PA to cover the entire catchment area. When a part of the catchment area is located outside the PA, there are several issues to consider when assessing the PA's ability to conserve freshwater. Those problems are whether the protected area has a buffer zone or not, whether human activities take place nearby and affect the flow beyond the protected area's borders, and whether the water from outside the borders is large enough to affect the water quality of the entire area (in the case of pollution) remains to be seen.

In addition, the zoning to preserve all catchments will occupy a large area, affecting living, mining, and production activities in mountainous areas. Therefore, while conserving the entire catchments of the river net is important, decision makers who should focus on conservation should focus on critical areas and allocate resources wisely. It is reasonable to protect other areas of the river system.

2, How well can the current NPs in Vietnam, Cambodia and Laos protect the riverine ecosystem?

The percentage of PAs qualified to become FWPAs varies significantly across the research region, with Vietnam accounting for 5.26 percent, Cambodia accounting for 17.39 percent, and Lao PDR accounting for 22.5 percent. Apart from the evident variance between the three countries, it is clear that these PAs represent a negligible proportion of overall terrestrial PAs in the three countries. Similar situation is in Europe, when only small part of European system o protected areas named NATURA 2000 cover all catchment of river net (Hermoso, Filipe et al. 2015)

While most protected areas in Cambodia are in the upper catchments of the country's various river basins, the rate of PA that qualify for FWPA indicates that the river net conservation status of the Cambodian PA system is not inferior but still has much undeveloped potential (ICEM © 2003b). An example of Samlout PA (figure 18), which could qualify for the FWPA if it was changed to cover most or all the catchment area.

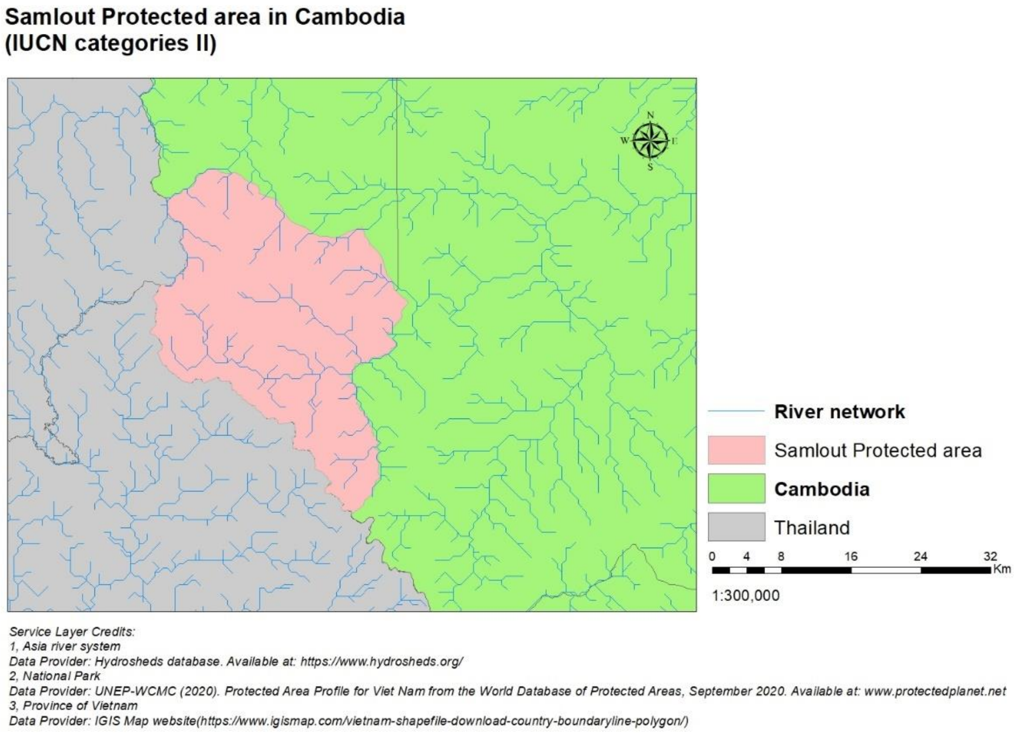

Figure 18: Samlout protected area in Cambodia. If properly improved, Samlout PA can qualify for FWPA (original map).

In the Lao PDR, national protected areas are established but not clearly classified as national parks, national wildlife sanctuaries, or similar areas. With a view to establishing multi-role conservation areas, the Lao PDR government points out that the country's protected areas are equivalent to an IUCN Category VI protected area (ICEM © 2003c).

Most of the protected areas that have been certified in Vietnam are special-use forests. Although Vietnam has several protected areas within the IUCN from categories I to IV, none of them are classified as Class V (Protected Landscape/Marine Landscape) or VI (Resource Use Areas protected by the IUCN). management), both of which allow for the sustainable use of protected area resources (ICEM © 2003).

However, many people live legally or illegally within the boundaries of most protected areas in Vietnam. Approximately 80% of Vietnam's current special-use forests are located at elevations above 500 m. These protected areas are extremely important in protecting watersheds and mitigating flood damage (ICEM © 2003). However, with 5.26% of PA meeting the criteria to become FWPA, Vietnam needs more investment and reasonable adjustments and updates to improve the quality of river net conservation and freshwater ecosystems.

The three countries in the study area share common characteristics suitable for freshwater ecosystem conservation, such as possessing many protected areas in the upper catchment area and having a dense river system. The conservation status of freshwater ecosystems in the protected area systems of the three countries, especially in Vietnam, is still not good enough compared to the conditions they possess. The system can also be modified and improved to achieve greater results in conserving the riparian ecosystem in the area.

In the three countries of the study area, responsibility for the management of protected areas rests with the state, with the participation of different ministries (ICEM © 2003). However, the management apparatus in the three countries is clearly different, and the coordination ability of the parties in the management stages is not good (Yen Mai et al., 2013). Improving the ability to exchange information and coordinate among management agencies is important to improve the conservation status of freshwater ecosystems in the countries in the study area (Heurich et al., 2010). In addition, governments and decision-makers should seek to coordinate conservation activities across countries to take full advantage of the conservation potential of protected areas located close together on a common border (Busch 2008).

3, Is it needed to expand protected area system for FWPAs effective protection?

According to the statistics reported to IUCN by Lao PDR, the country is doing an excellent job of conservation through PAs. With its rugged terrain and concentration of tiny river system watersheds, this country appears to make it easier to create PAs that encompass all critical areas, such as the catchment management zone or the critical management zone. The Lao PDR should now prioritize the implementation of river ecosystem conservation strategies in specified national parks over geographical expansion (Laurance et al., 2012).

Cambodia's indications indicate that the protection of riverine habitats is a high priority while developing the country's network of PAs. However, there are still numerous instances where PAs fail to meet the criteria for riparian ecosystem protection due to geographical constraints, such as being unable to encompass a catchment management zone (Saunders et al., 2002), as illustrated in figure 19. While Cambodia's protected area system is adequately constructed, it is important to extend and add small geographical alterations to fully utilize PAs and national parks and efficiently conserve their riverine ecosystems.

Vietnam has the largest national territory and the most PAs among the three countries. However, PAs cover a relatively small area. Vietnam also has fewer PAs that meet the target than the other two countries, partly because many PAs are too small and partly because their conservation scope does not include all critical areas for river ecosystem conservation, such as catchment management zones or critical management zones (Abell et al., 2007).

Numerous PAs in Vietnam do not fit the criteria since the PAs coverage does not cover catchment areas. In addition, Vietnam has many PAs with only tributaries flowing through them, not located in the upstream areas where conservation has yielded the best results (figure 18). This will have a direct effect on the overall ecology within the protected area since it will act as a conduit for contaminants or alien creatures to enter the protected area from the non-conserved area. Additionally, as illustrated in map x, Vietnam has protected zones that are divided into two isolated sections that are adjacent to one another. This also influences the management department's decision-making on the conservation of the ecosystems and the life of the organisms within.

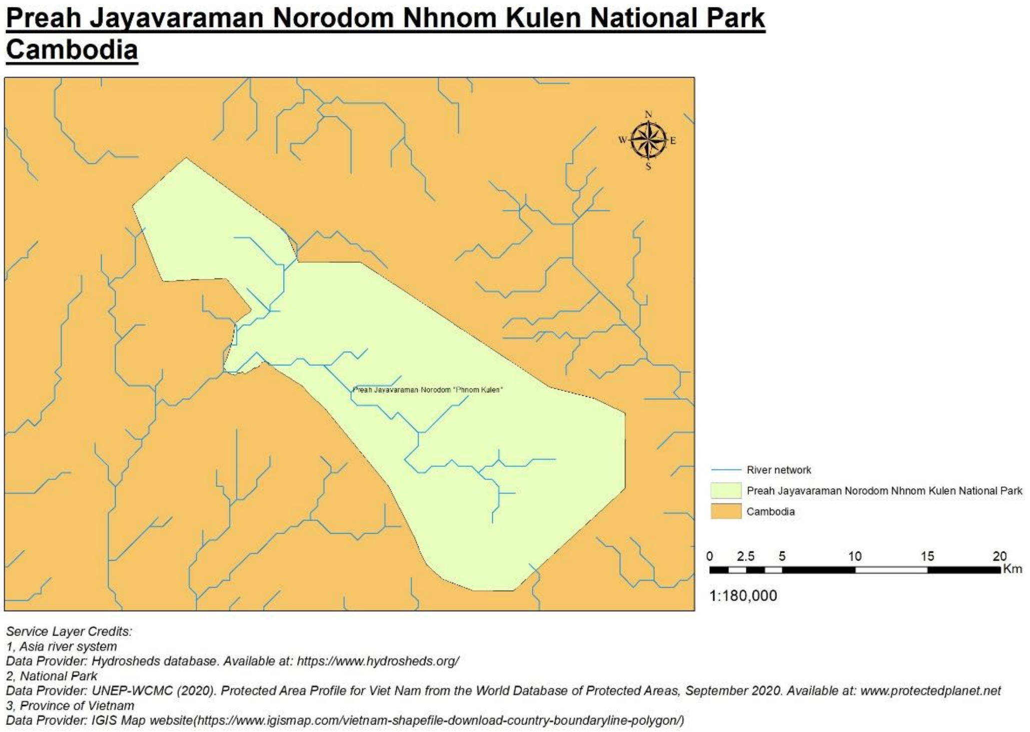

Figure 19: Preah Jayavaraman-Norodom Nhnom Kulen National Park, Cambodia with river sections whose watersheds are outside the reserve's borders (Original Map).

Additionally, based on the map of PAs in Vietnam that do not fit the criteria, it is obvious that both freshwater and riverbank habitats were overlooked when protecting areas were constructed. Most PAs in Vietnam are devoted to forest conservation. Vietnam's protected area system needs to be expanded and changed to safeguard river ecosystems more effectively (Abell et al., 2019).

Therefore, the expansion of the PAs system is essential to preserve the river net in the study area. Besides expanding geographically to fully cover essentials such as watersheds and catchment areas, PAs can be invested in other aspects to increase conservation (Abell et al., 2011). It is important for decision-makers to think about a set of factors that balance the ability to keep freshwater and the river network safe with other things like protecting forests and biodiversity.

All the preceding conclusions indicate that the null hypothesis (H0) is correct. This indicates that the existing state of PAs in Vietnam is insufficient for freshwater conservation and that they should be expanded.

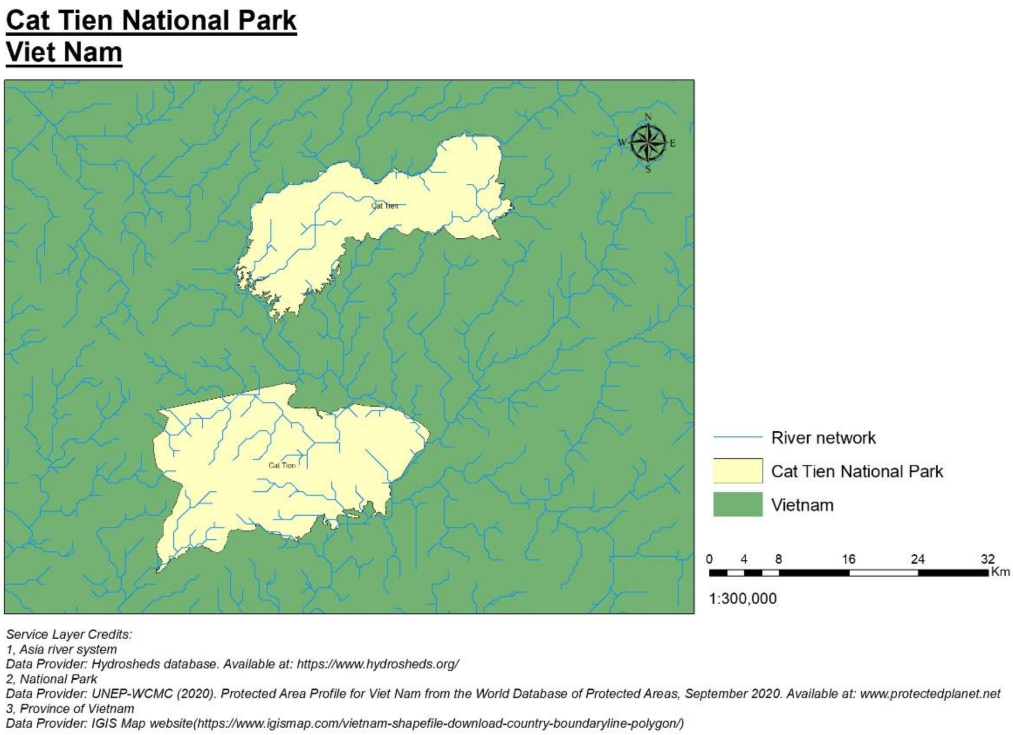

Figure 20: Cat Tien National Park, Vietnam is divided into two areas located close to each other (original map).

In addition, the three countries in the research area still have conservation areas that are too small (figure 20) or geographically fragmented, as seen in the Map of Cat Tien PA. The geographical boundaries set by humans are often not the same as natural areas in the ecosystem, so the separation of PAs can cause the ecosystem in the area to be fragmented, affecting the functioning of the ecosystem and the conservation potential of PAs. Thus, it is important to go back and look for ways to connect PAs that are spread out across a lot of land. This will help them be more conservation friendly.

Regarding the interaction of conservation work between countries, not much is known about the linkage of conservation activities. Sharing a common border gives the three countries many advantages when conserving and expanding PAs near the border (figure 21). Cooperation in conservation work between different countries can also provide multi-dimensional perspectives for conservationists, broadening the scope of decision-making (Busch 2008). Decision makers should consider collaborative measures that can expand the area of PAs, increasing the conservation capacity of the PA systems of both countries.

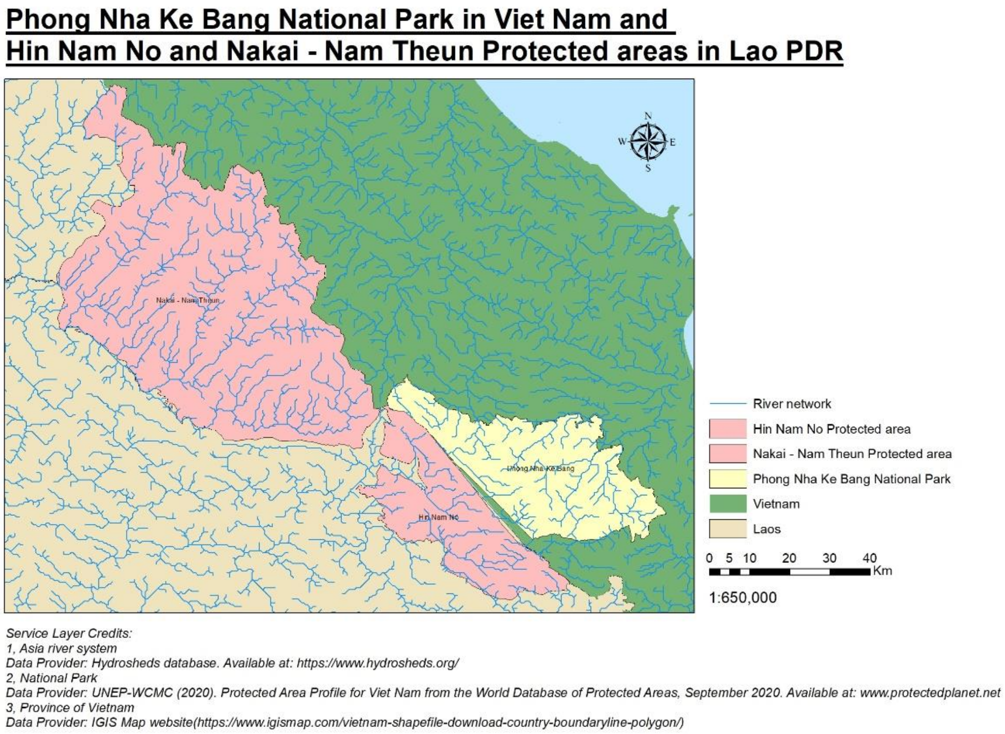

Figure 21: Phong Nha- Ke Bang Nation Park in Viet Nam and Hin Nam Ho, Nakai- Nam Theun National Park in Lao PDR. Those NPs belongs to different countries but can be link to each other to raise the ability of conservation actions (original map).

4, Is it important to imply 100% of catchment area in FWPAs borders? How small part is possible

Among the conditions for becoming an FWPAs introduced in their study by Saunders et al., 2002, catchment area coverage is an important factor in determining whether a protected area is eligible for freshwater ecosystems and river nets conservation (Saunders et al., 2002). However, the idea of covering 100% of the catchment area inside FWPAs borders can be difficult to implement in practice (Hermoso et al., 2016).

The countries in the research area are located in the tropical belt with hot and humid climate, high rainfall and complex river system (figure 22). Determining the entire catchment area will consume a lot of human and material resources (Hermoso et al., 2015, Abell et al., 2017). In the scope of this study, determining the exact catchment coverage rate suitable for best conservation has not yet been calculated due to limited resources.

However, the catchment area should be covered as much as possible to increase the capacity and impact of conservation activities. At the very least, the main watersheds and watersheds that supply large amounts of water to the entire watershed need to be prioritized (Saunders et al., 2002). In addition, if it is not possible to cover 100% of the catchment area within the FWPAs borders, decision makers need to consider factors that affect water quality as well as the types of alien species that may enter the conservation area through the river net system.

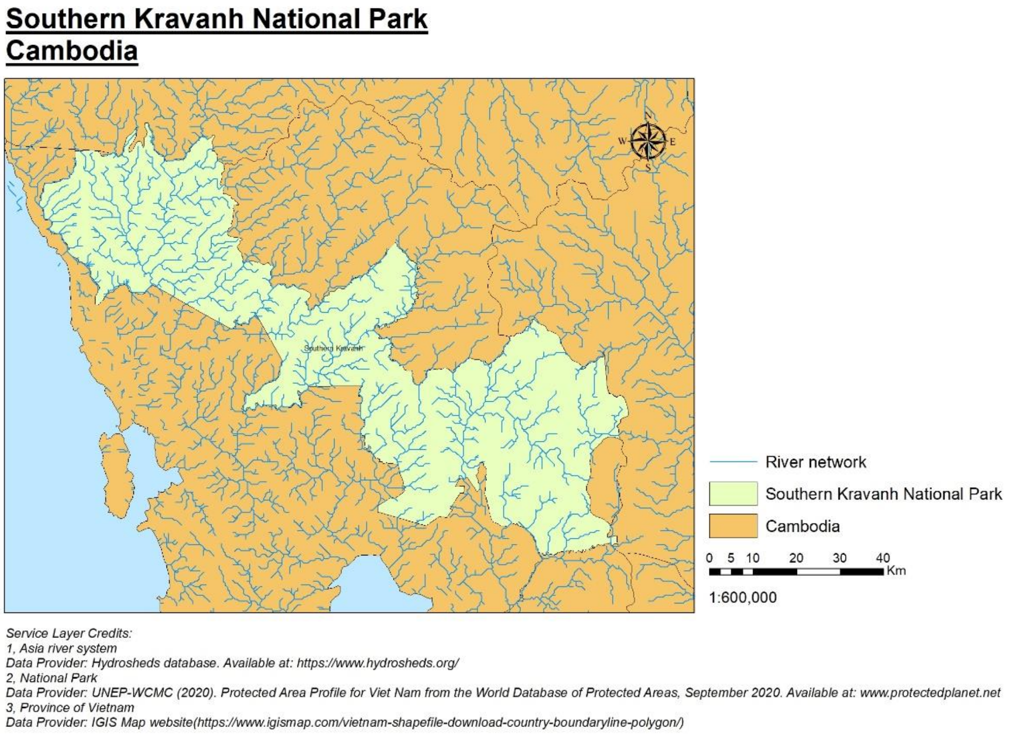

Figure 22: Southern Kravanh National Park in Cambodia, PA with complex river system inside (original map).

5, Set of simple indicators for long-term monitoring of tropical Asia freshwater protected area

In middle or low-income countries, it is not possible to organise long-term water quality monitoring programs using the traditional approach used in Europe or North American countries (Lamberti and Hauer, 2017). One exception is the famous Mekong River Commission international monitoring program. This expensive system covered the main channel of the river and some tributaries. It is not realistic to use this system for hundreds of middle and small rivers in national parks in the Indochina region.

A new set of indicators developed in this study is based on continually measurable parameters (pH, EC, turbidity) and bioindicators (benthic macroinvertebrates and fish).

The whole set of parameters consists of the following:

Continually measurable parameters:

- pH
- EC
- Turbidity

The bioindicators includes:

- Benthic macroinvertebrates
- Fish

Physico-chemical parameters are needed to be measured continually at high frequency (1 hour or higher) by automatic probes (Cano-Paoli et al., 2019). Many companies (like Onset, for example) produce independent probes that need only simple regular cleaning and can work for many months or years. All probes measure temperature too. This continuous data provides us with an excellent opportunity to monitor many characteristics of riverine ecosystems for an extended period (Benettin and Van Breukelen 2017, Demers et al., 2021).

Riverine ecosystem bioindicators give a complex picture of water quality and riverine ecosystem biota too. If long-lived animals are used (molluscs, crayfishes, fishes), it is possible to use a long period of monitoring (1–5 years) to detect long-term changes in water quality (Simeone et al., 2021).

An important and complicated issue in many countries is the development of a system of data storage and archiving (Ortega et al., 2021). Proper data management is the basis of successful long-time monitoring success.

Conclusion

The research results allow me to draw conclusions about the riverine conservation status of the national park system in Vietnam. This system is already capable of preserving the riverine ecosystem in certain PAs. However, the number of PAs meeting the criteria is not much, even when compared to the total number of PAs in the country or when compared with two countries in the same region, Lao PDR, and Cambodia.

Expansion of the protected area system is necessary to increase the capacity and effectiveness of riverine ecosystem conservation. With many PAs located in the upper catchment areas, the conservation status of riverine ecosystems in the protected area is in Viet Nam and the two countries that share a border in the Indochina Peninsula, Cambodia, and Lao PDR, have great potential for improvement. Buffer zones are an effective tool to overcome the problem of streams beyond protected area boundaries. However, to come up with an appropriate plan, many issues need to be considered.

In addition to assessing the conservation status of riverine ecosystems in the protected area system of Viet Nam, a simple and cheap set of indicators has been proposed to measure water quality over the long term for countries in the study area and similar areas. Based on Mekong River Commission's open indicies, Water quality index for protection of aqua life, a simple and inexpensive set of metrics including continually measurable parameters (pH, EC, turbidity) and bioindicators (benthic macroinvertebrates, fishes) is suggested for long-time monitoring water quality in countries in the study area and areas with similar natural conditions.

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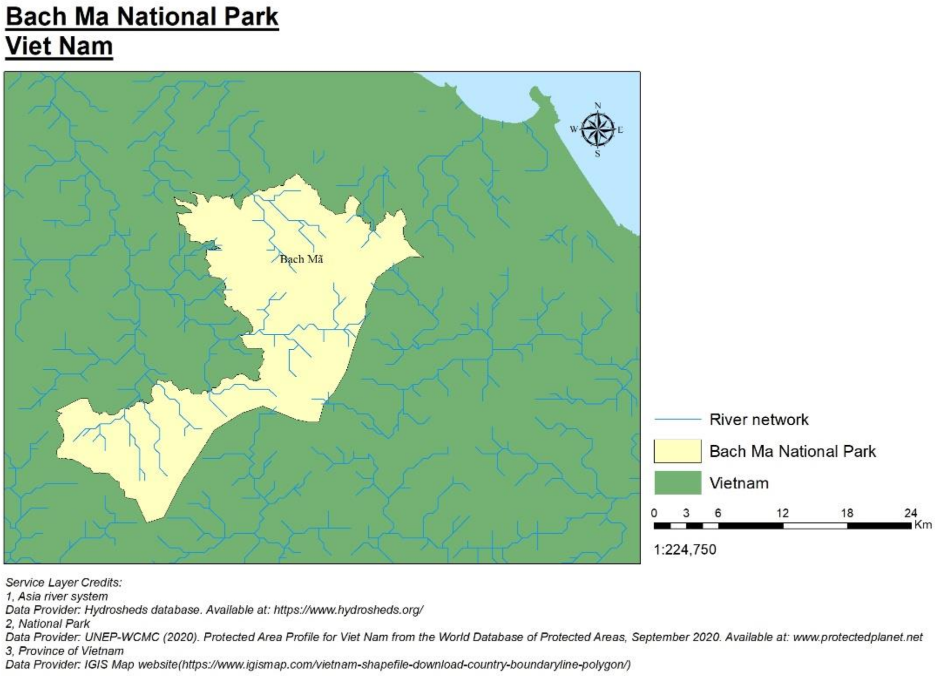
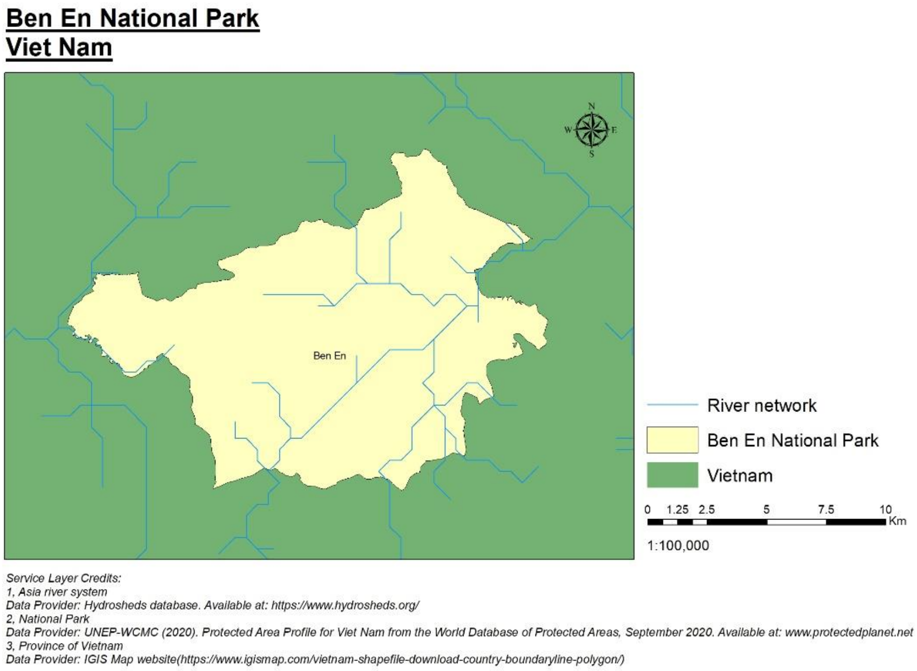
APPENDIX

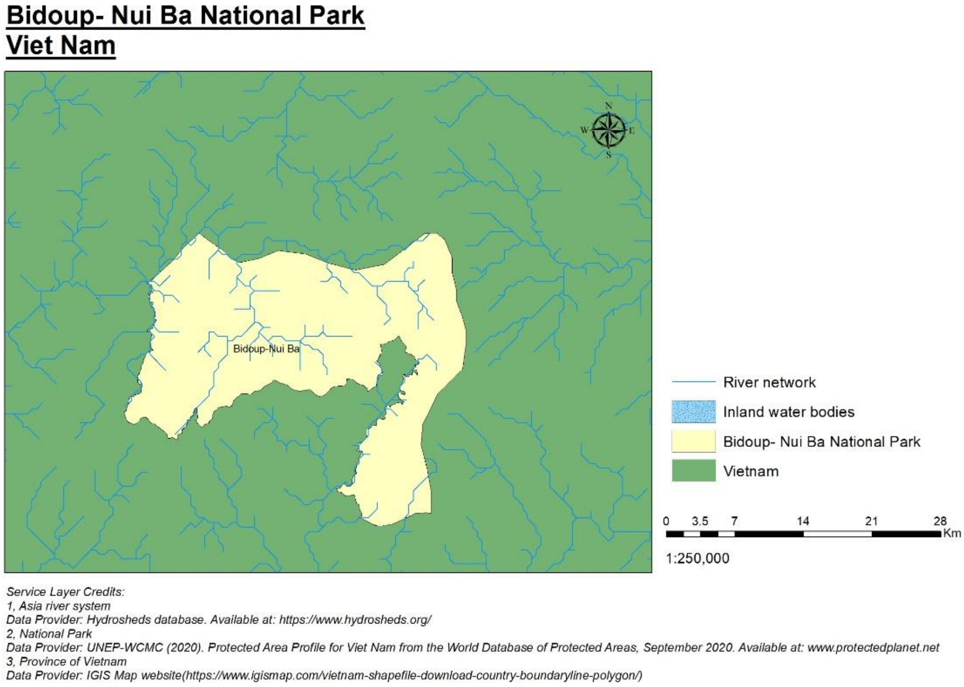
APPENDIX I: Maps of National Parks, and Protected Areas in Viet Nam.



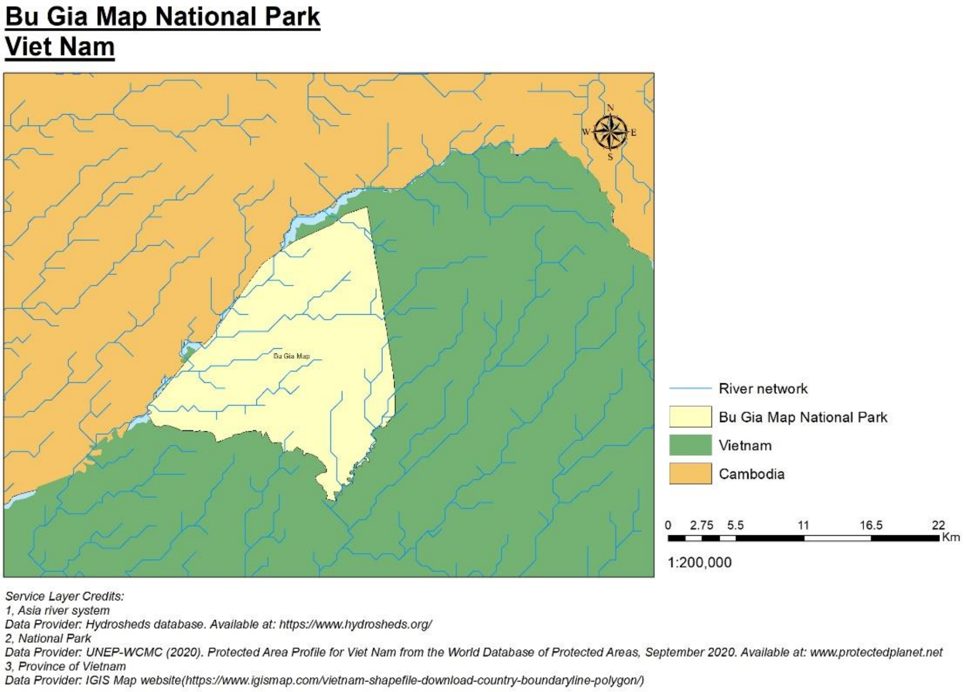
Map 1: Bach Ma National Park in Viet Nam.



Map 2: Ben En National Park in Viet Nam.

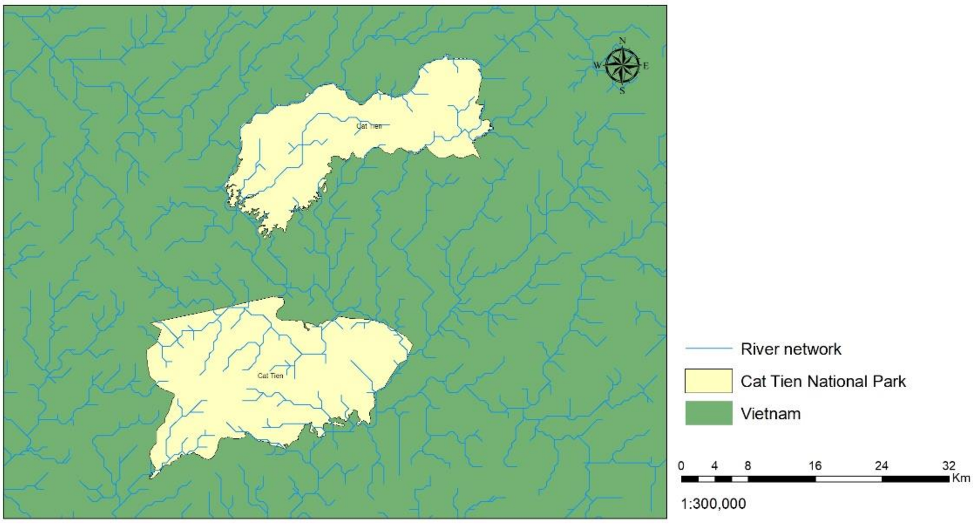


Map 3: Bidoup – Nui BaNational Park in Viet Nam.



Map 4: Bu Gia Map National Park in Viet Nam.

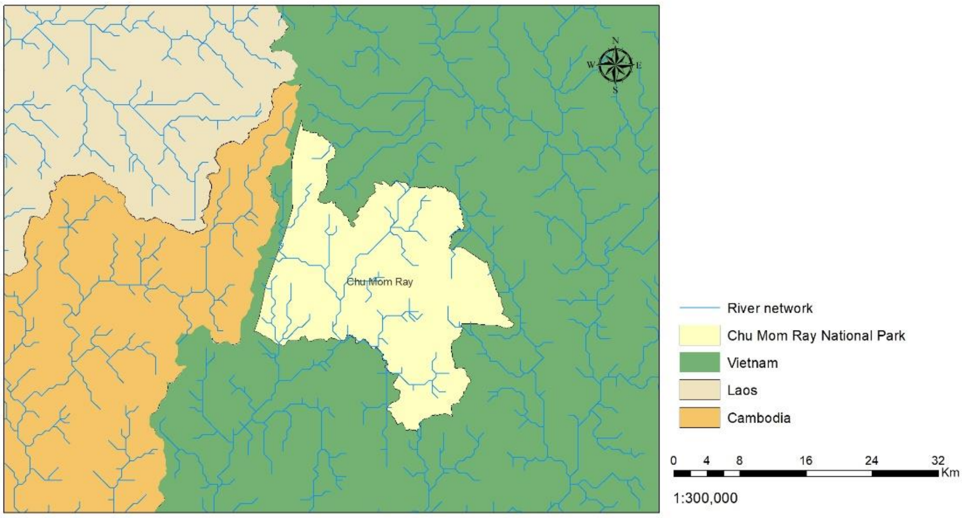
Cat Tien National Park
Viet Nam



Service Layer Credits:
1, Asia river system
Data Provider: Hydrosheds database. Available at: https://www.hydrosheds.org/
2, National Park
Data Provider: UNEP-WCMC (2020). Protected Area Profile for Viet Nam from the World Database of Protected Areas, September 2020. Available at: www.protectedplanet.net
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

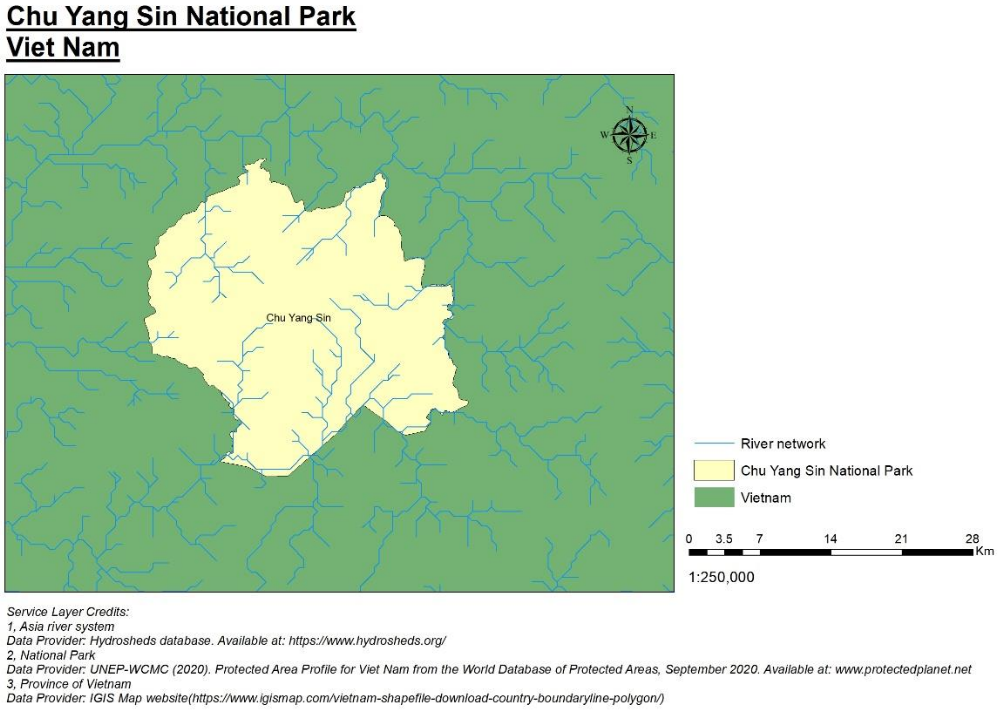
Map 5: Cat Tien National Park in Viet Nam.

Chu Mom Ray National Park
Viet Nam

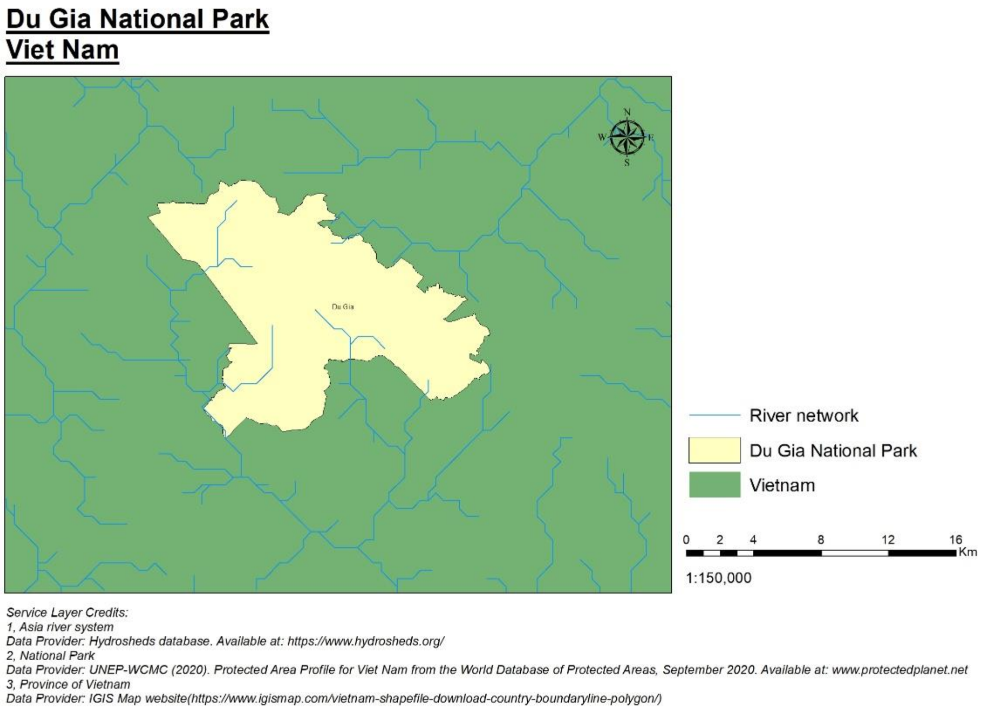


Service Layer Credits:
1, Asia river system
Data Provider: Hydrosheds database. Available at: https://www.hydrosheds.org/
2, National Park
Data Provider: UNEP-WCMC (2020). Protected Area Profile for Viet Nam from the World Database of Protected Areas, September 2020. Available at: www.protectedplanet.net
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

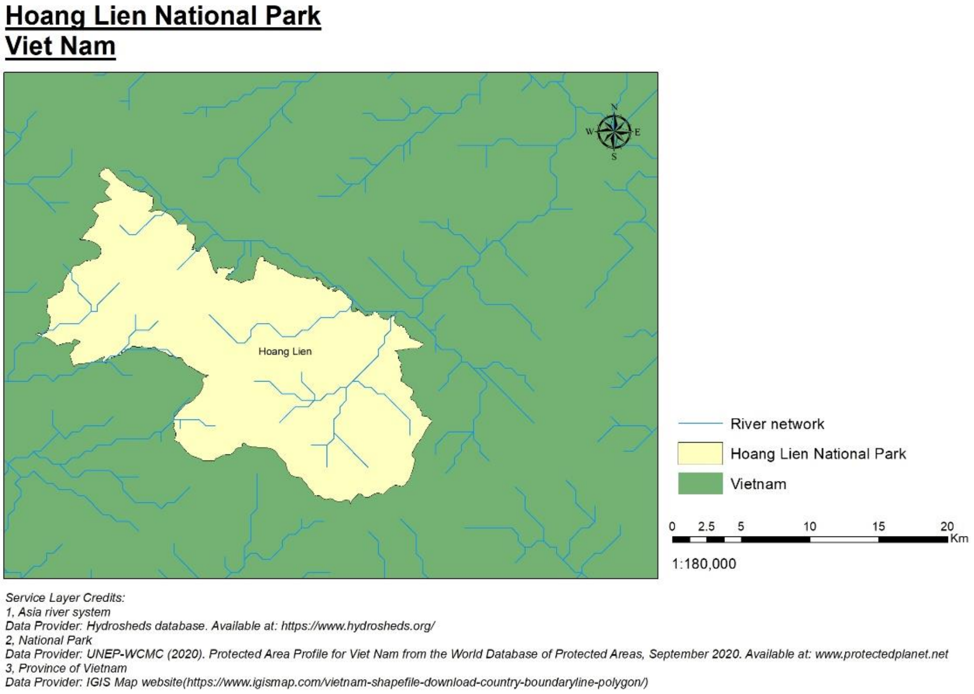
Map 6: Chu Mom Ray National Park in Viet Nam



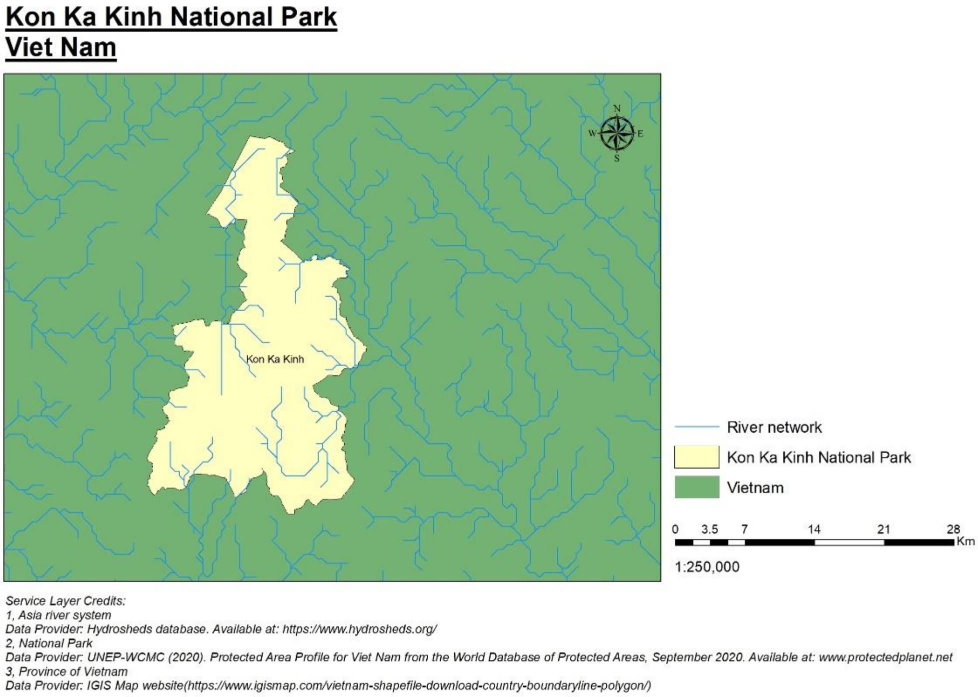
Map 7: Chu Yang Sin National Park in Viet Nam.



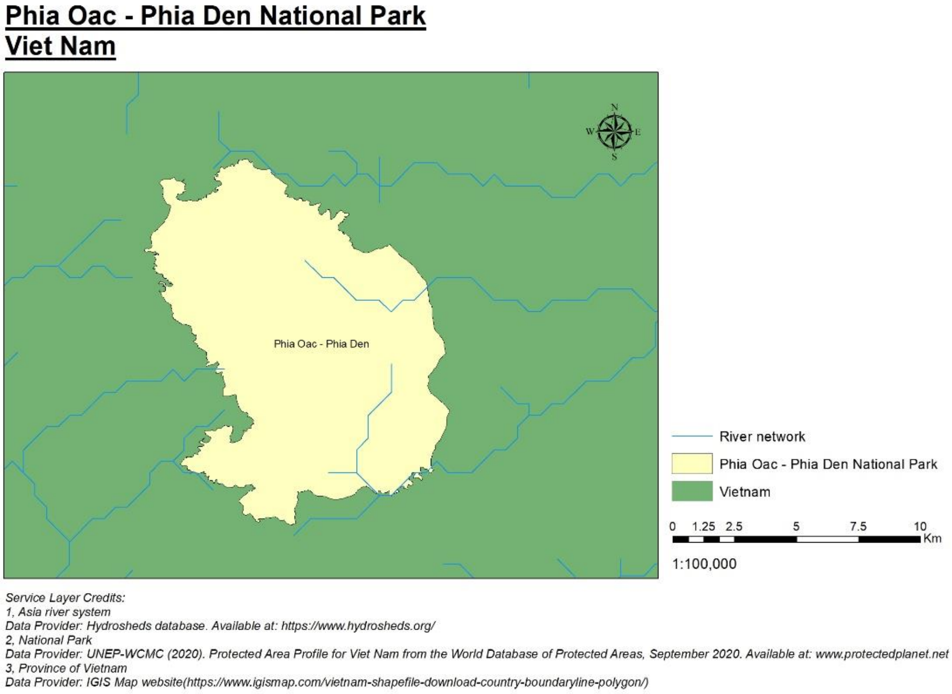
Map 8: Du Gia National Park in Viet Nam.



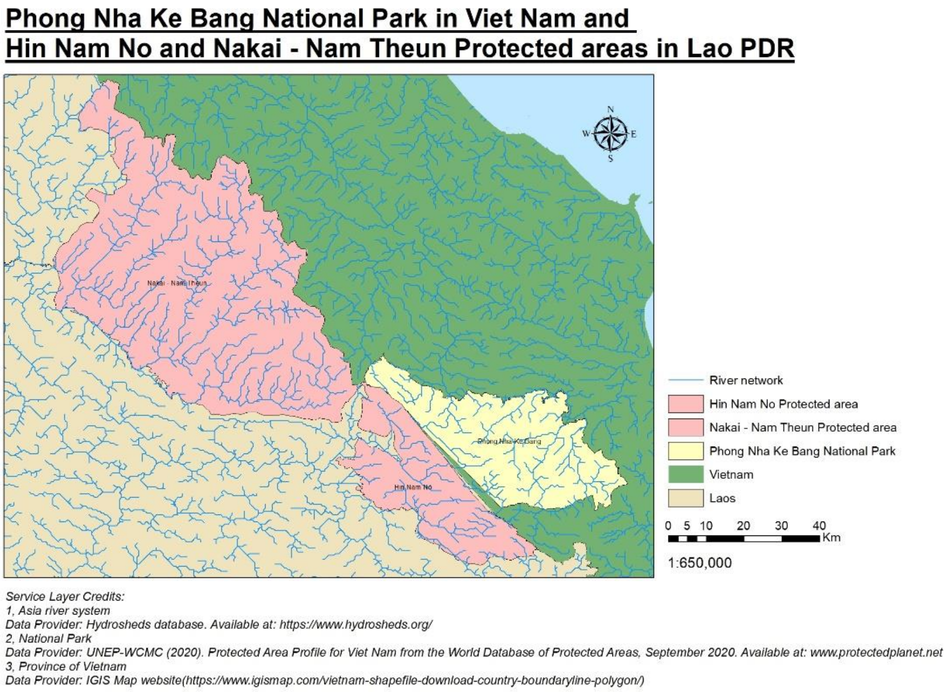
Map 9: Hoang Lien National Park in Viet Nam.



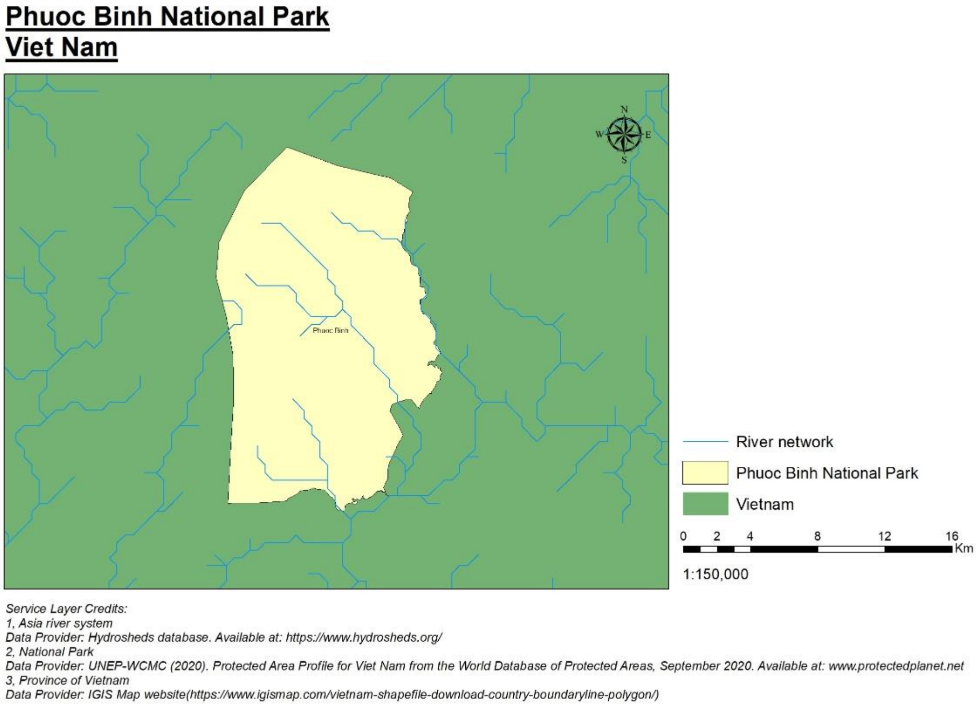
Map 10: Kon Ka Kinh National Park in Viet Nam.



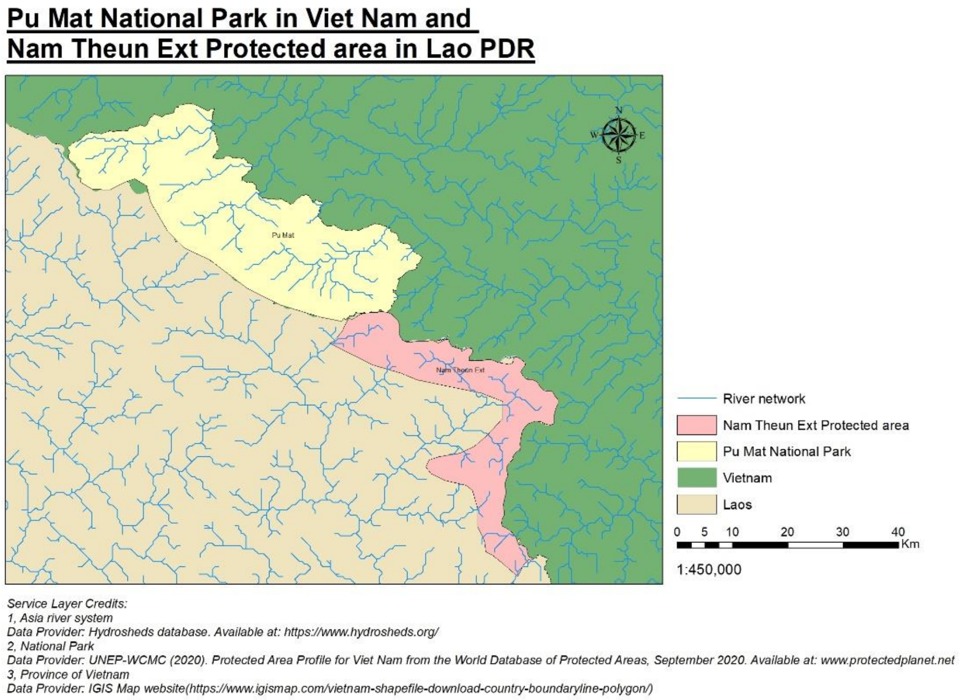
Map 11: Phia Oac Phia Den National Park in Viet Nam.



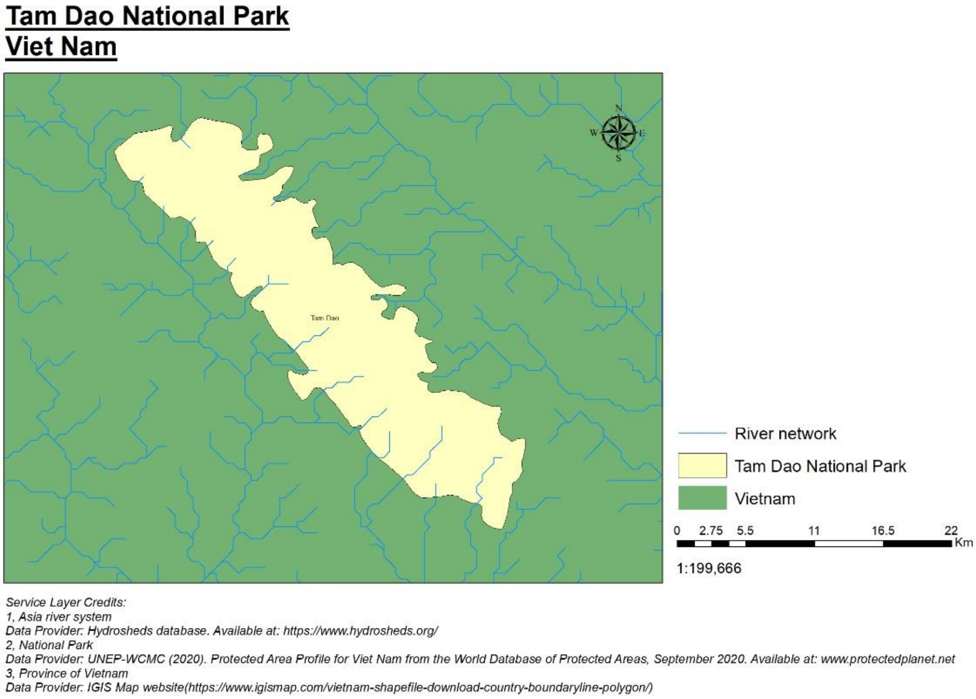
Map 12: Phong Nha – Ke Bang National Park in Viet Nam.



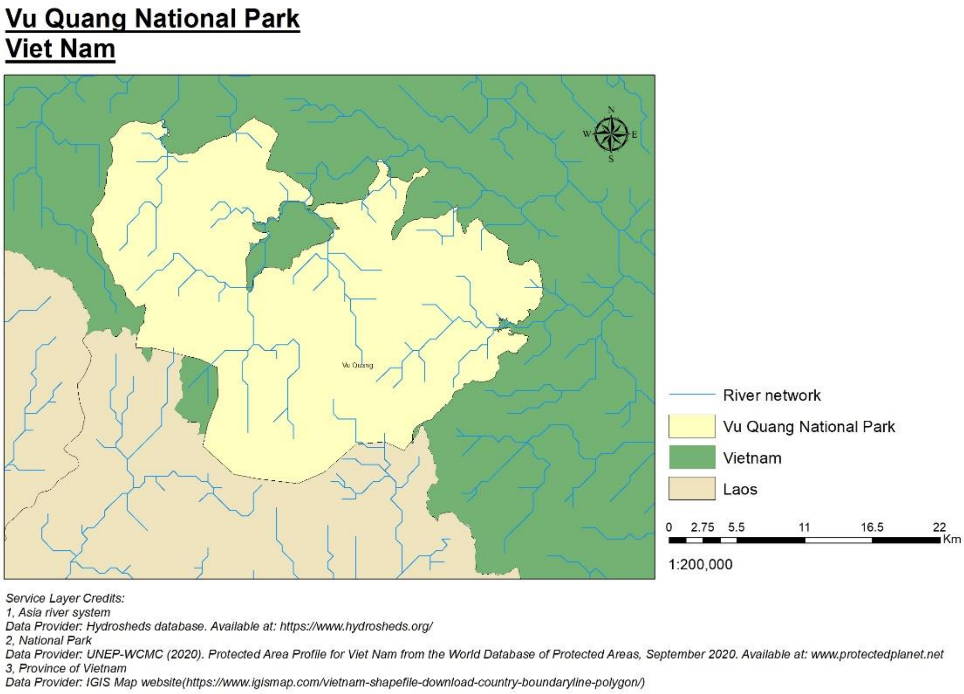
Map 13: Phuoc Binh National Park in Viet Nam.



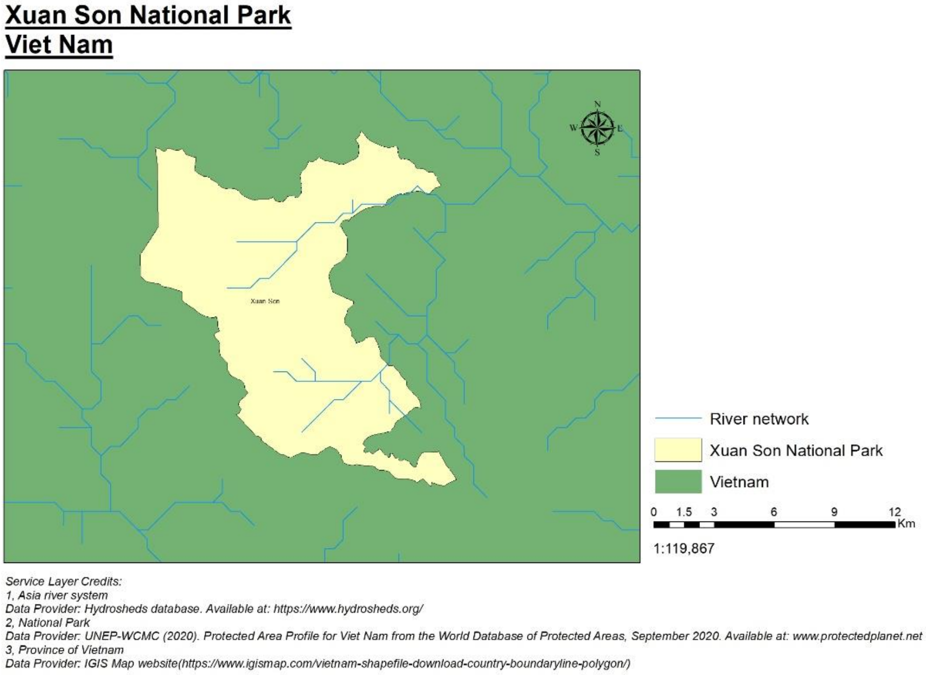
Map 14: Pu Mat National Park in Viet Nam and Nam Thien Ext National Park in Lao PDR.



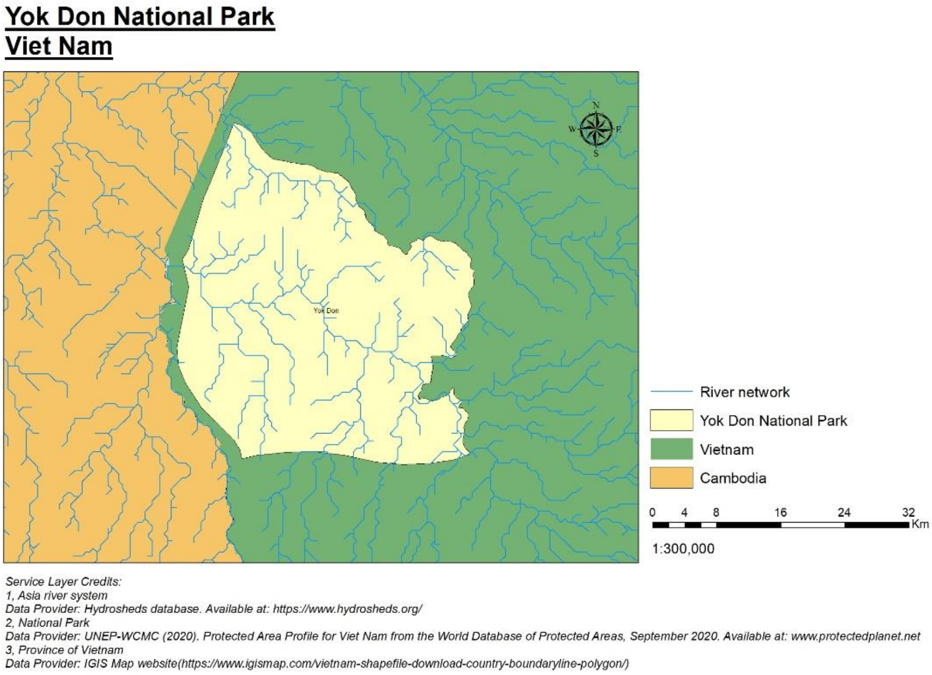
Map 15: Tam Dao National Park in Viet Nam.



Map 16: Vu Quang National Park in Viet Nam.

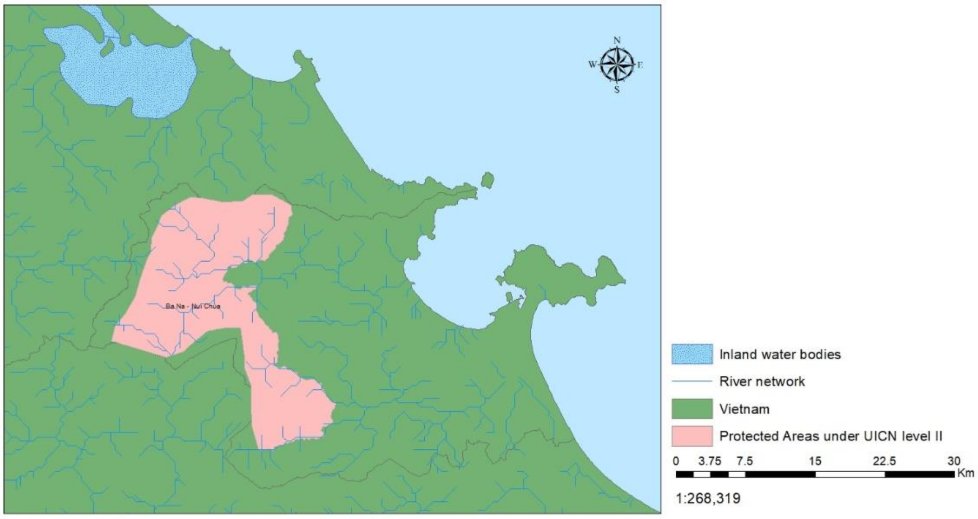


Map 17: Xuan Son National Park in Viet Nam.



Map 18: Yok Don National Park in Viet Nam.

Ba Na - Nui Chua Protected Area
Vietnam



Service Layer Credits:
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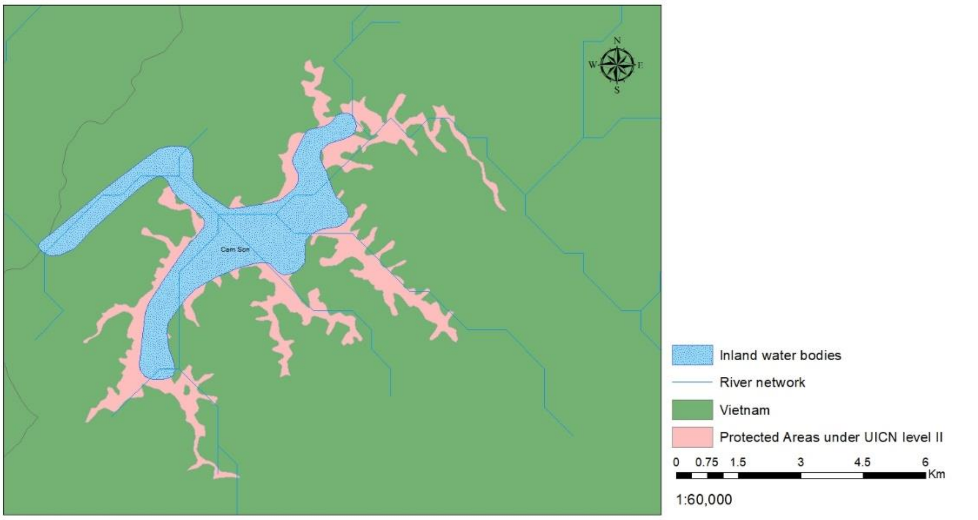
2, National Park
Data Provider: UNEP-WCMC (2020). Protected Area Profile for Viet Nam from the World Database of Protected Areas, September 2020. Available at: www.protectedplanet.net
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 19: Ba Na – Nui Chua Protected area in Viet Nam.

Cam Son Protected Area
Vietnam



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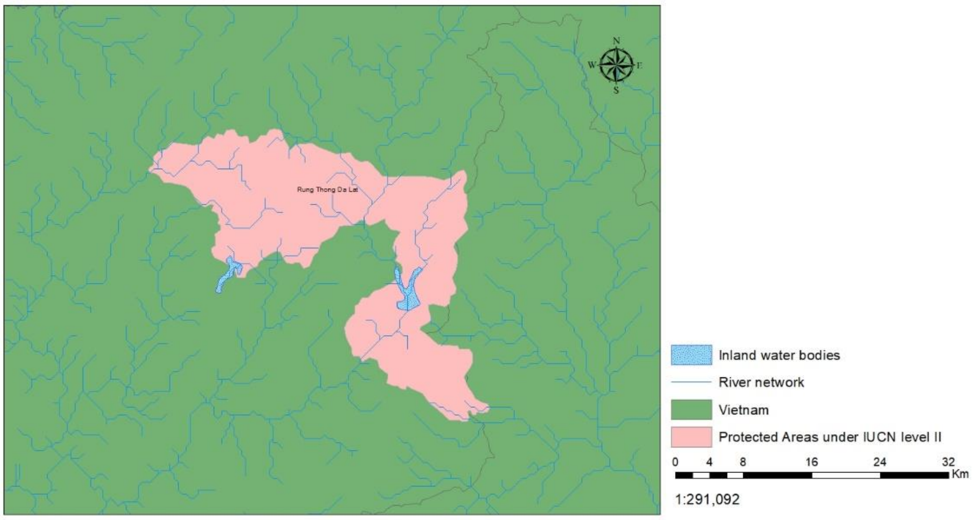
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 20: Cam Son Protected area in Viet Nam.

Dalat Pine Forest Protected Area
Vietnam



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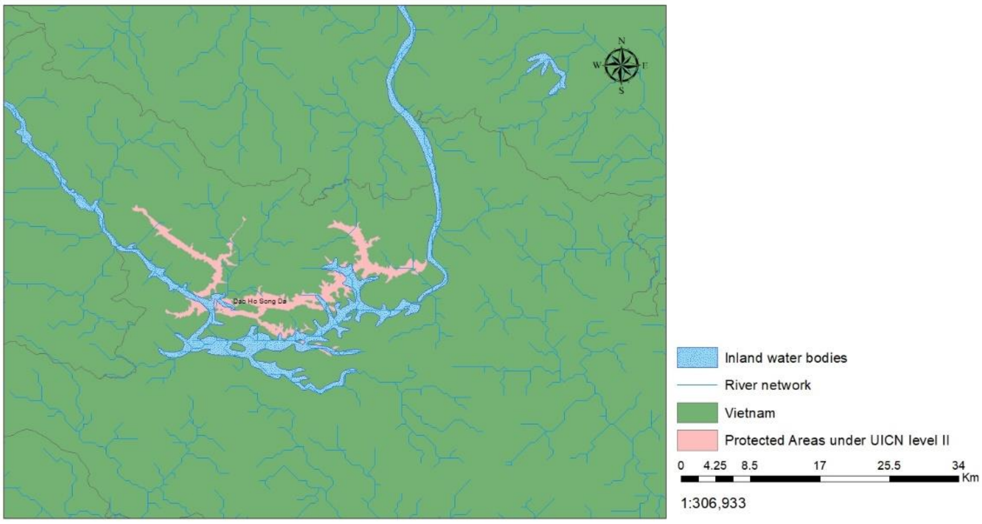
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 21: Dalat Pine Forest Protected area in Viet Nam

Dao Ho Song Da Protected Area
Vietnam



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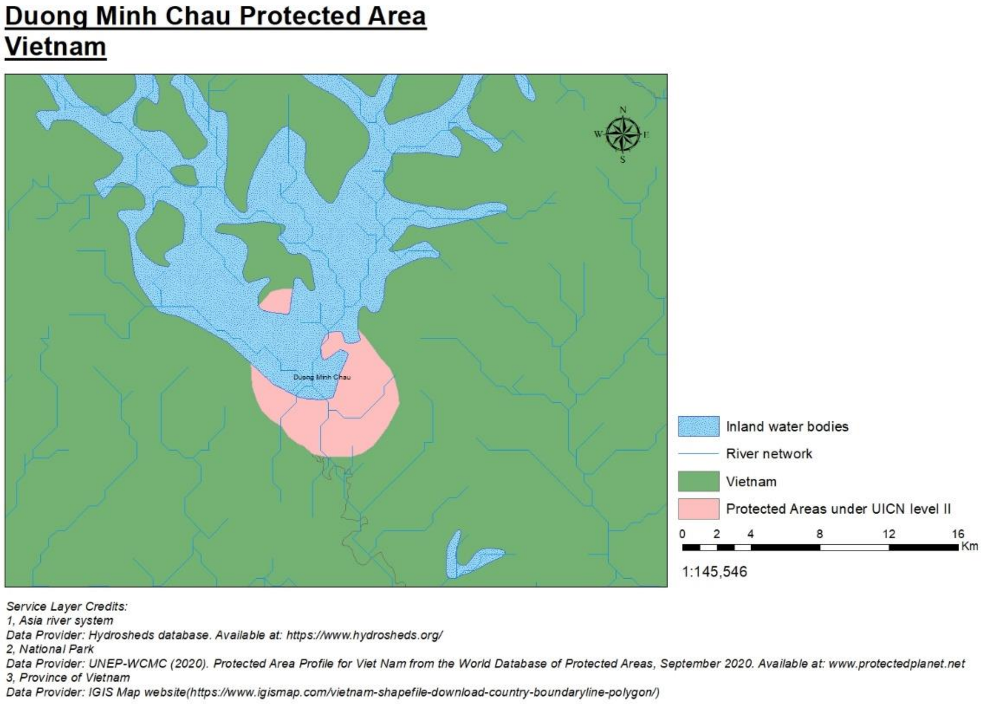
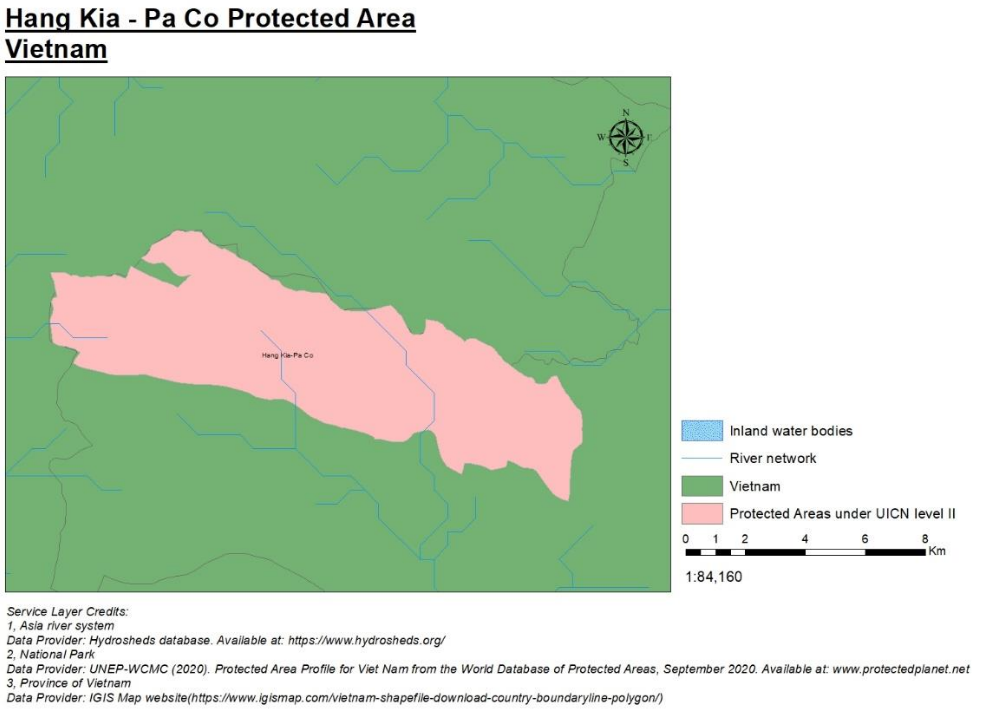
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 22: Dao Ho Song Da Protected area in Viet Nam.

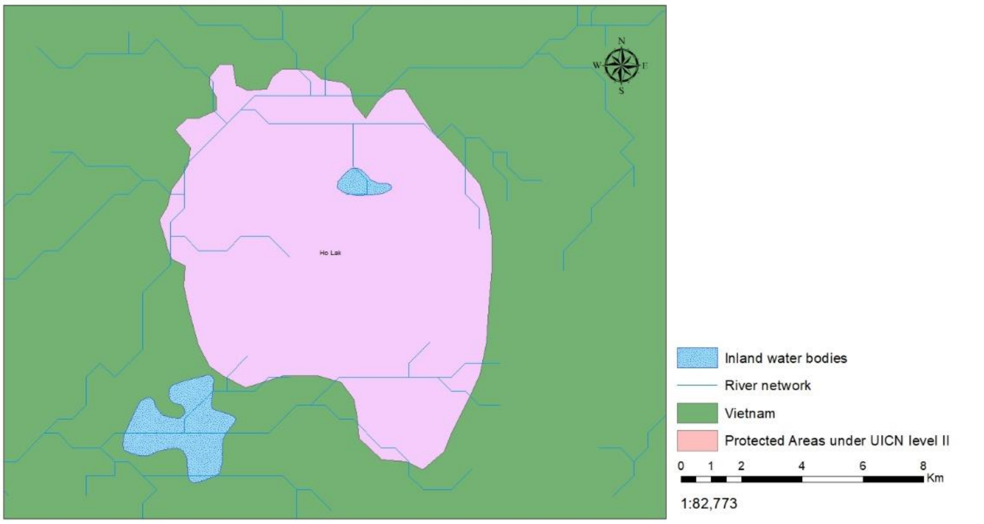


Map 23: Duong Minh Chau Protected area in Viet Nam.



Map 24: Hang Kia – Pa Co Protected area in Viet Nam.

Ho Lak Protected Area
Vietnam



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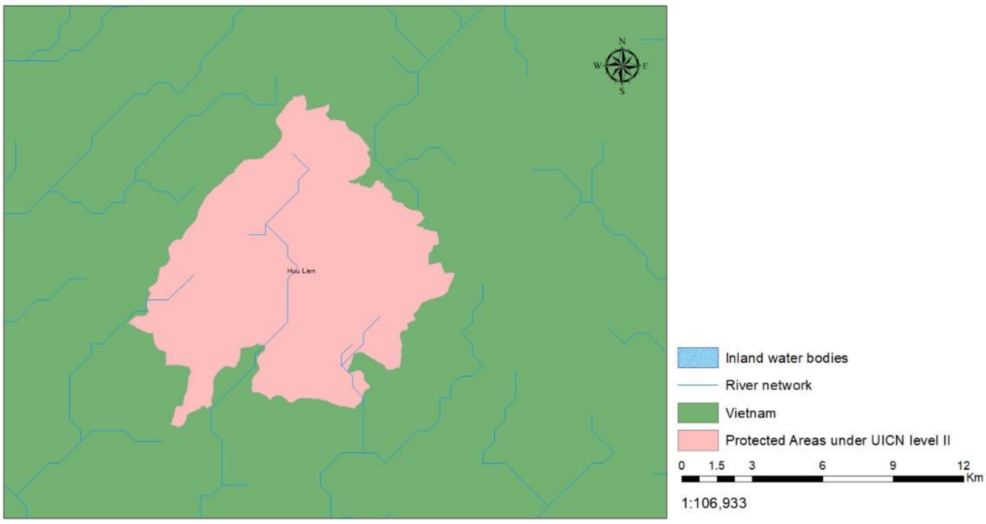
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 25: Ho Lak Protected area in Viet Nam.

Huu Lien Protected Area
Vietnam



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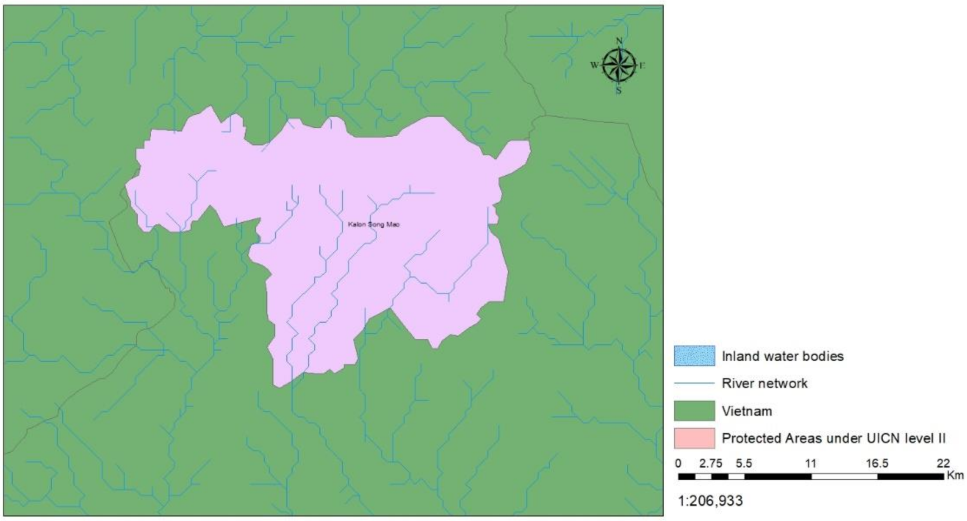
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 26: Huu Lien Protected area in Viet Nam.

Kalon Song Mao Protected Area
Vietnam



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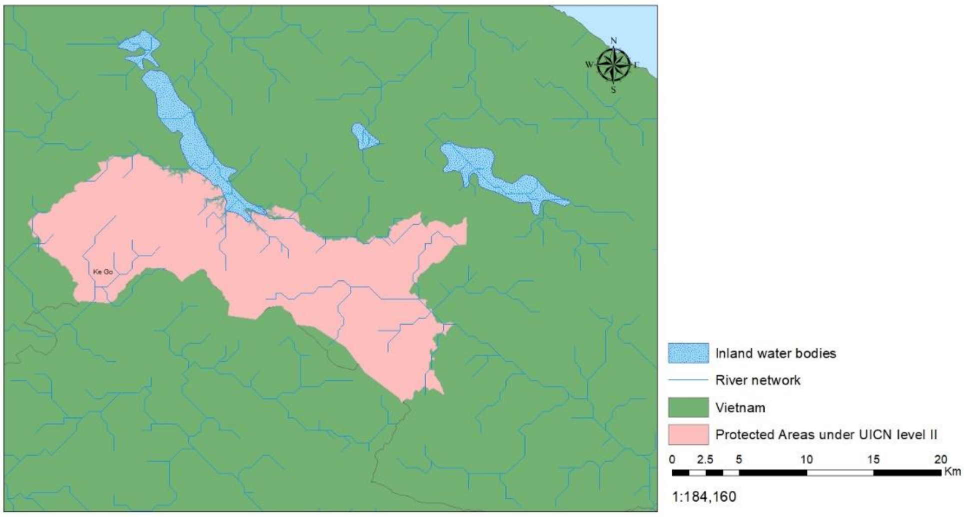
Map 27: Kalon Song Mao Protected area in Viet Nam.

Ke Go Protected Area
Vietnam



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3, Province of Vietnam
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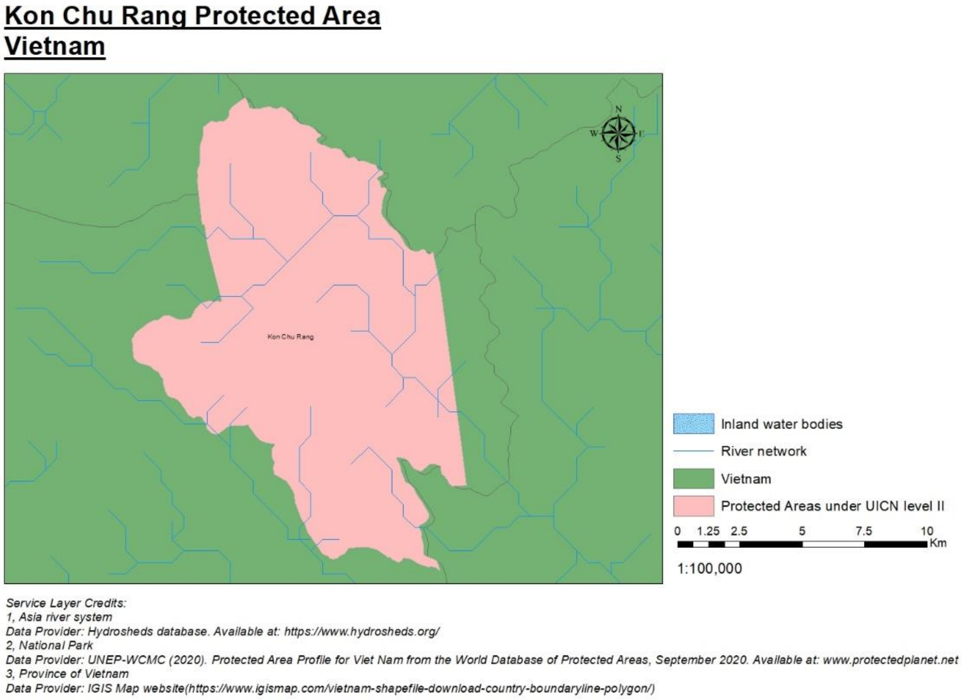
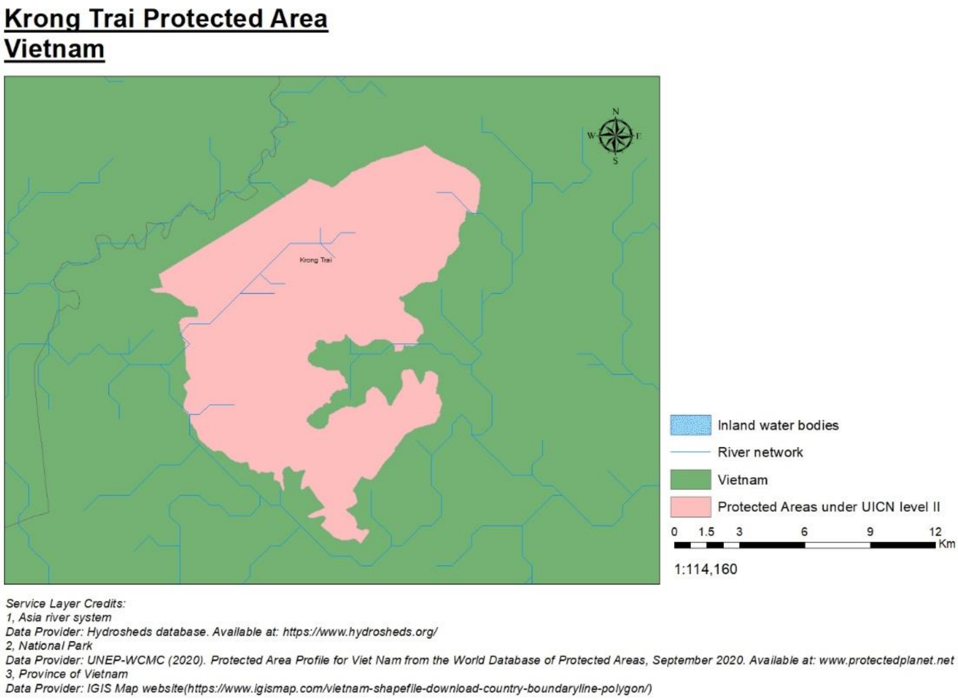
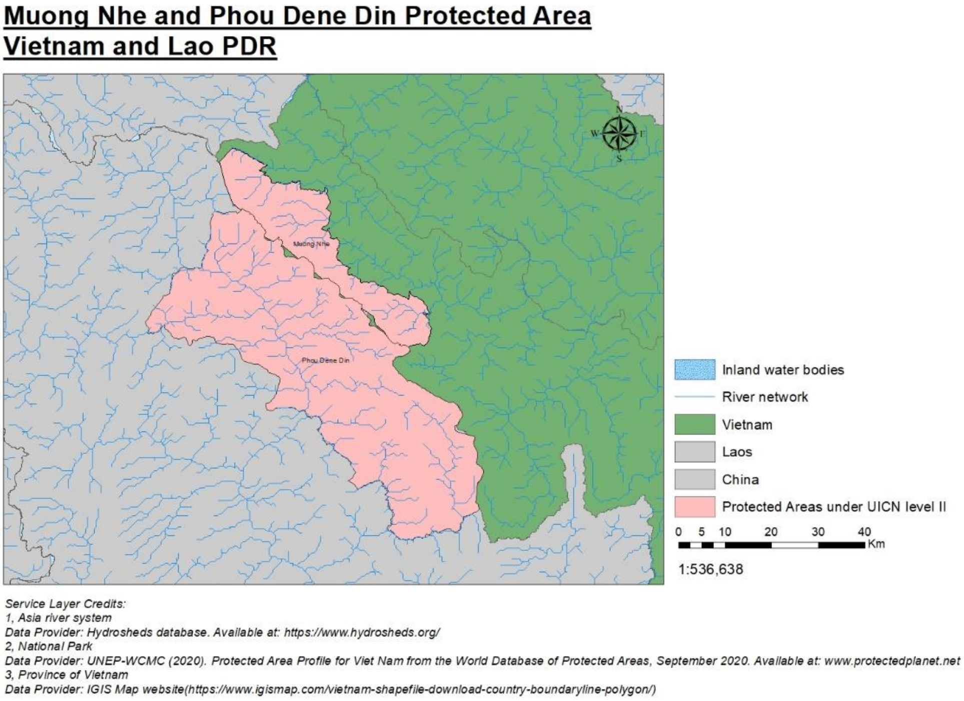
Map 28: Ke Go Protected area in Viet Nam.



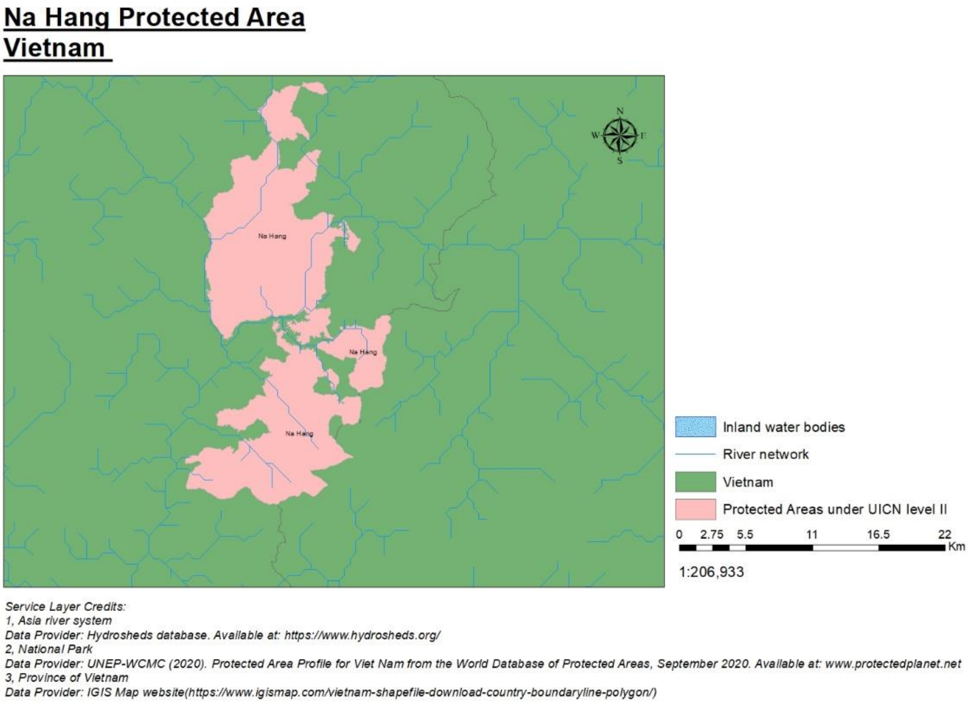
Map 29: Kon Chu Rang Protected area in Viet Nam.



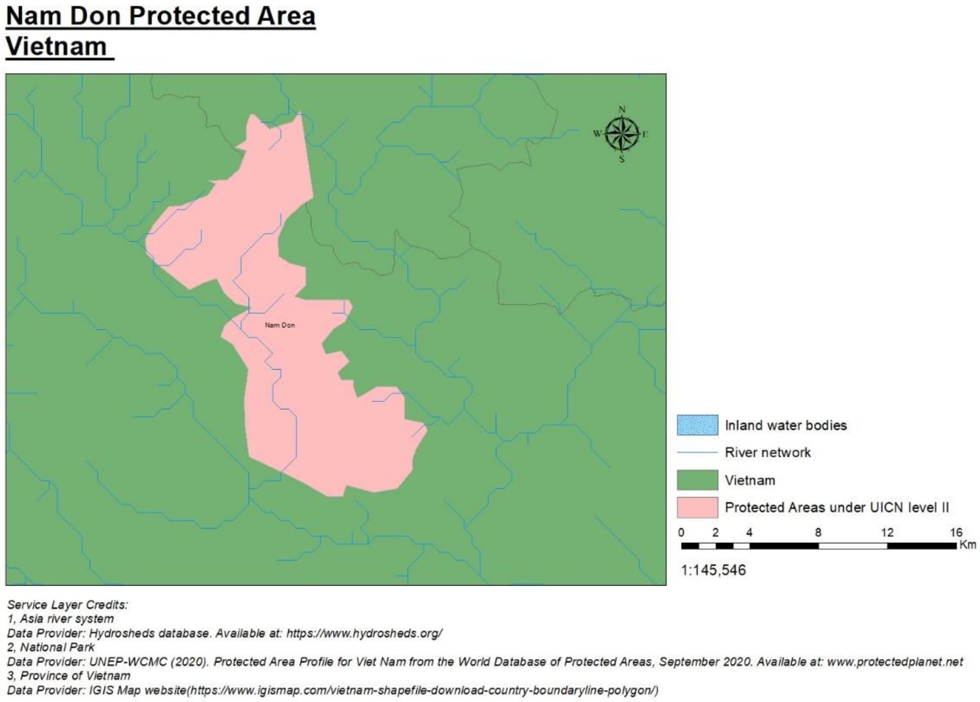
Map 30: Krong Trai Protected area in Viet Nam.



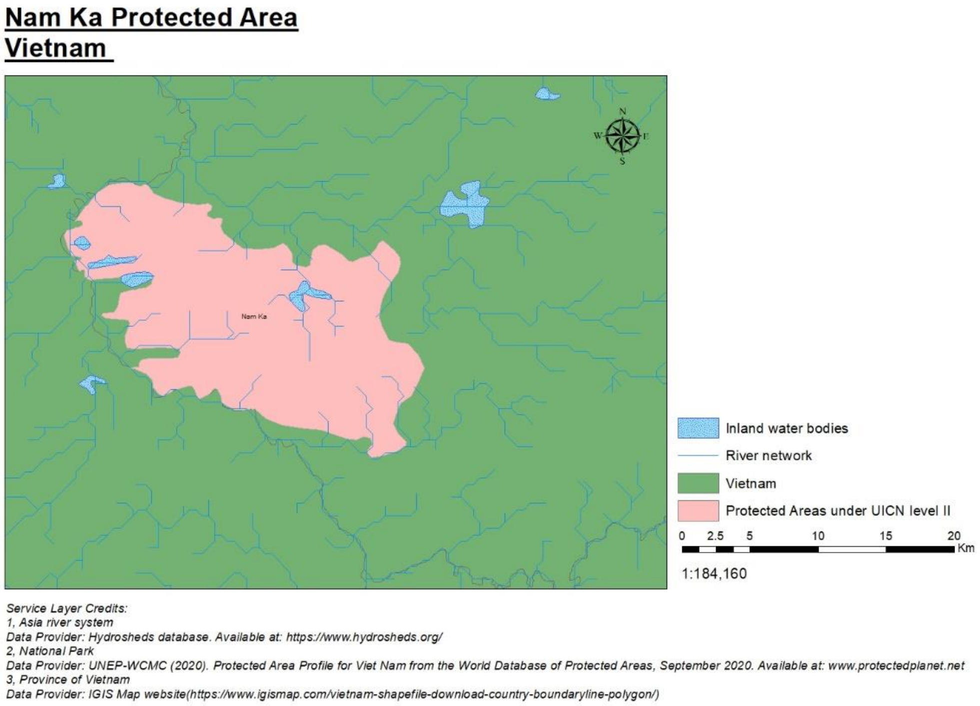
Map 31: Muong Nhe Protected area in Viet Nam and Phou Dene Din Protected area in Lao PDR.



Map 32: Na Hang Protected area in Viet Nam.

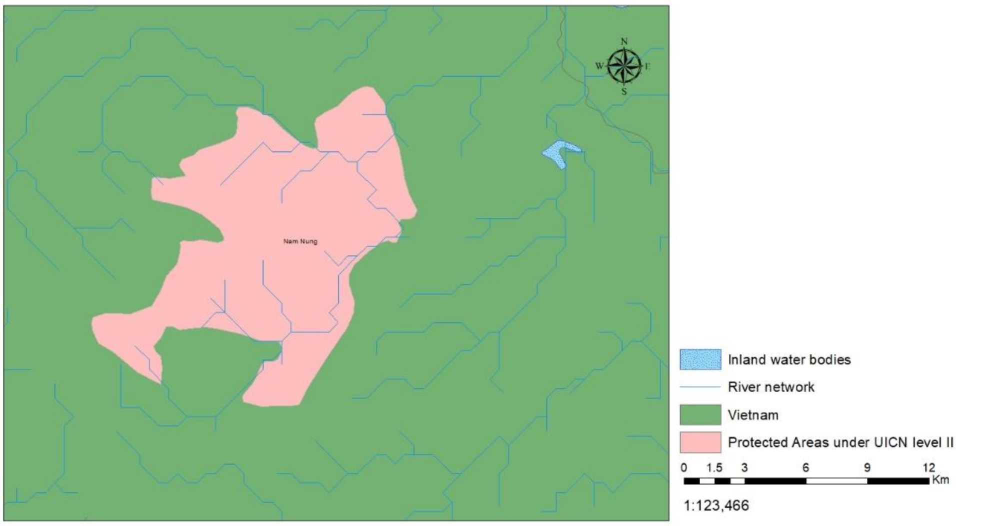


Map 33: Nam Don Protected area in Viet Nam.



Map 34: Nam Ka Protected area in Viet Nam.

Nam Nung Protected Area
Vietnam



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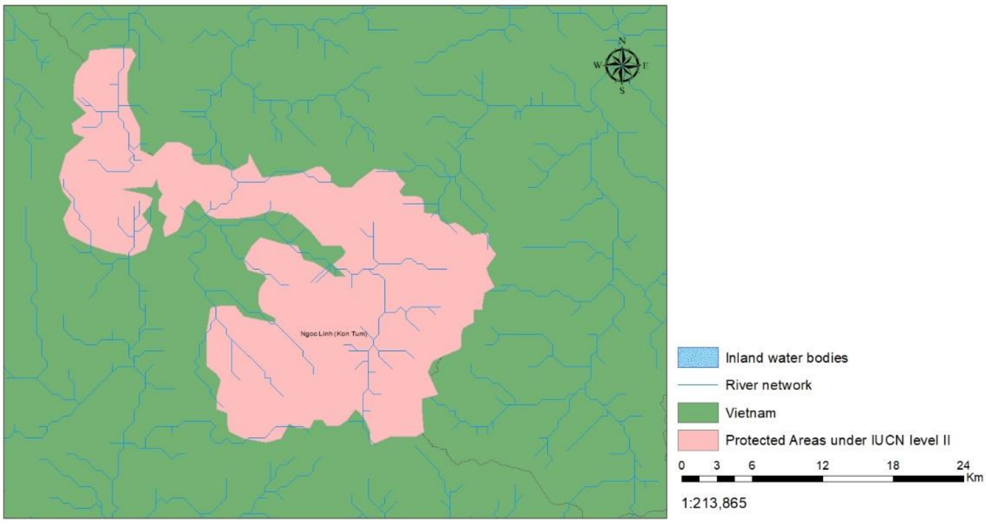
Map 35: Nam Nung Protected area in Viet Nam.

Ngoc Linh Protected Area
Vietnam



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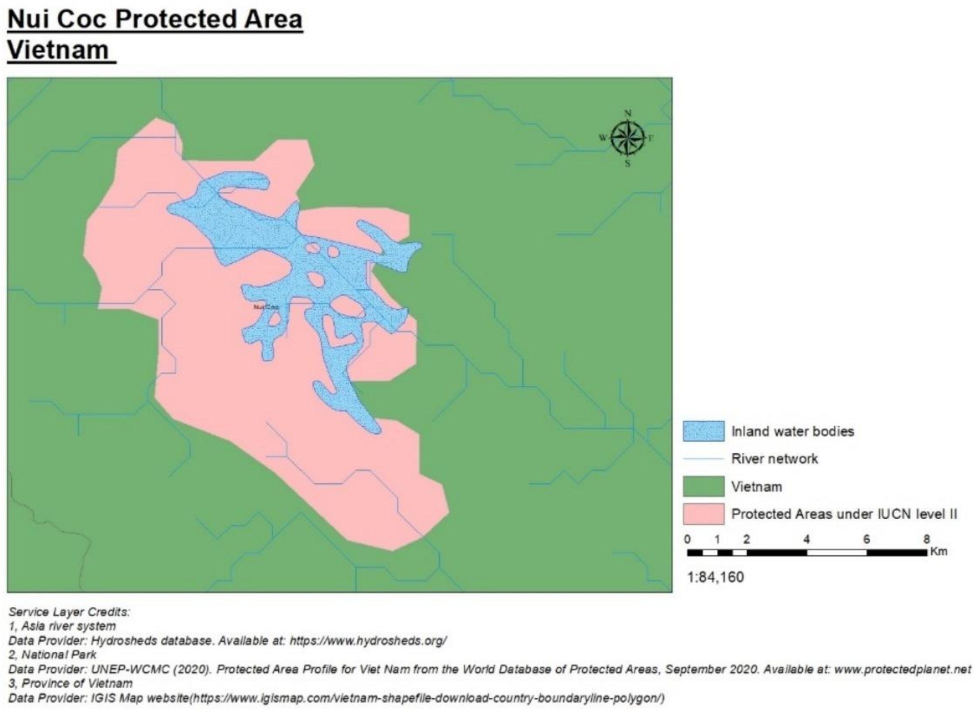
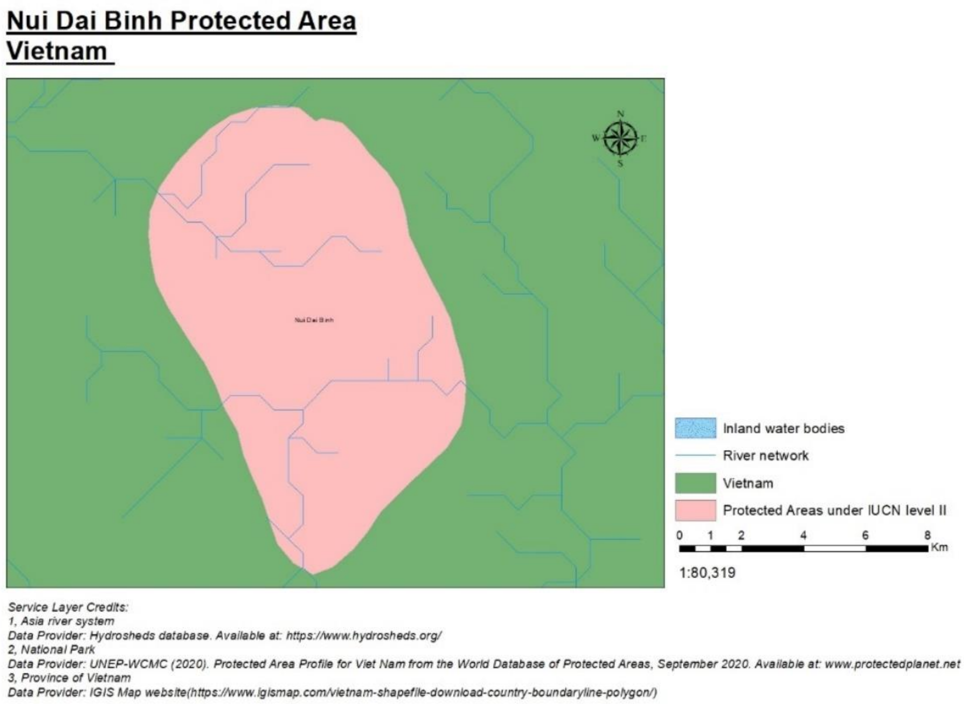
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

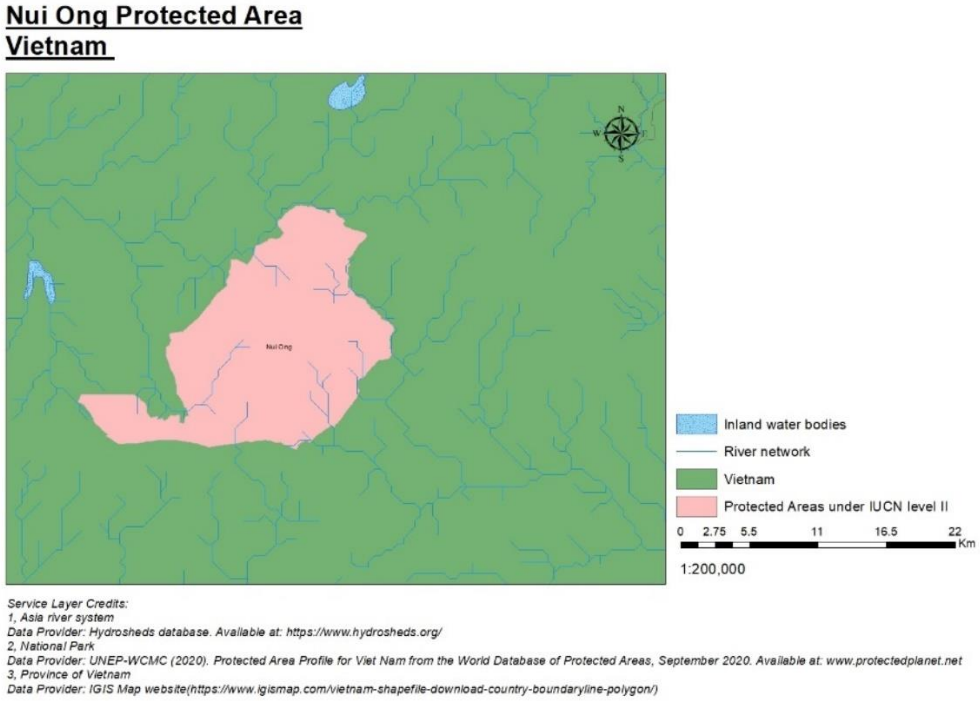
Map 36: Ngoc Linh Protected area in Viet Nam.



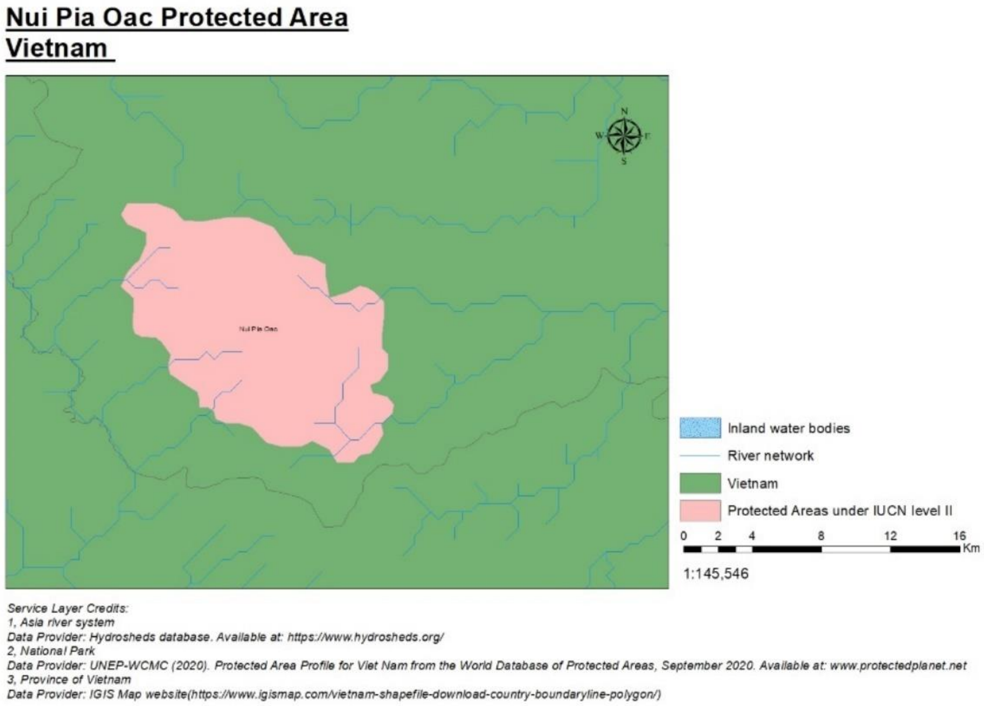
Map 37: Nui Coc Protected area in Viet Nam.



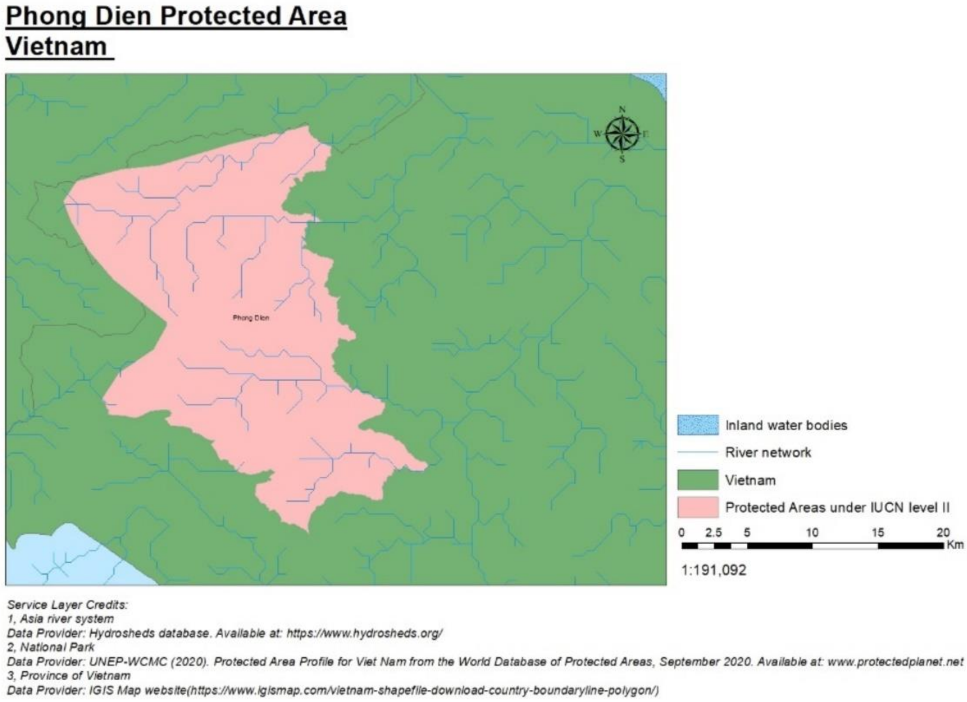
Map 38: Nui Dai Binh Protected area in Viet Nam.



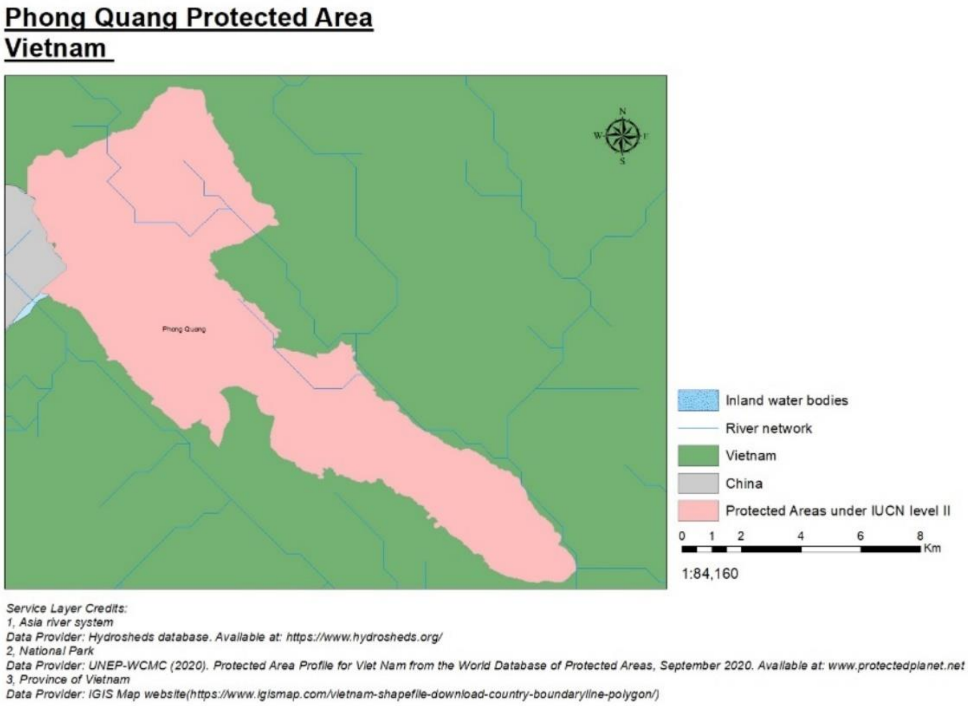
Map 39: Nui Ong Protected area in Viet Nam.



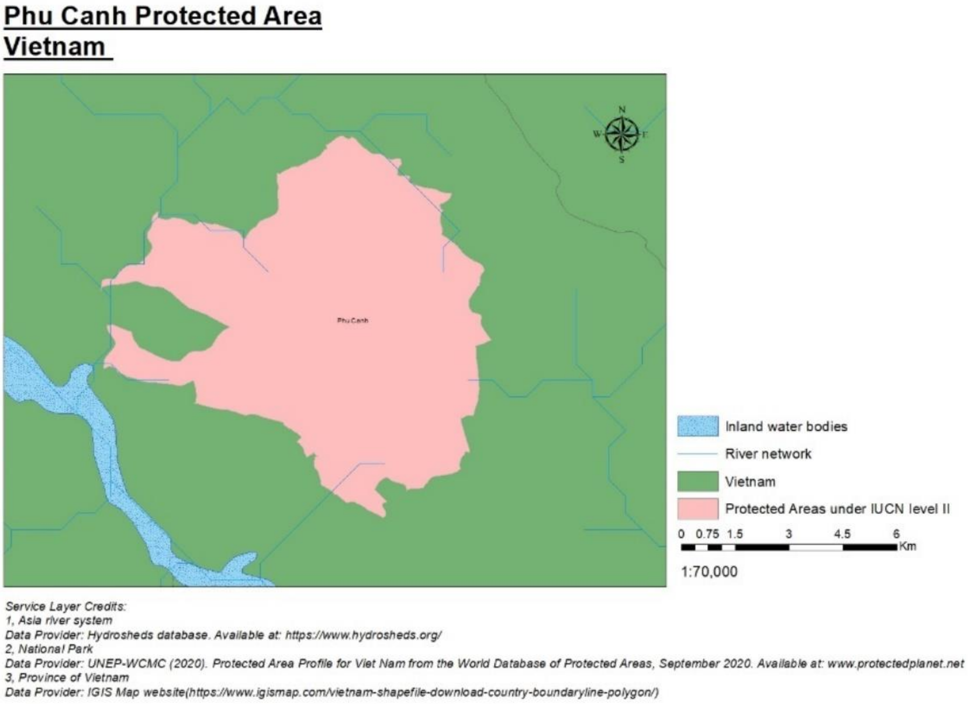
Map 40: Nui Pia Oac Protected area in Viet Nam.



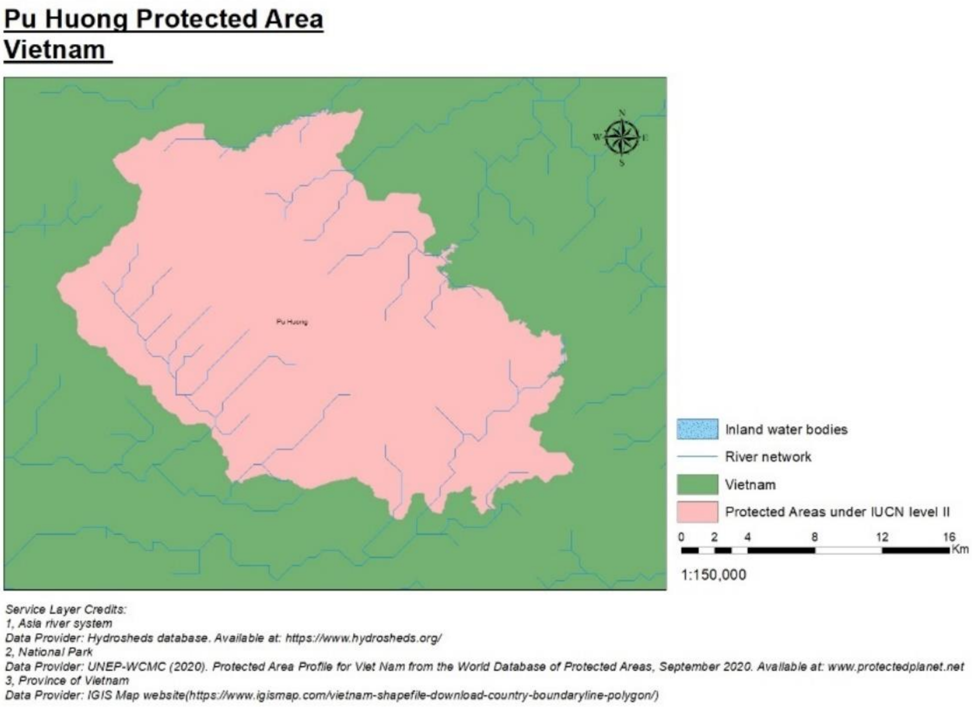
Map 41: Phong Dien Protected area in Viet Nam.



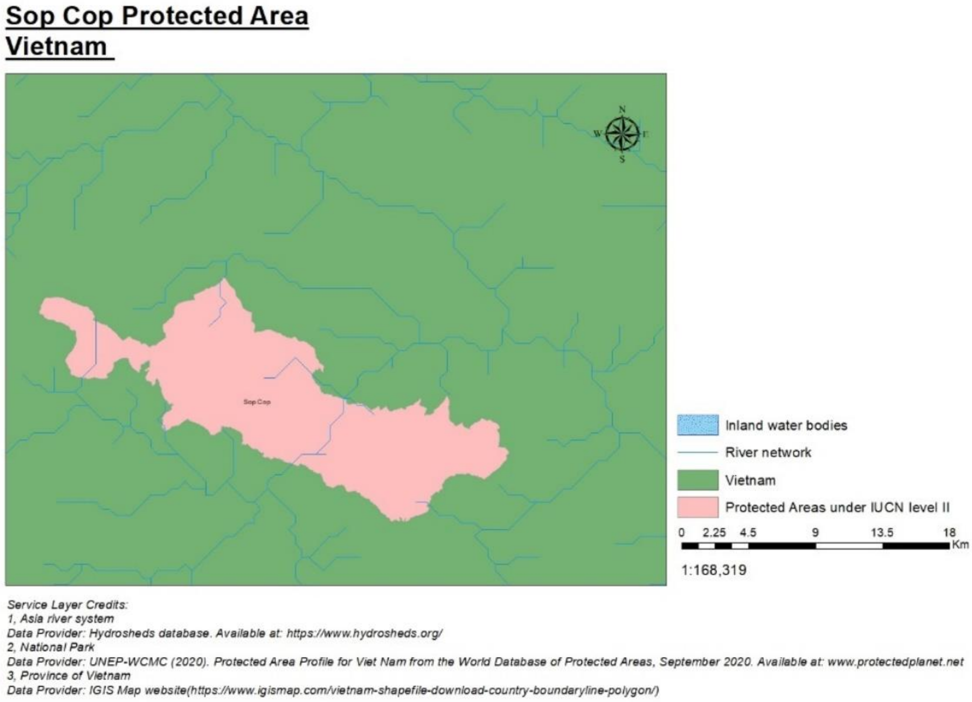
Map 42: Phong Quang Protected area in Viet Nam.



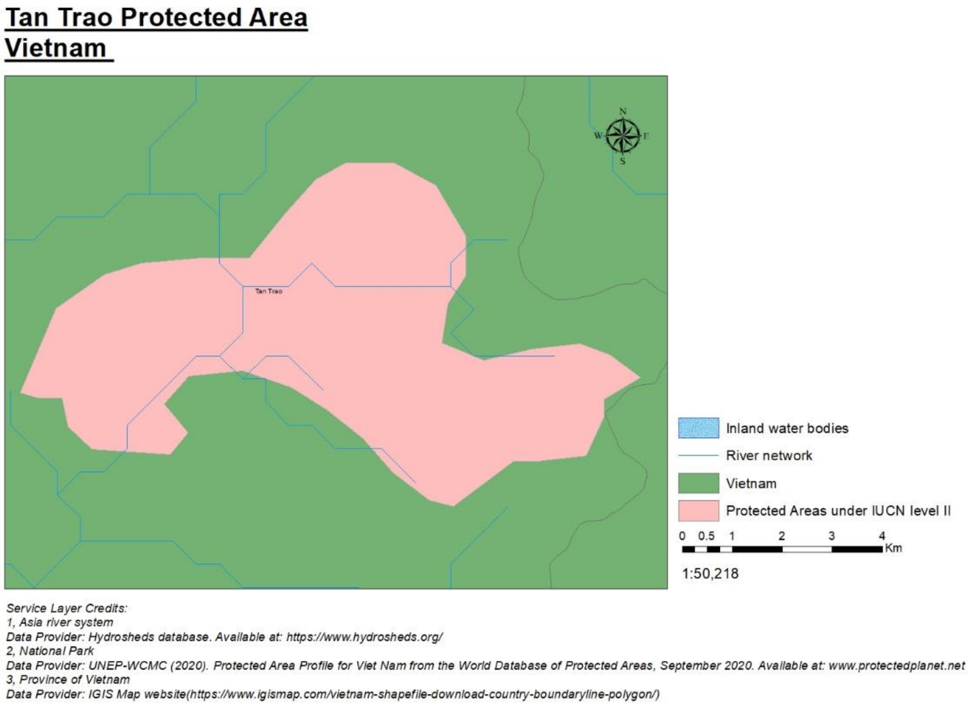
Map 43: Phu Canh Protected area in Viet Nam.



Map 44: Pu huong Protected area in Viet Nam.

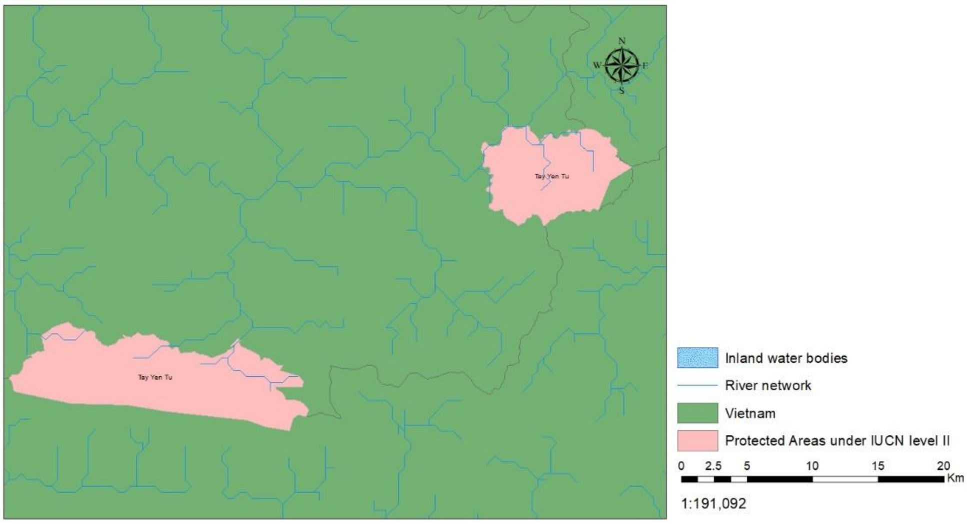


Map 45: Sop Cop Protected area in Viet Nam.



Map 46: Tan Trao Protected area in Viet Nam.

Tay Yen Tu Protected Area
Vietnam



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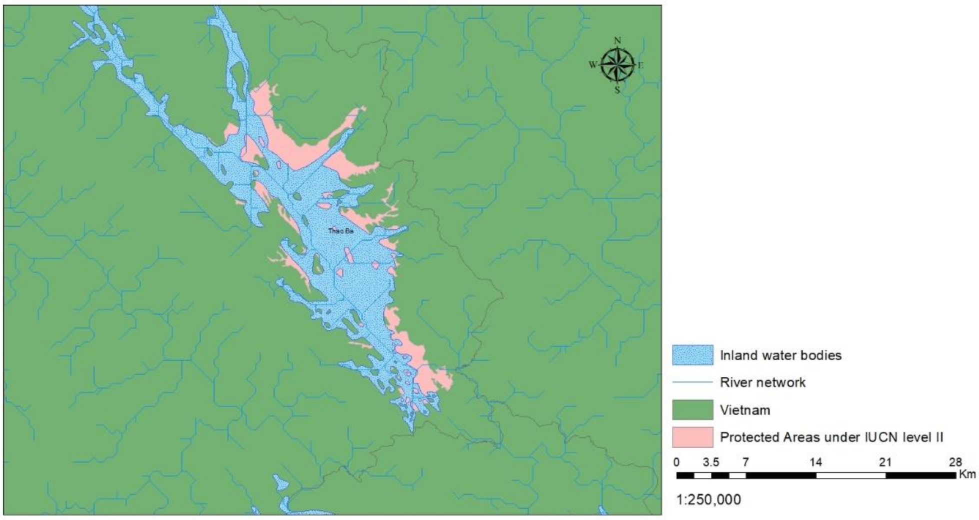
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 47: Tay Yen Tu Protected area in Viet Nam.

Thac Ba Protected Area
Vietnam



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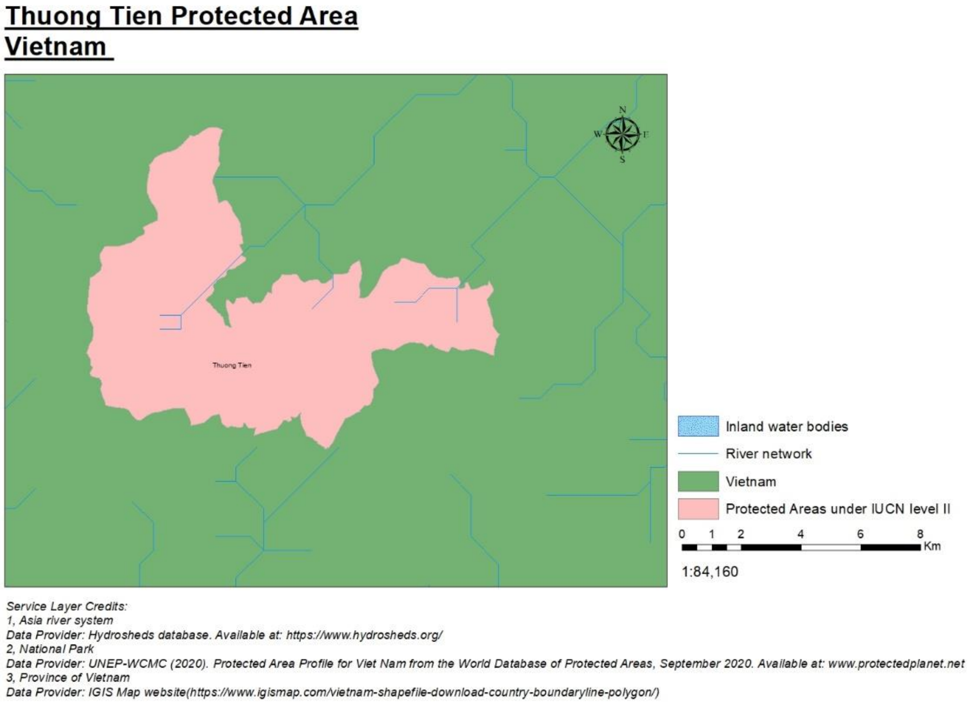
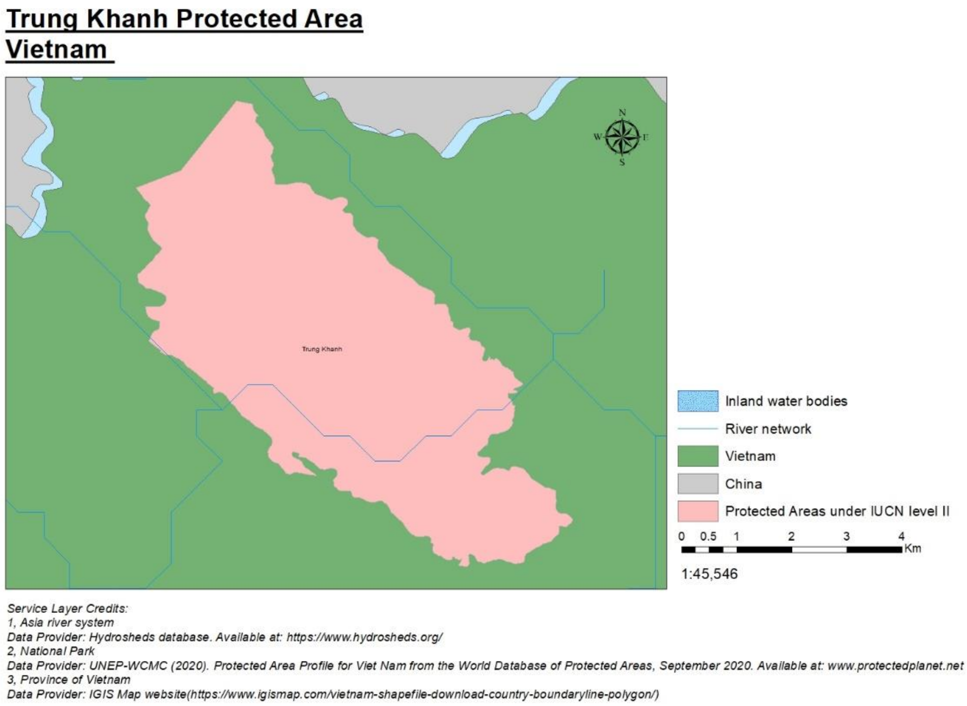
Map 48: Thac Ba Protected area in Viet Nam.

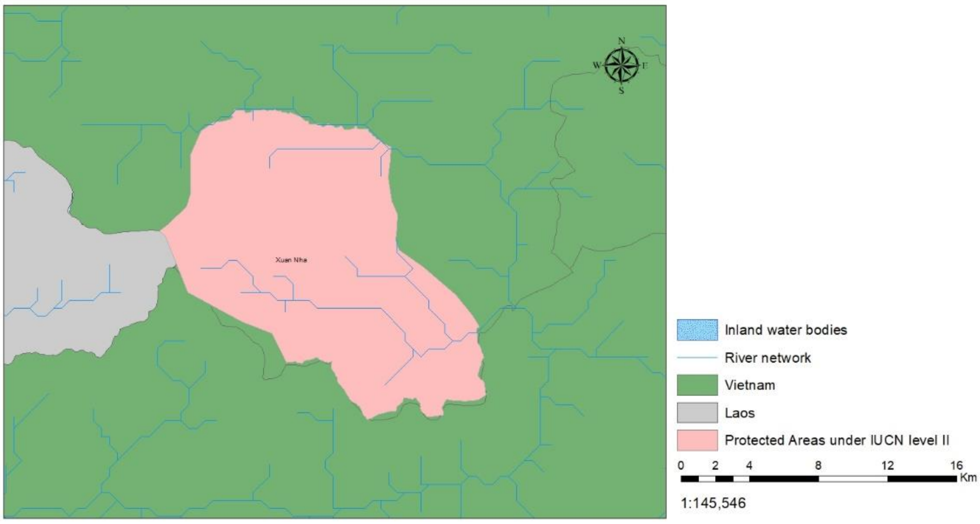


Map 49: Thuong Tien Protected area in Viet Nam.



Map 50: Trung Khanh Protected area in Viet Nam.

Xuan Nha Protected Area
Vietnam



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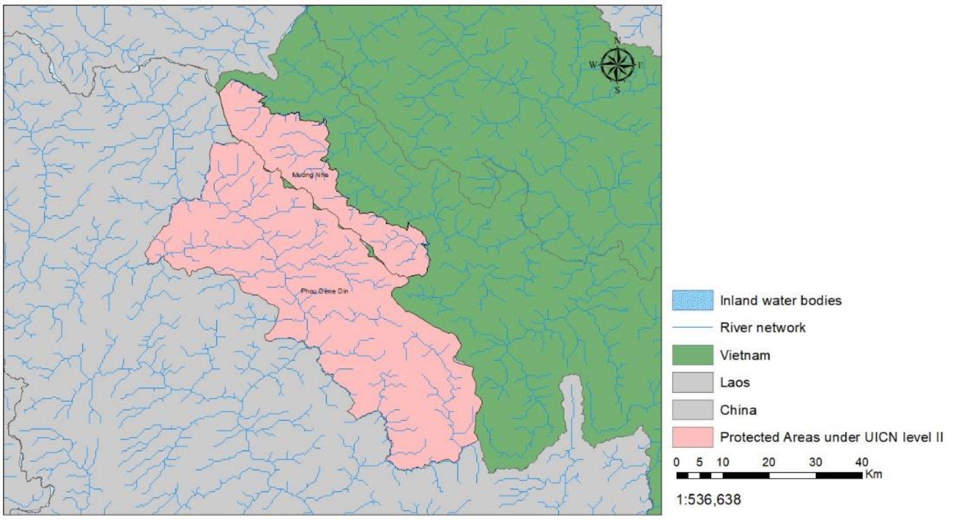
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 51: Xuan Nha Protected area in Viet Nam.

Muong Nhe and Phou Dene Din Protected Area
Vietnam and Lao PDR



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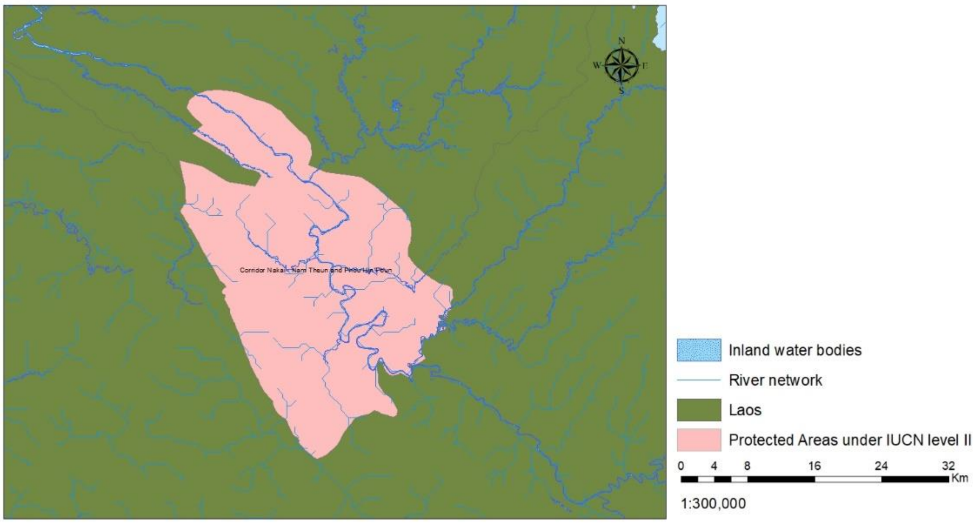
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 52: Muong Nhe Protected area in Viet Nam and Phou Dene Din Protected Area in Lao PDR.

Corridor Nakai Protected Area
Vietnam



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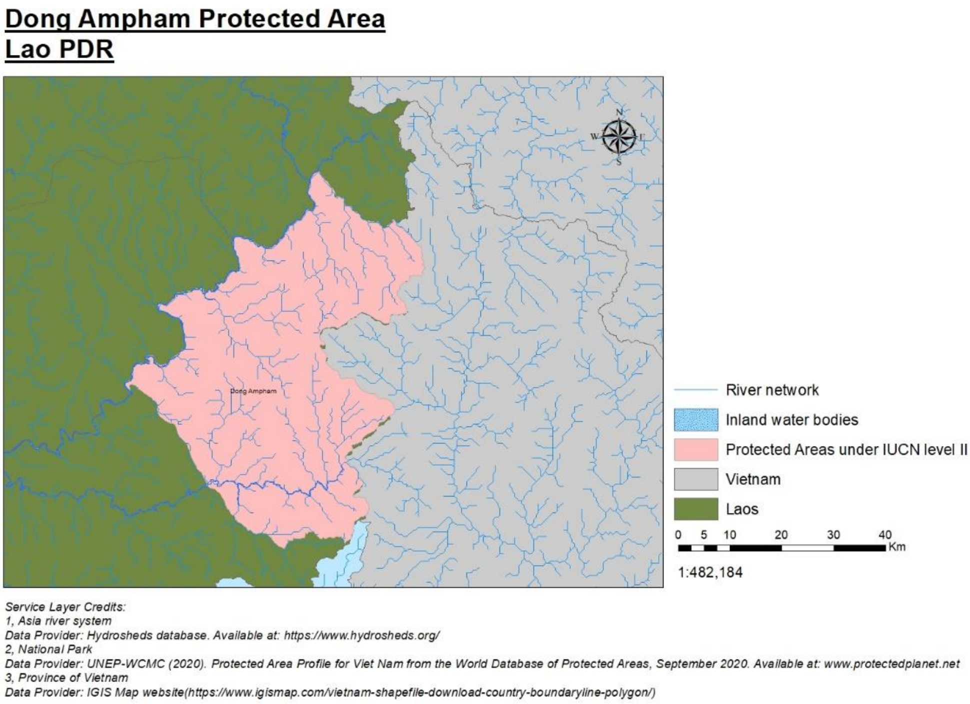
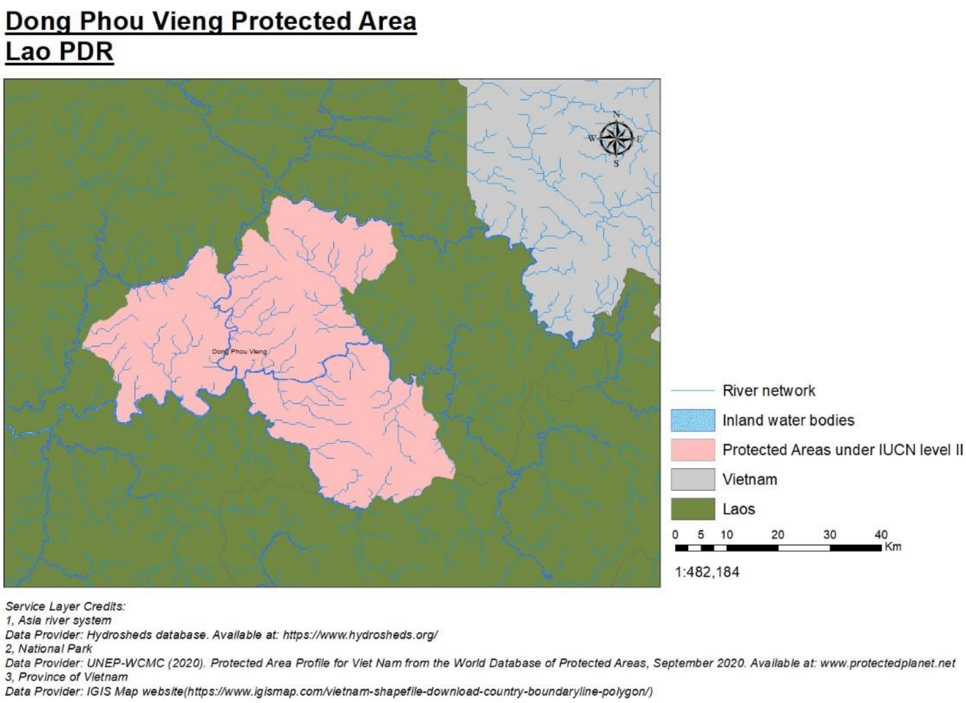
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 53: Corridor Nakai Protected area in Viet Nam.

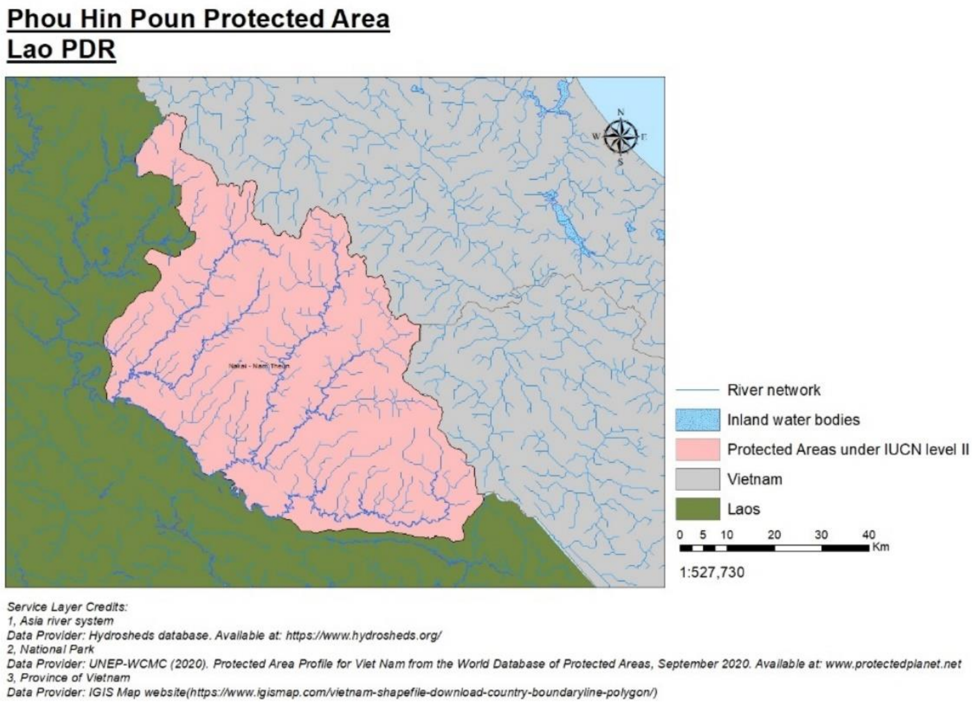
APPENDIX II: Maps of National Parks and Protected Areas in Lao PDR



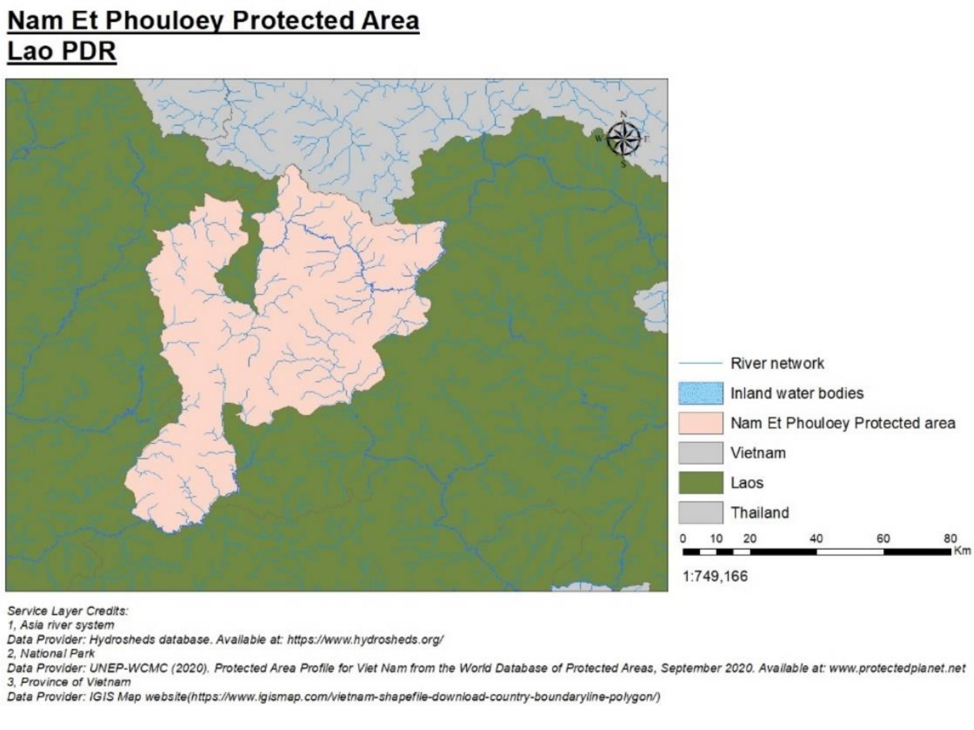
Map 54: Dong Ampham Protected area in Lao PDR.



Map 55: Dong Phou Vieng Protected area in Lao PDR.

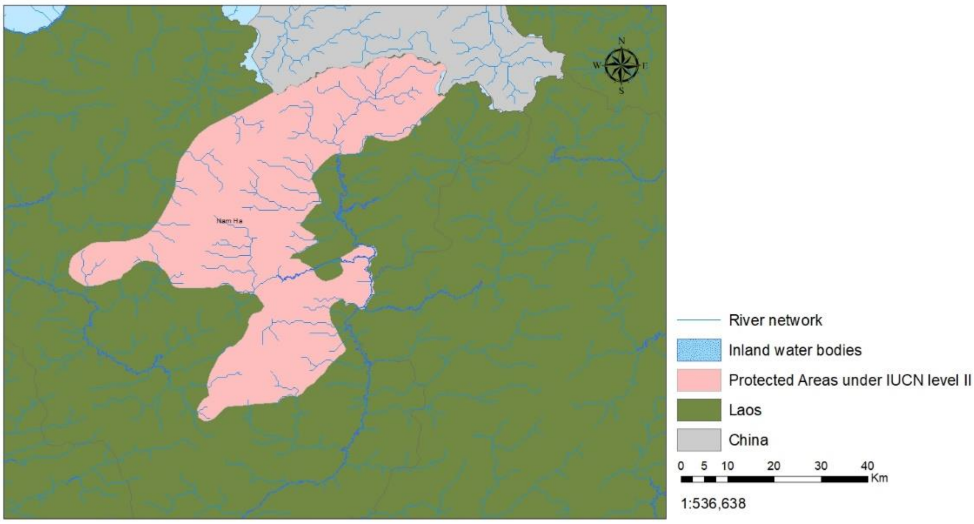


Map 56: Phou Hin Poun Protected area in Lao PDR.



Map 57: Nam Et Phouloey Protected area in Lao PDR.

Nam Ha Protected Area
Lao PDR



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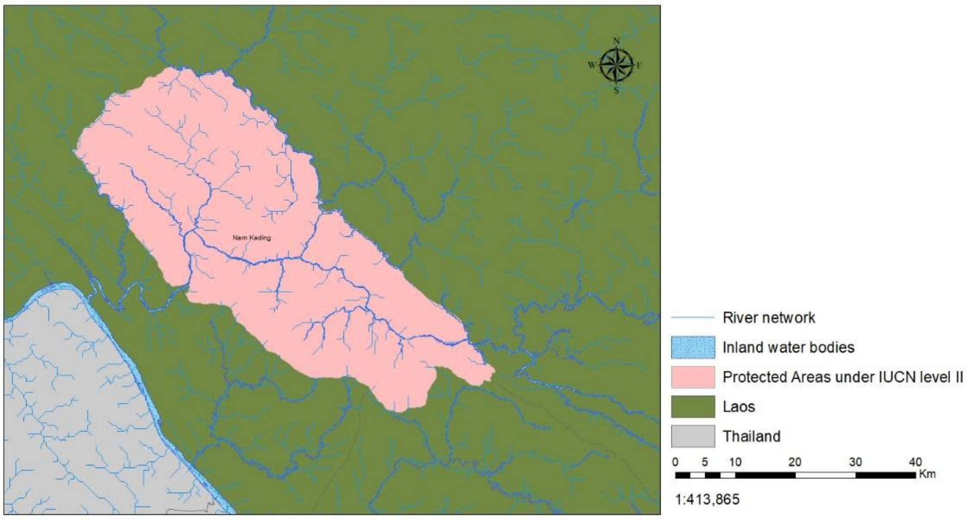
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 58: Nam Ha Protected area in Lao PDR.

Nam Kading Protected Area
Lao PDR



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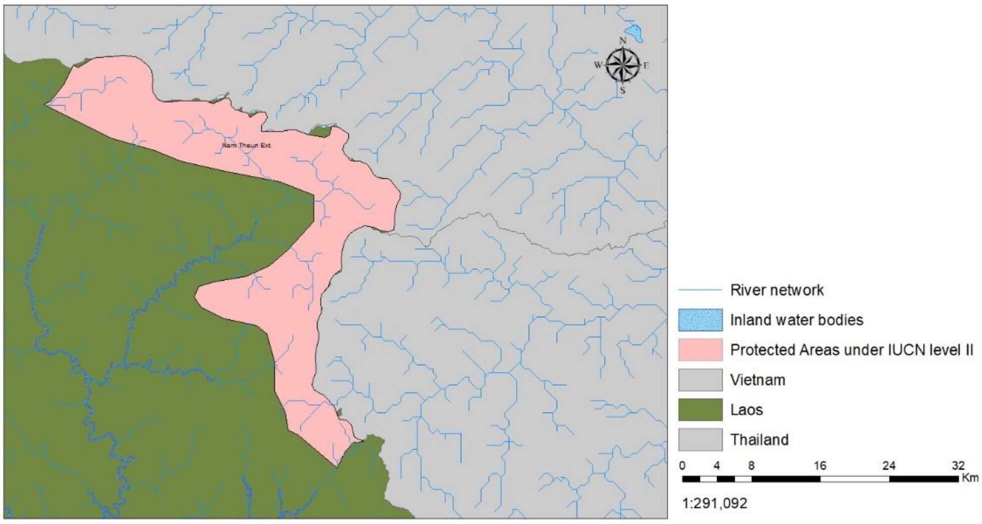
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 59: Nam Kading Protected area in Lao PDR.

Nam Theun Ext Protected Area
Lao PDR



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Data Provider: Hydrosheds database. Available at: https://www.hydrosheds.org/
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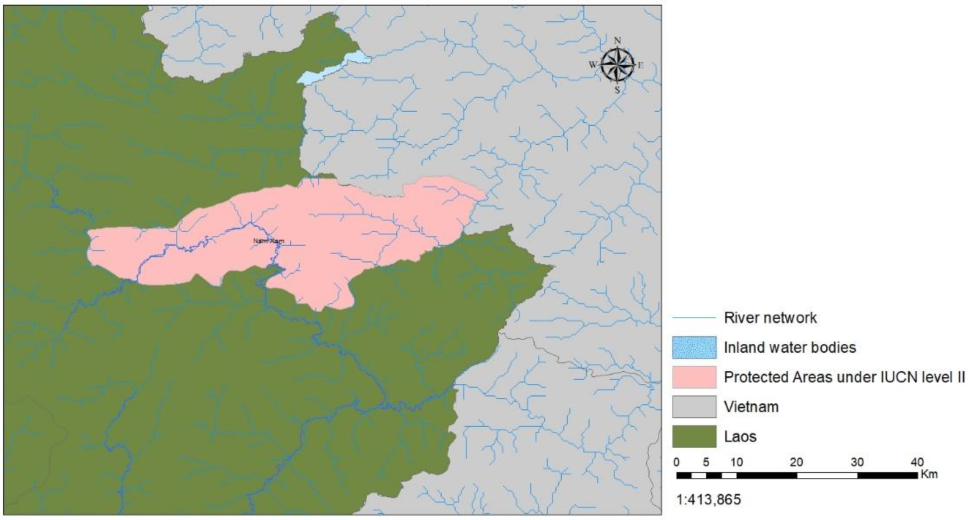
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 60: Nam Theun Ext Protected area in Lao PDR.

Nam Xam Protected Area
Lao PDR



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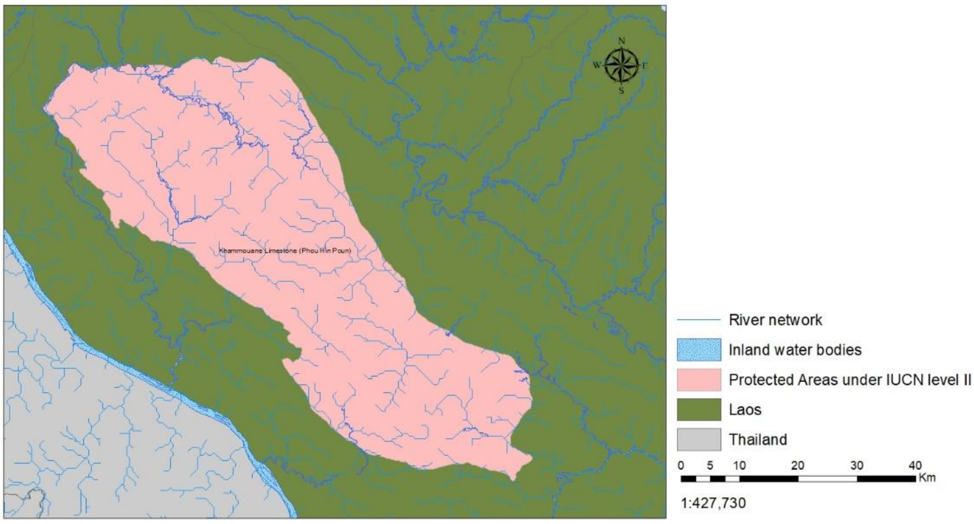
Data Provider: Hydrosheds database. Available at: https://www.hydrosheds.org/
2, National Park
Data Provider: UNEP-WCMC (2020). Protected Area Profile for Viet Nam from the World Database of Protected Areas, September 2020. Available at: www.protectedplanet.net
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

Map 61: Nam Xam Protected area in Lao PDR.

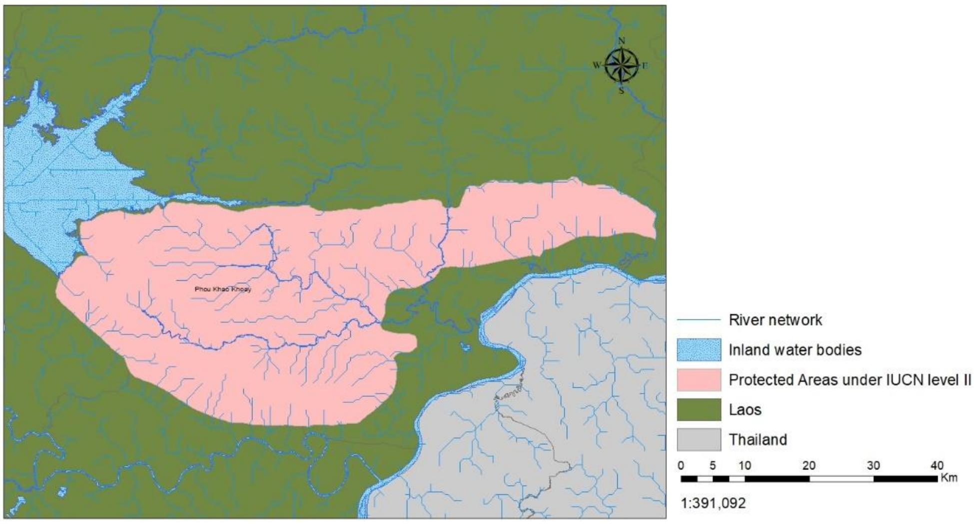
Phou Hin Poun Protected Area
Lao PDR



Service Layer Credits:
1, Asia river system
Data Provider: Hydrosheds database. Available at: https://www.hydrosheds.org/
2, National Park
Data Provider: UNEP-WCMC (2020). Protected Area Profile for Viet Nam from the World Database of Protected Areas, September 2020. Available at: www.protectedplanet.net
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

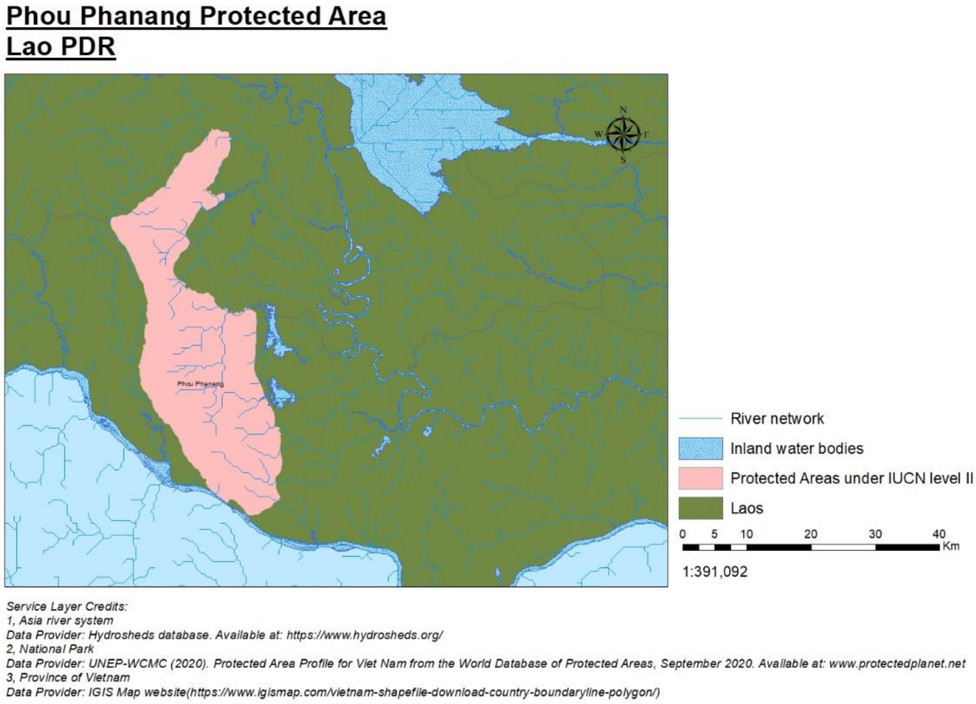
Map 62: Phou Hin Poun Protected area in Lao PDR.

Phou Khao Khoay Protected Area
Lao PDR

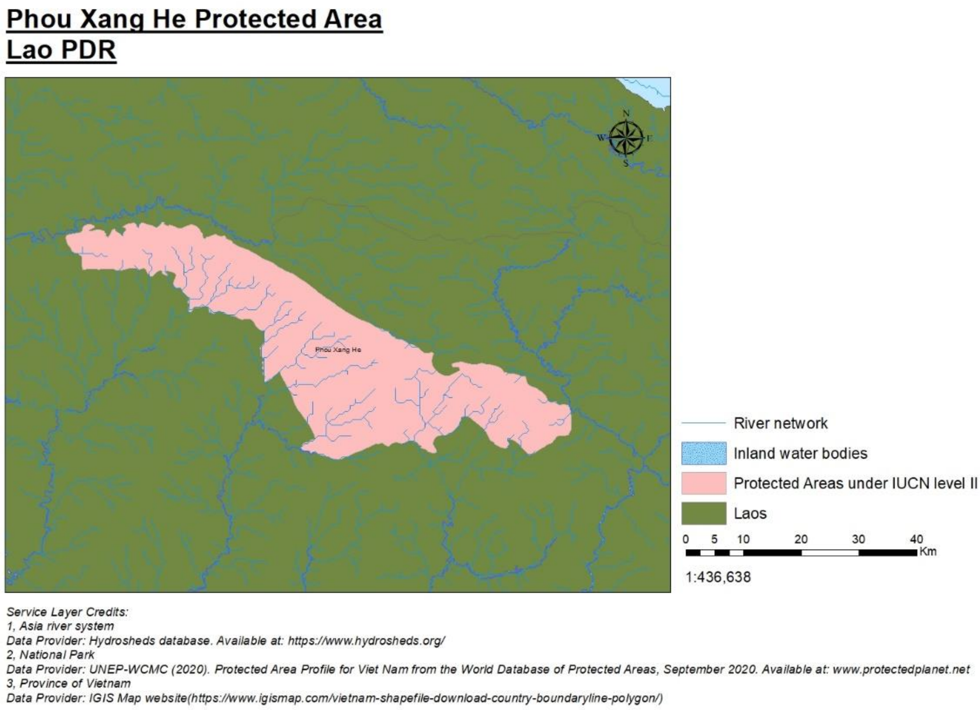


Service Layer Credits:
1, Asia river system
Data Provider: Hydrosheds database. Available at: https://www.hydrosheds.org/
2, National Park
Data Provider: UNEP-WCMC (2020). Protected Area Profile for Viet Nam from the World Database of Protected Areas, September 2020. Available at: www.protectedplanet.net
3, Province of Vietnam
Data Provider: IGIS Map website(https://www.igismap.com/vietnam-shapefile-download-country-boundaryline-polygon/)

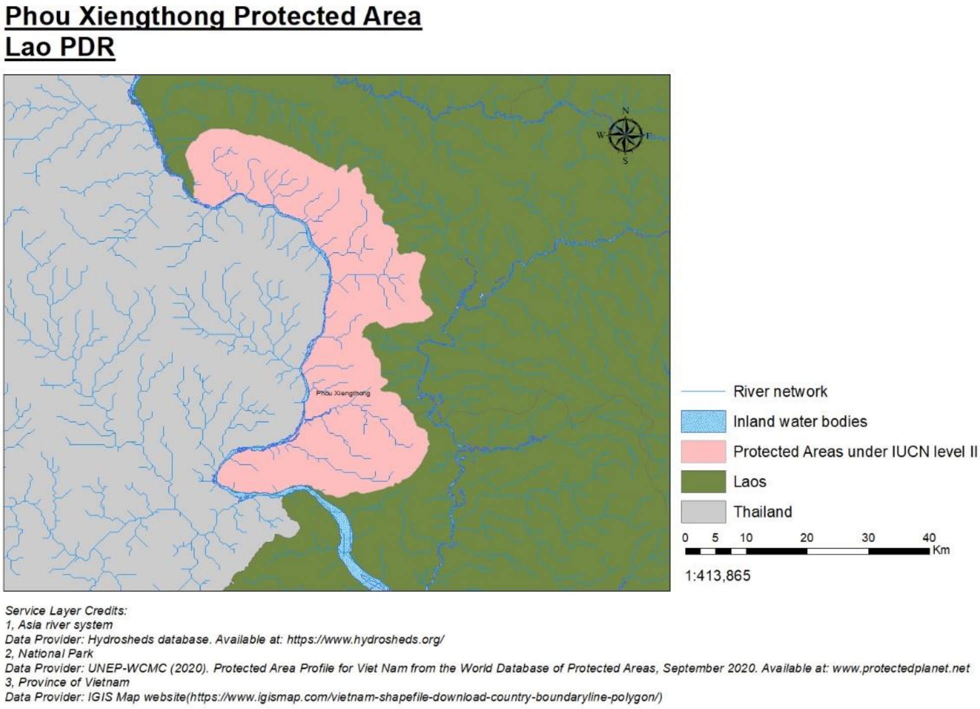
Map 63: Phou Khao Khoay Protected area in Lao PDR.



Map 64: Phou Phanang Protected area in Lao PDR.

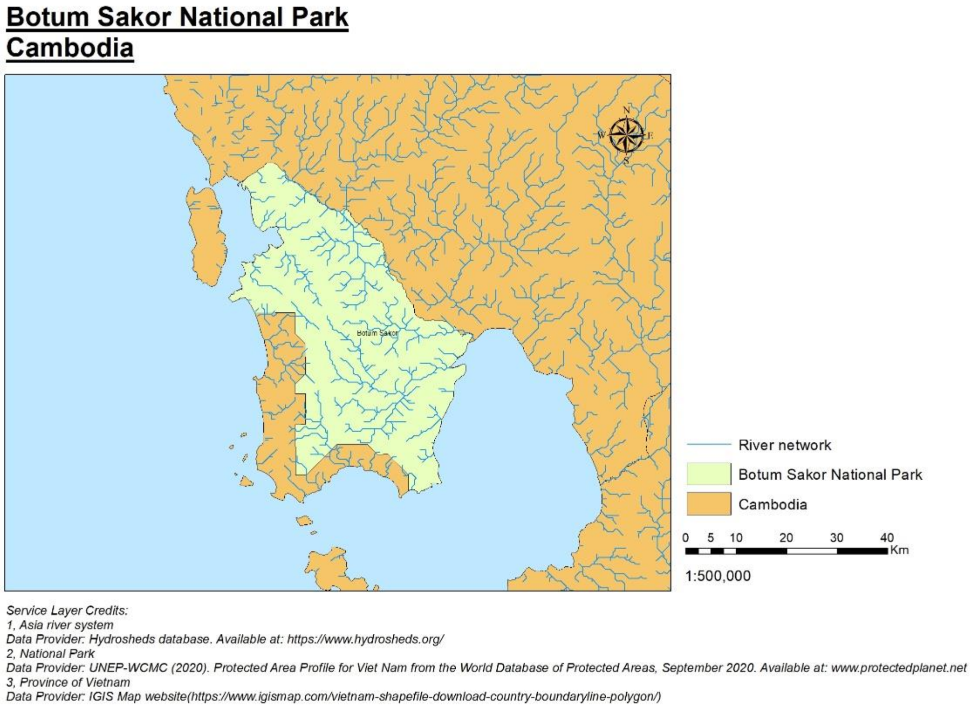


Map 65: Phou Xang He Protected area in Lao PDR.

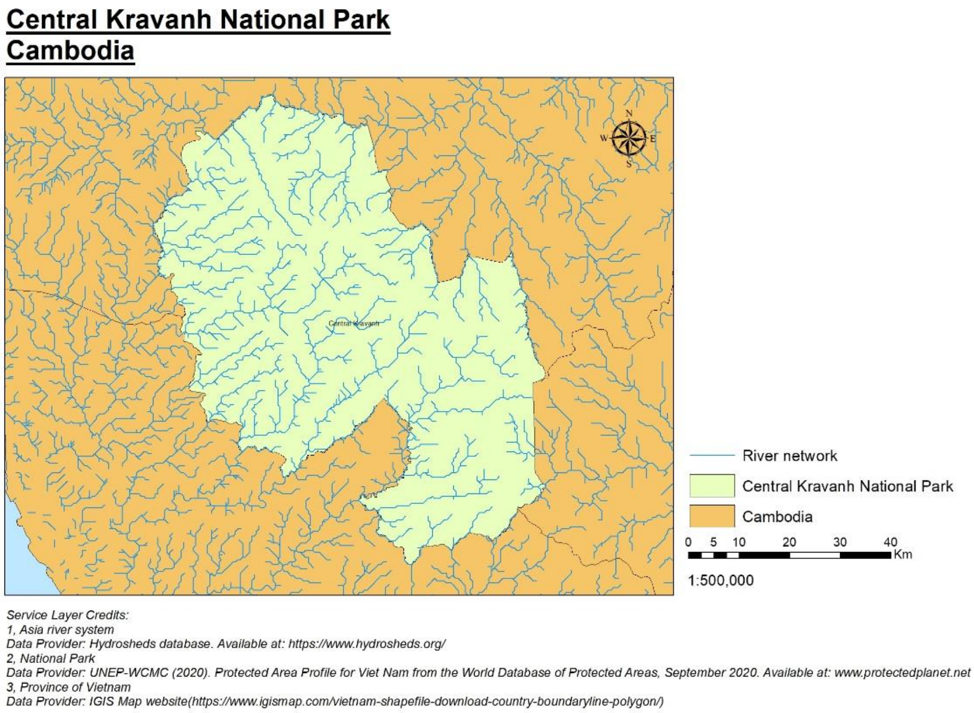


Map 66: Phou Xiengthong Protected area in Lao PDR.

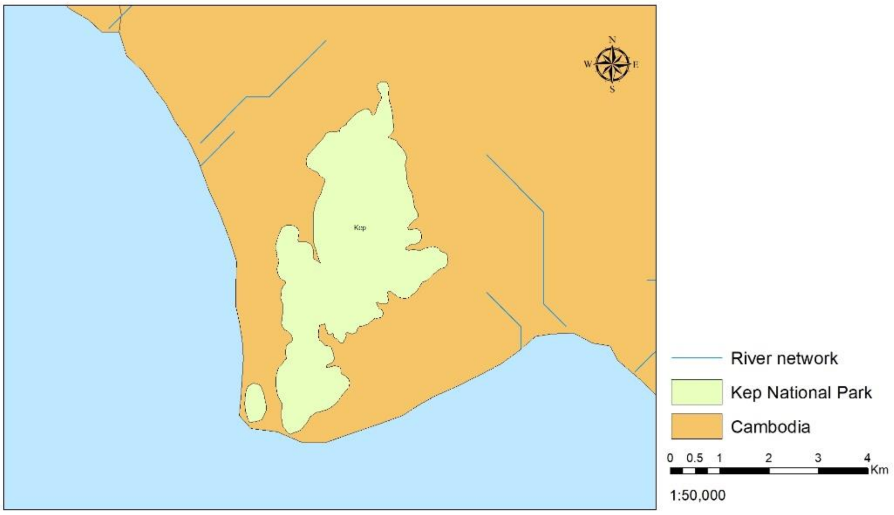
APPENDIX III: Maps of National Parks and Protected Areas in Cambodia.



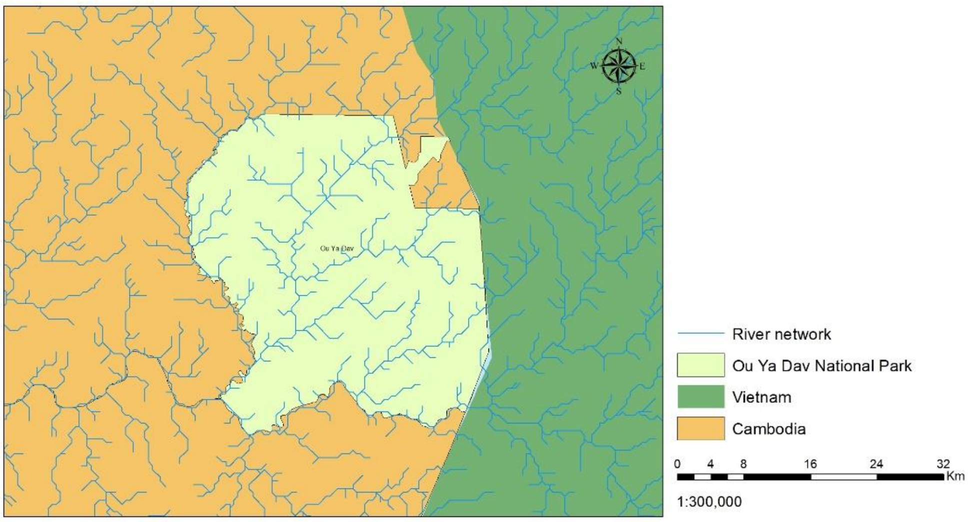
Map 67: Botum Sakor National Park in Cambodia.



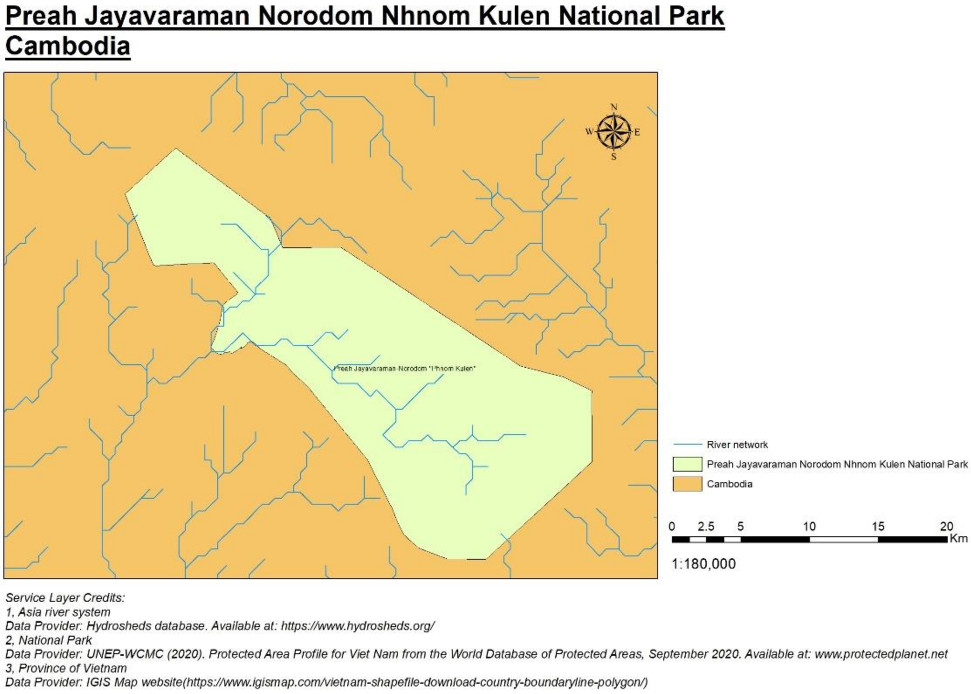
Map 68: Central Kravanh National Park in Cambodia.



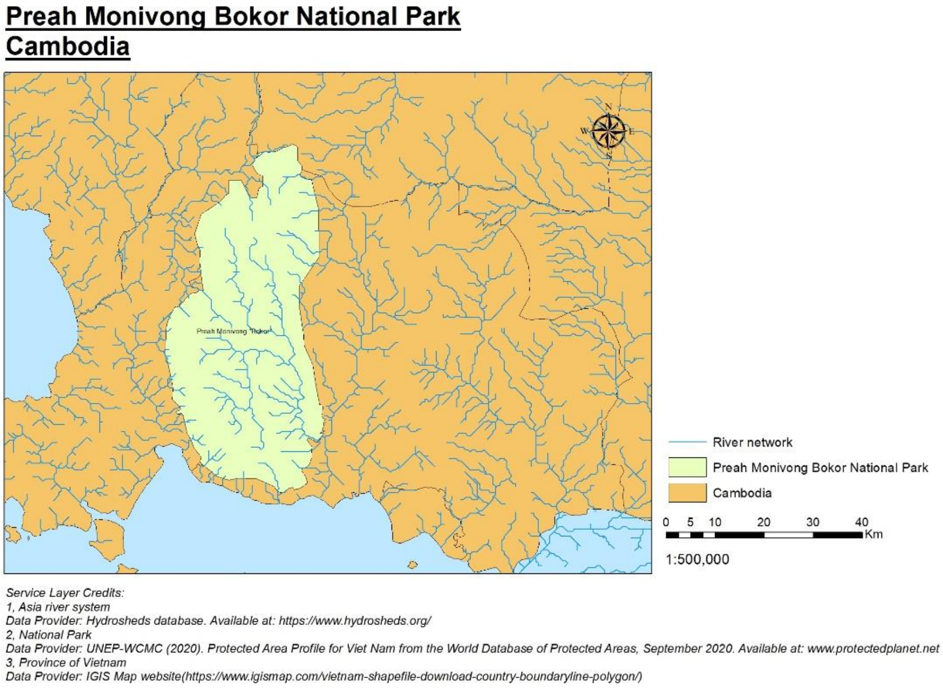
Map 69: Kep National Park in Cambodia.



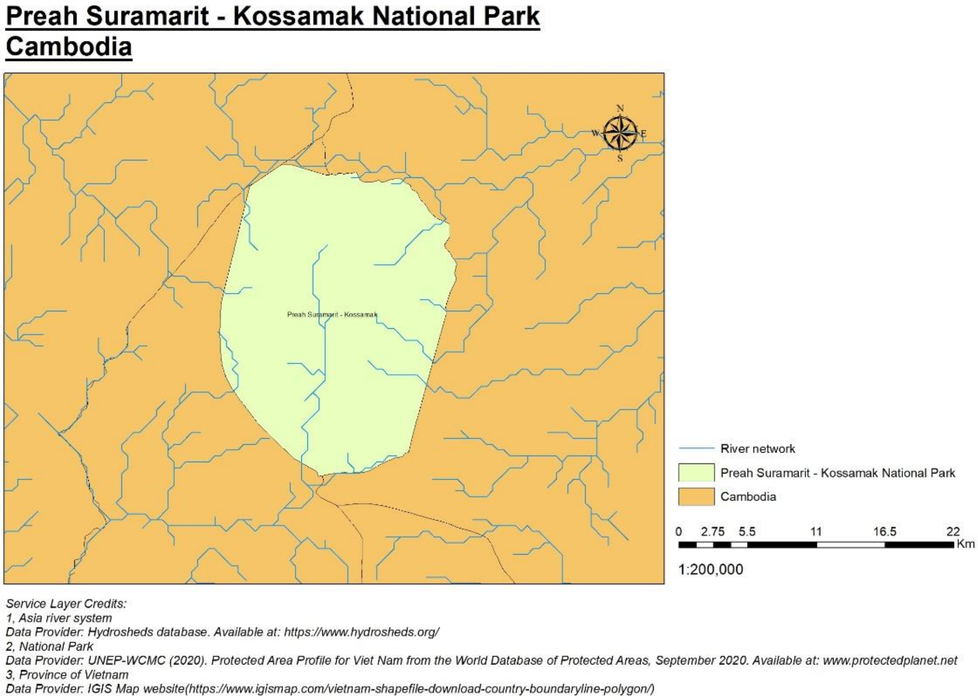
Map 70: Ou Ya Dav National Park in Cambodia.



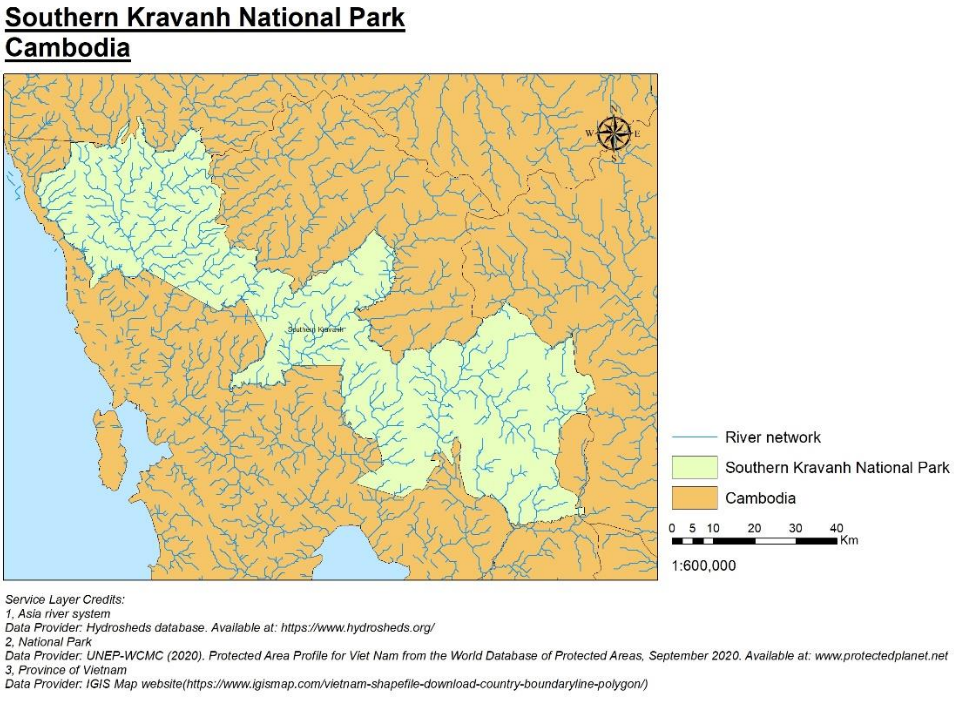
Map 71: Preah Jayavaraman Norodom Nhnom Kulen National Park in Cambodia.



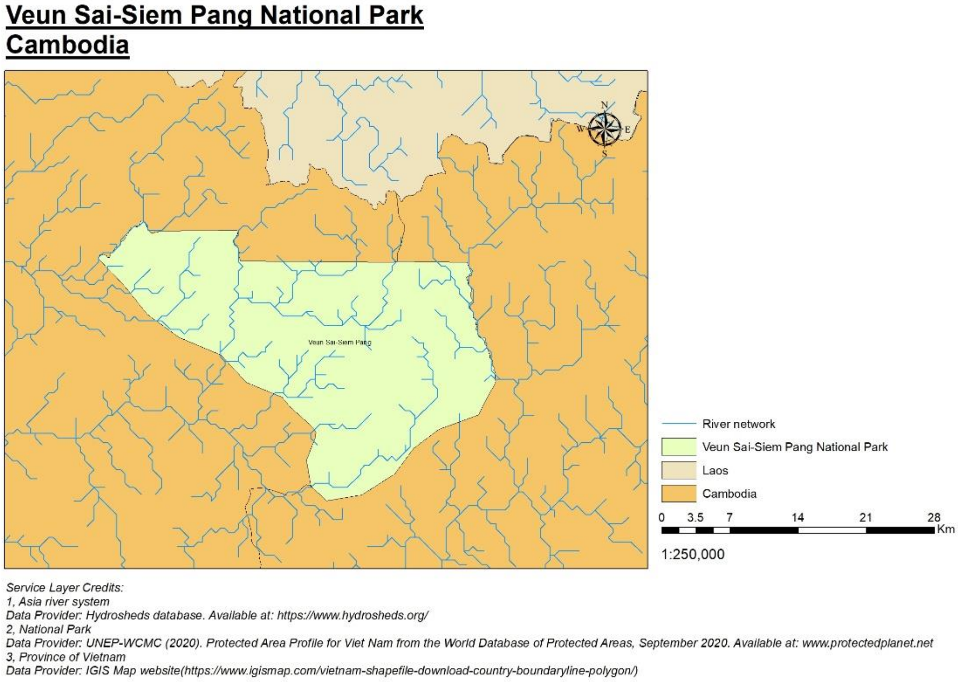
Map 72: Preah Monivong Bokor National Park in Cambodia.



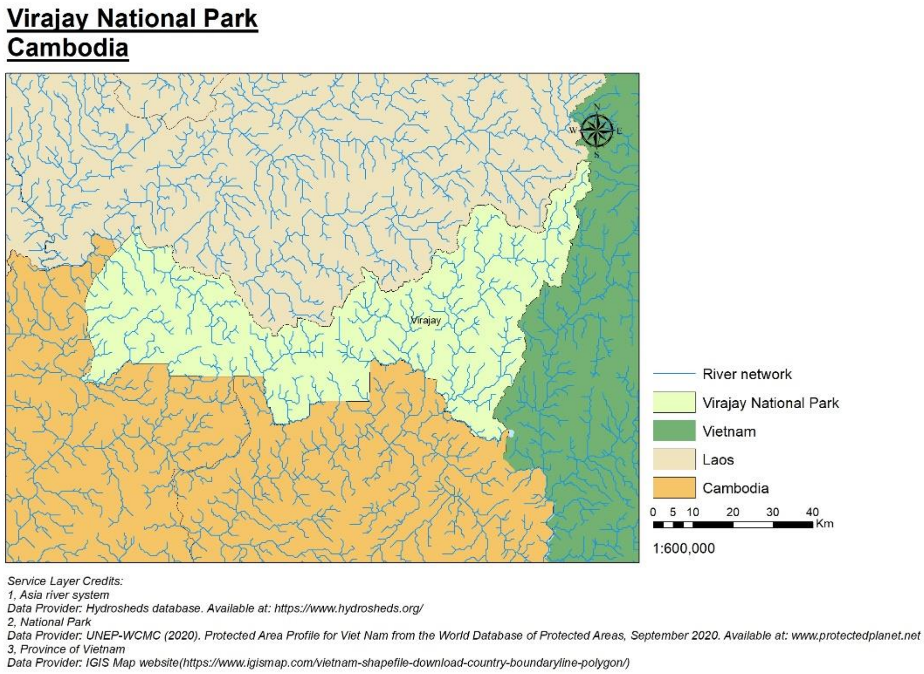
Map 73: Preah Suranarit – Kossamak National Park in Cambodia.



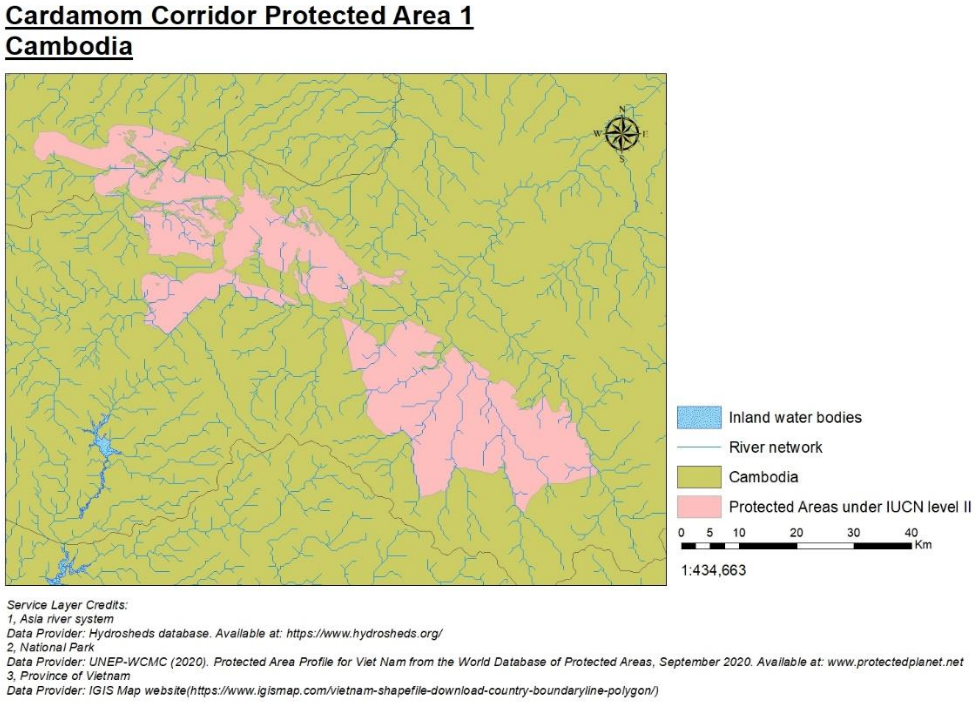
Map 74: Southern Kravanh National Park in Cambodia.



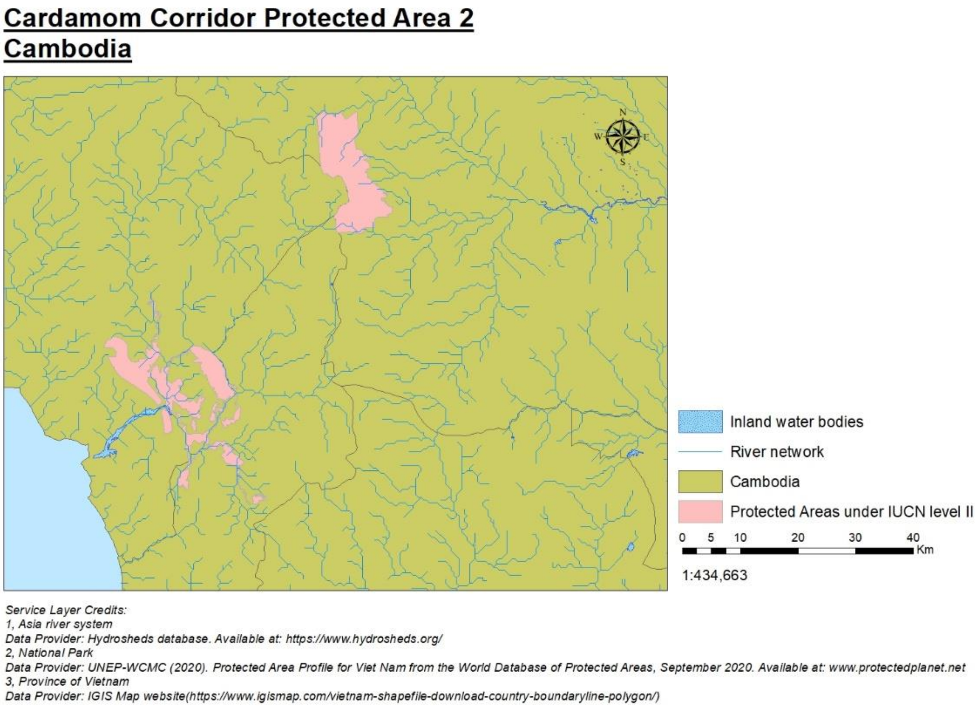
Map 75: Veun Sai-Siem Pang National Park in Cambodia.



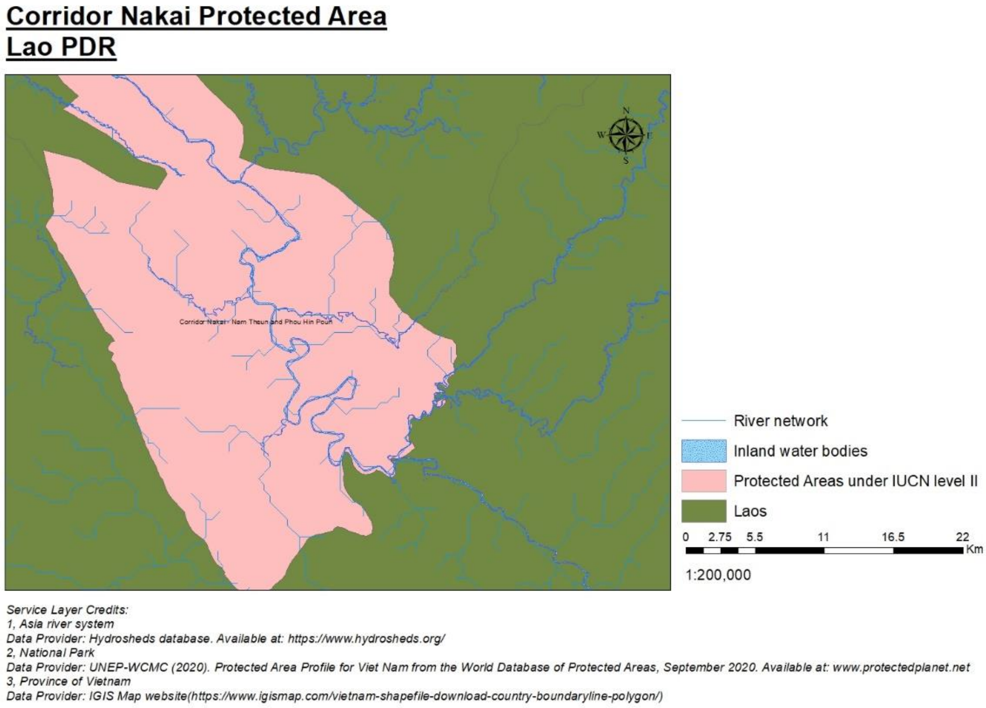
Map 76: Virajay National Park in Cambodia.



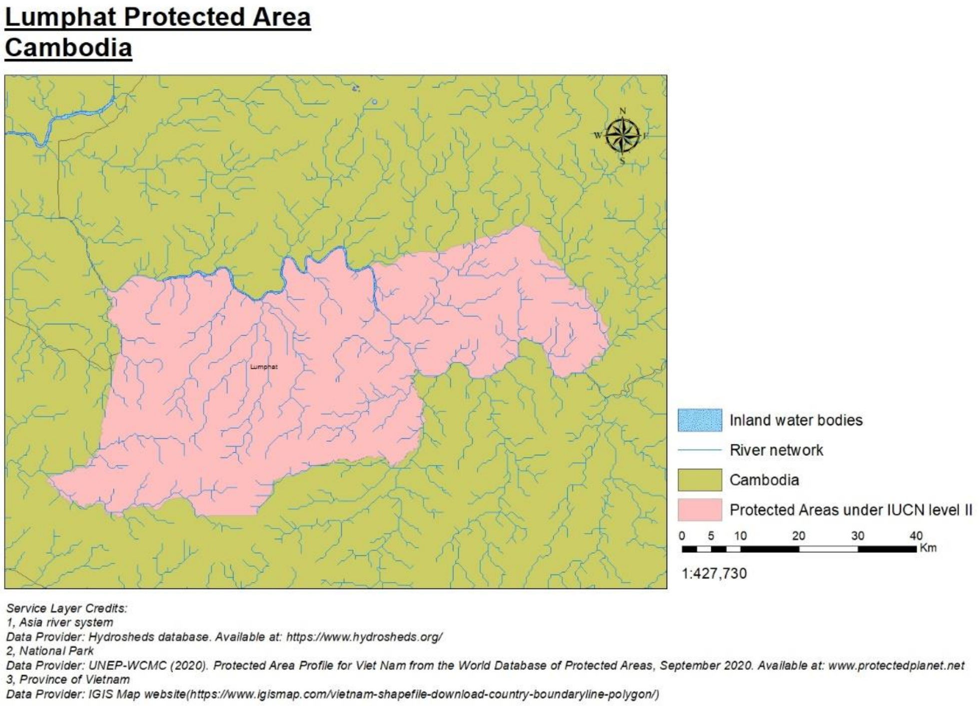
Map 77: Cardamom Corridor National Park in Cambodia.



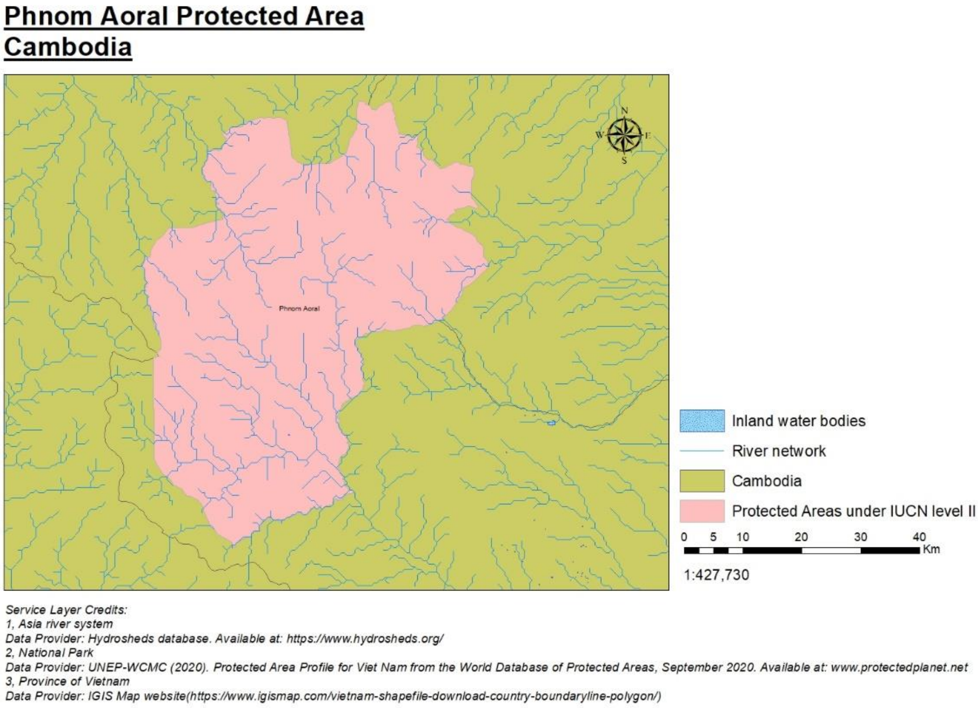
Map 78: Cardamom Corridor National Park in Cambodia.



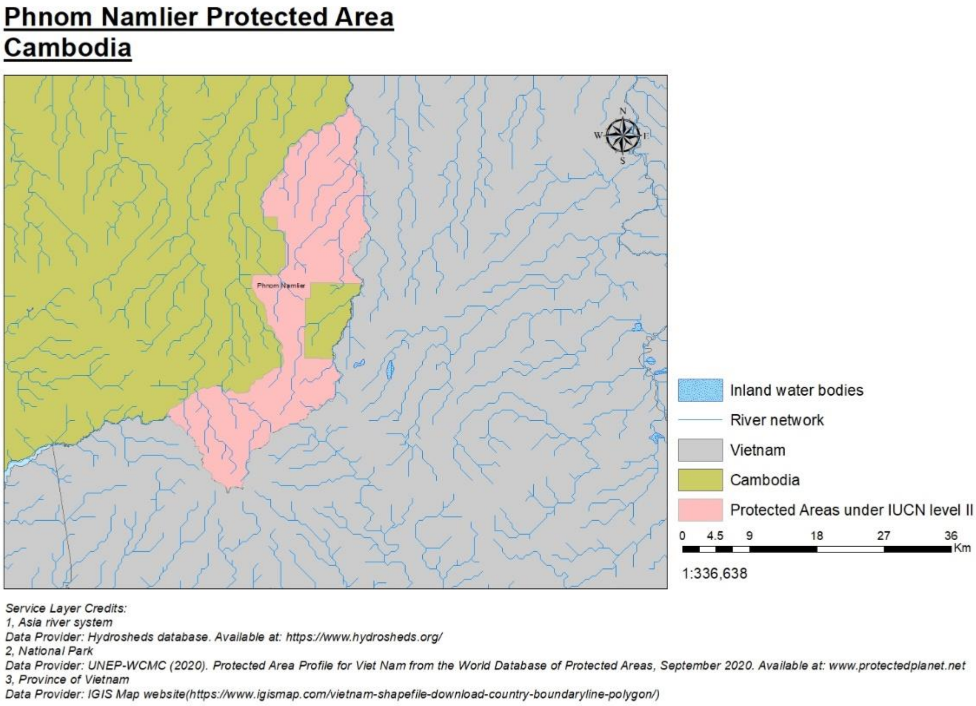
Map 79: Corridor Nakai Protected area in Cambodia.



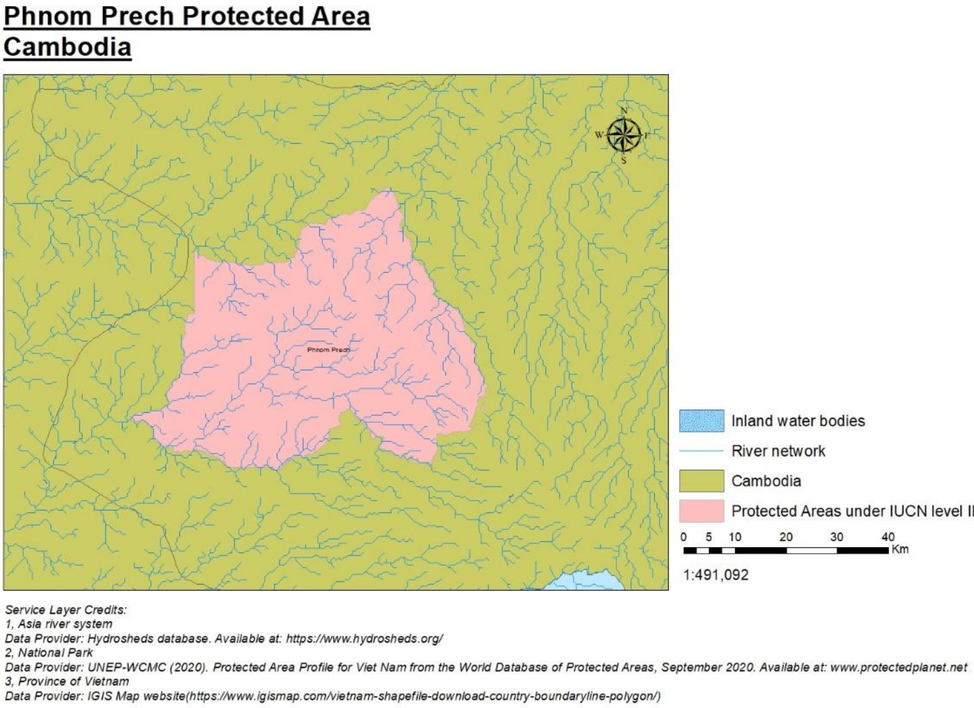
Map 80: Lum Phat Protected area in Cambodia.



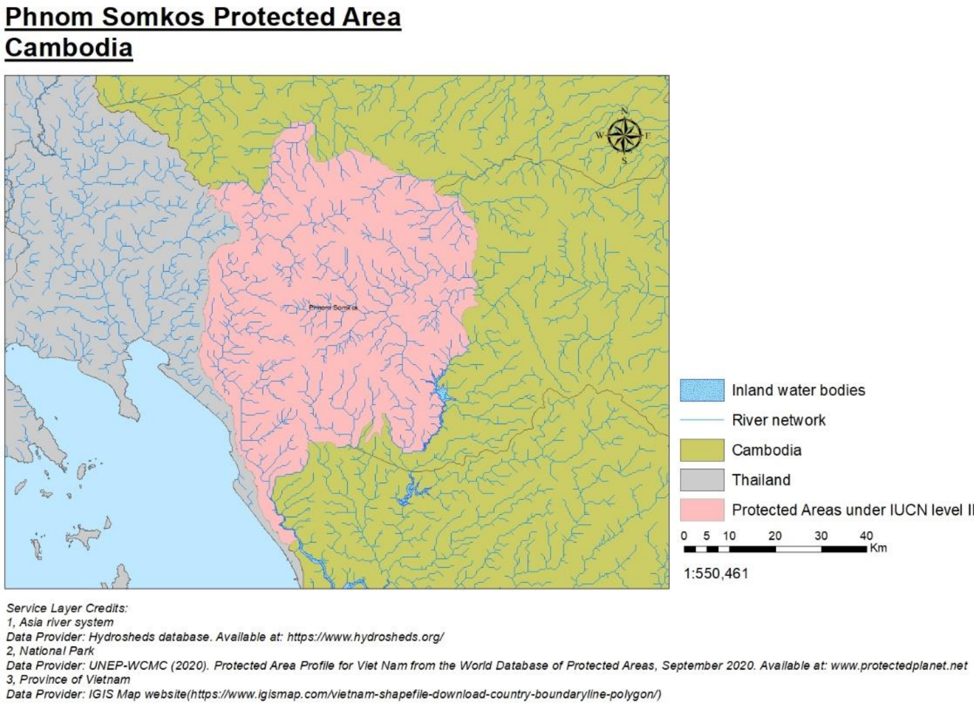
Map 81: Phnom Aoral Protected area in Cambodia.



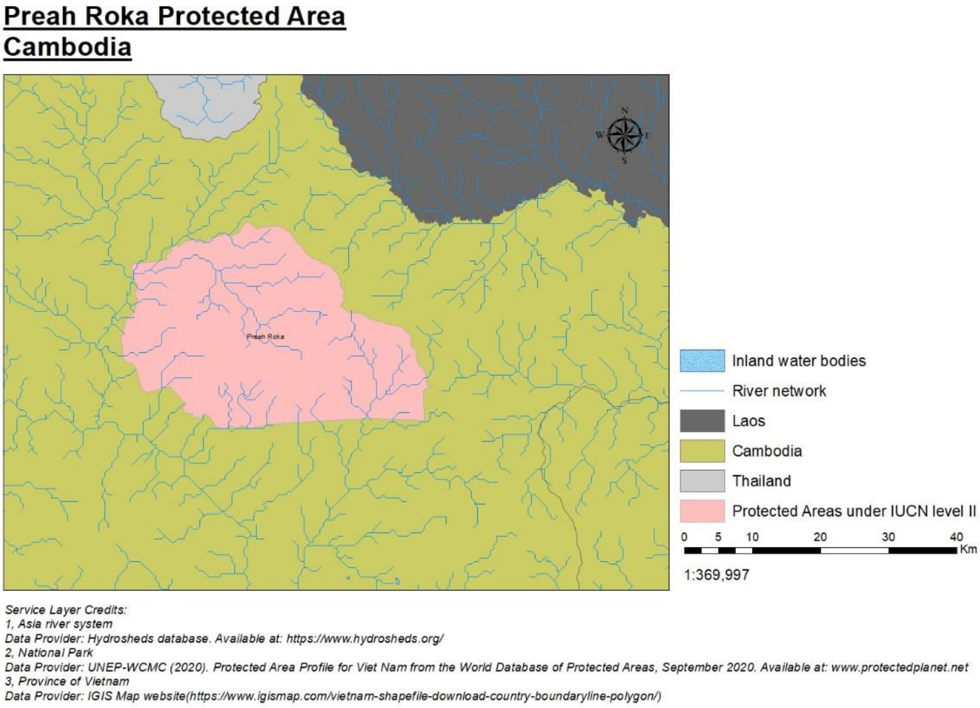
Map 82: Phnom Namlier Protected area in Cambodia.



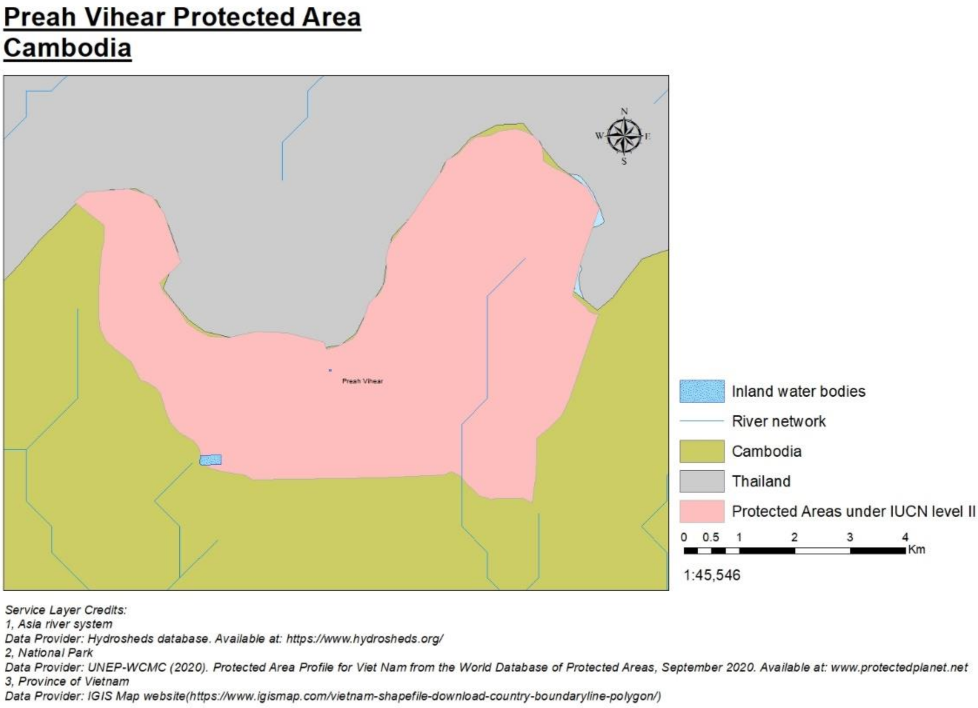
Map 83: Phnom Prech Protected area in Cambodia.



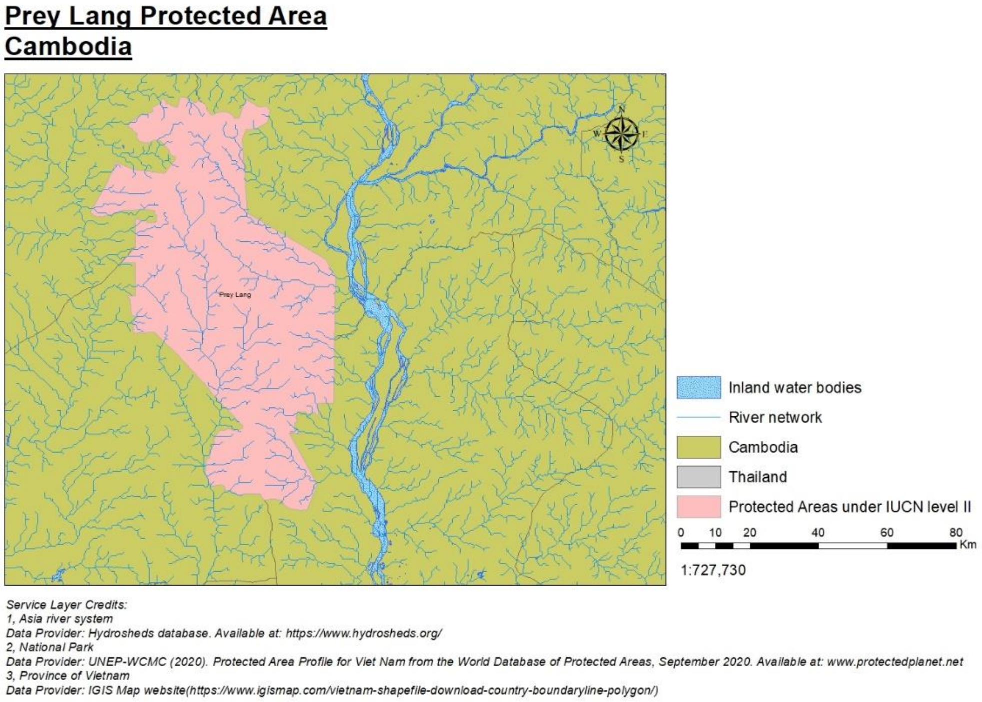
Map 84: Phnom Somkos Protected area in Cambodia.



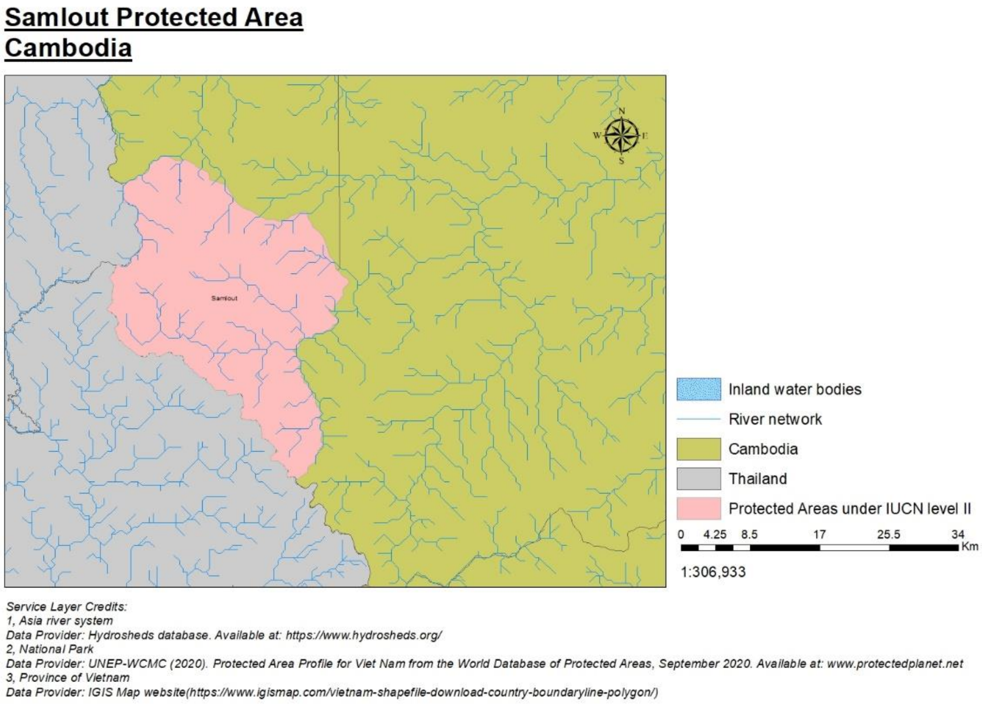
Map 85: Preah Roka Protected area in Cambodia.



Map 86: Preah Vihear Protected area in Cambodia.



Map 87: Prey Lang Protected area in Cambodia.



Map 88: Samlout Protected area in Cambodia.