TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Environmental Sciences

APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING IN MULTIPLE CRITERIA ANALYSIS TO IDENTIFY PRIORITY AREAS FOR BIODIVERSITY CONSERVATION IN VIETNAM

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Dresden, 08.2020

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Dresden, 08.2020

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Declaration

I hereby declare that the submission entitled "***Application of Geographic Information System and Remote Sensing in Multiple Criteria Analysis to identify priority areas for biodiversity conservation in Vietnam***," is my own work and that, to the best of my knowledge and belief. It contains no material previously published or written by another person and has not been previously submitted or accepted elsewhere to any other university or institute for the award of any other degree.

Vu Xuan Dinh

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Vu Xuan Dinh

Abstract

There has been an increasing need for methods to define priority areas for biodiversity conservation since the effectiveness of biodiversity conservation in protected areas planning depends on available resources (human resources and funds) for the conservation. The identification of priority areas requires the integration of biodiversity data together with social data on human pressures and responses. However, the deficit of comprehensive data and reliable methods are key challenges in zoning where the demand for conservation is most urgent and where the outcomes of conservation strategies can be maximized. In order to fill this gap, the environmental model *Pressure–State–Response* (PSR) was applied to suggest a set of criteria to identify priority areas for biodiversity conservation.

The empirical data have been compiled from 185 respondents, categorizing into three main groups: Governmental Administration, Research Institutions, and Protected Areas in Vietnam, by using a well-designed questionnaire. Then, the Analytic Hierarchy Process (AHP) theory was used to identify the weight of all criteria. These results show that three main factors could identify the priority level for biodiversity conservation: Pressure, State, and Response, with weights of 41%, 26%, and 33%, respectively. Based on the three factors, seven criteria and 17 sub-criteria were developed to determine priority areas for biodiversity conservation. In addition, this study also indicates that the groups of Governmental Administration and Protected Areas put a focus on the "Pressure" factor while the group of Research Institutions emphasized the importance of the "Response" factor in the evaluation process.

Then these suggested criteria were applied by integrating with Geographic Information System (GIS) and Remote Sensing (RS) to define priority areas for biodiversity conservation in a particular conservation area (Pu Luong-Cuc Phuong area) in Vietnam. The results also reveal the proportion of very high and high priority areas, accounting for 84.9%, 96%, and 65.9% for Cuc Phuong National Park, Pu Luong Nature Reserve, and Ngoc Son Ngo Luong Nature Reserve, respectively. Based on these results, recommendations were provided to apply the developed criteria for identifying priority areas for biodiversity conservation in Vietnam.

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Acronyms and Abbreviations

AGCM	Atmosphere General Circulation Model
AHP	Analytic Hierarchy Process
CCAM	Conformal Cubic Atmospheric Model
CPNP	Cuc Phuong National Park
DARD	Department of Agriculture and Rural Development
DEM	Digital Elevation Model
DOS	Dark Object Subtraction
EHDP	Expert Health Data Programming
ENGO	Environmental Non-Government Organization
ESA	European Space Agency
FFI	Fauna and Flora International
FPD	Forest Protection Department
GDLA	General Department of Land Administration
GIS	Geographic Information System
GOs	Government Organizations
GVF	Goodness of Variance Fit
HCP	Habitat Conservation Planning
IUCN	International Union for Conservation of Nature
JNB	Jenks Natural Breaks
KDE	Kernel Density Estimation
LST	Land Surface Temperature
LULC	Land Use - Land Cover
MARD	Vietnam Ministry of Agriculture and Rural Development
MONRE	Vietnam Ministry of Natural Resources and Environment
NDVI	Normalized Difference Vegetation Index
NGO	Non-Government Organization
NP	National Park
NR	Nature Reserve
NSNLNR	Ngoc Son - Ngo Luong Nature Reserve
OECD	Organization for Economic Co-operation and Development
OLI	Operational Land Imager
PAs	Protected Areas

PLNR	Pu Luong Nature Reserve
PRECIS	Providing Regional Climates for Impacts Studies
RCM	Regional Climate Model
RegCM	Regional Climate Model developed by the International Centre for Theoretical Physics in Italy
RCP	RepresentativeConcentration Pathways
ROIs	Regions of Interest
RS	Remote Sensing
SA	Study Area
SR	Specific Region
TIRS	Thermal Infrared Sensor
TM	Thematic Mapper
TOA	Top of Atmosphere
URIs	Universities and Research Institutes
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VAOF	Vietnam Administration of Forestry
VEA	Vietnam Environment Administration
VLRI	Vietnam Legislative Research Institute
VN2000	Vietnam Projection
VNA	Vietnam National Assembly
VNG	Vietnam Government
VNRB	Vietnam Red Data Book
WGS	World Geodetic System
WWF	World Wildlife Fund for Nature

Chapter 1. Introduction

1.1. Problem statement and motivation

Why does the identification of priority areas matter in biodiversity conservation?

The establishment of Protected Areas (PAs) has received much attention in recent years due to its vital importance to biodiversity conservation and sustainable development (Naughton-Treves et al., 2005). A protected area is defined as "a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values." (Dudley, 2008). Protected areas play an important role in biodiversity conservation (Bruner et al., 2001). Protected areas are not isolated, but they are components of their surrounding social and ecological contexts (Brandon et al., 1998). In order to support for planning conservation through the creation of protected areas, the selection of priority areas for conservation is crucial. However, the identification of priority areas for conservation requires the integration of biodiversity data together with social data on human pressures and responses. The deficit of comprehensive data and reliable methods becomes a key challenge in zoning priority areas for biodiversity conservation.

There has been an increasing need for methods to demarcate where the need for conservation actions is most urgent and where the outcomes of conservation strategies might be maximized (Balram et al., 2004). From a perspective of the geographic scale of investigation, the establishment of biodiversity conservation priorities can be classified into three categories (Balram et al., 2004). At the local scale, researchers and conservationists use criteria on genetic diversity and indicator species to provide a focus for establishing priority areas of biodiversity conservation (Balram et al., 2004). At the regional scale, Habitat Conservation Planning (HCP) practice is applied to make use of information on the home range and condition of organisms to allocate habitat reserves. At the regional to the global scale, priority areas for biodiversity conservation are identified by using criteria such as species richness, rarity, endemism, representativeness, and complementarity to drive the conservation efforts (Kier & Barthlott, 2001; Myer et al., 2000; Woodhouse et al., 2000). However, the effectiveness of these strategies mainly relies on the availability of reliable biodiversity data (Balram et al., 2004). Strategic conservation initiatives cannot wait for the establishment of a comprehensive database (Miller, 1994; Sutherland et al., 2004). This research contributes to the creation of a criteria system for defining conservation priority areas through literature review and expert interviews.

Vietnam is one of the important biodiversity hotspots in the world (CEPF & IUCN, 2016). However, the rate of loss of biodiversity in Vietnam continues at an alarming rate (Gordon et al., 2005; Myers et al., 2000). Many efforts have been made to protect the remaining biodiversity and halt the loss of species in Vietnam. Of these, the establishment of protected areas is considered as a useful tool. The country has 164 protected areas, including 30 National Parks, 69 Nature Reserves, 45 landscape protection areas, and 20 areas for scientific research (MARD, 2014). The total area of terrestrial protected areas is 2,198,744 hectares, accounting for about 13.5% of the country's natural land area (MARD, 2014). To establish a protected area in Vietnam, feasibility studies have to be undertaken to provide information on demarcation, area, and biodiversity. Although the number of protected areas is expected to increase in the coming years (MARD, 2014), there are still obstacles to identify priority areas for biodiversity conservation in Vietnam. In this study, the determined criteria were calculated, interpolated, and assessed by applying Remote Sensing (RS) and Geographic Information System (GIS) technologies to define priority areas for biodiversity conservation in a particular conservation area of Vietnam.

1.2. Research objectives and questions

The overall objective of this study is to develop a set of criteria in defining priority areas for biodiversity conservation and applying these criteria for a particular conservation area in Northern Vietnam.

Specific objectives are:

- *To identify criteria for establishing priority areas for biodiversity conservation*
- *To calculate weights of these criteria for biodiversity conservation in Vietnam*
- *To apply the determined criteria by integrating GIS and RS to define priority areas for a conservation area in Northern Vietnam.*

In connection with the above specific objectives, the following questions have been formulated:

- *What are the criteria for defining priority areas for biodiversity conservation?*
- *What are the importance levels of these criteria?*
- *How do GIS and RS support for applying these criteria?*

1.3. Study contribution

To better understand the process of establishing protected areas in Vietnam, we reviewed the reports of several established protected areas. One crucial step of the process is monitoring, investigation, and assessment on the status of species and ecosystems of the proposed areas. However, this process depended to a large extent on field surveys conducted by experts on species and conservation status throughout the areas and required a considerable amount of time and effort. Finding a solution to this burden and increasing the capability of monitoring, assessing, and managing the priority areas for biodiversity conservation in Vietnam is, therefore, both helpful and necessary.

This study provides a criteria system based on the environmental model (Pressure-State-Response model) to define priority areas for biodiversity conservation. The identification of biodiversity components and functions is an invaluable and significant step in evaluating biodiversity conservation value (Hill, 2005). The environmental model has been considered a popular conceptual framework to monitor biodiversity based on three key factors, namely state, pressure, and response (Long et al., 2016). The model demonstrates the relationships among human activities, biodiversity, and management solutions to assess the levels of influence on biodiversity conservation (Lee et al., 2005; Long et al., 2016; OECD, 1993b, 2003). The environmental model is considered to be able to identify key influences on biodiversity over time (Lee et al., 2005). The model provides three essential factors based on the concept of causality, including state, pressure, and response that help decision-makers and the public to identify, understand, and solve problems that cover the environmental and social challenges of sustainable development. The selection of priority areas for biodiversity conservation is one of the most critical tasks for monitoring, management of present protected areas or identifying potential boundaries for the establishment of new protected areas. A set of criteria was determined based on the previous studies by several ENGOs across the world, and Vietnam. They were then selected and organized into three factors of the environmental model based on their dimensions regarding biodiversity conservation. This combination formulated a system of indicators with three levels (factors, criteria, and sub-criteria) to cover many aspects of states, pressures, and responses that influence on biodiversity conservation in Vietnam.

This study provides the weight of each criterion through the consultation from experts that assesses its importance levels to define priority areas for biodiversity conservation.

The assessment of priority areas for biodiversity conservation should only be implemented once the importance levels of the proposed criteria are evaluated and calculated. The Analytic Hierarchy Process (AHP) has been referred to as an essential method to assist decision-makers in identifying the weights of multiple criteria (Malczewski, 2004; Saaty, 1977; Saaty & Gholamnezhad, 1982; Zhang, Su, Wu, & Liang, 2015). To calculate the weights of the criteria, a questionnaire was specifically designed to gauge the opinions of various experts and scientists in Vietnam who have responsibilities as well as insight into forestry, biodiversity, and conservation. The respondents came from across Vietnam and worked in the following five main sectors: Protected Areas (PAs), Government Organizations (GOs), Non-Government Organizations (NGOs), Universities and Research Institutes (URIs), and Forestry Companies (FCs). The data from the interviews were used to identify the pair-wise comparisons based on the relationship among the criteria. The method does not only help to reduce the complexity in evaluation for multiple criteria but also increases the objective aspects of choices (Saaty, 1980). The resulting weights of the criteria were calculated through the data of three main groups (PAs, GOs, URIs), and all individual respondents. It shows the common interests as well as the separate interests of the groups that represent administrators, implementers, decision-makers, researchers, scientists, and students in the field of biodiversity conservation in Vietnam.

This study provides an insight into the application of Geographic Information System (GIS) and Remote Sensing (RS) to map each criterion and synthesize all criteria to define priority areas for biodiversity conservation in Vietnam. GIS is considered a powerful tool based on its capacity for the capture, storage, retrieval, analysis, and display of spatial data (Chakhar & Martel, 2003; Elez et al., 2013; Esri, 2010; Hossain & Das, 2010). Meanwhile, RS helps to investigate, monitor, and analyze the environmental conditions, as well as ecosystem patterns (Franklin, 2010; Gould, 2000). The integration of RS and GIS has significantly become common in many mapping applications (Franklin, 2010; Hano, 2013; Hinton, 1996). In this thesis, RS and GIS were applied to gain the essential inputs, improve the data, analyze and synthesize the maps of the criteria. The key strength of RS is the ability to provide the primary data sources for many criteria through various satellite images. Landsat 4-5, Landsat 8, and Sentinel-2 are the sensors that were used in this research because of their diversity of spatial, temporal, and spectral resolution, and their accessibility, i.e., freely downloadable and cost-free data. They contributed to establishing the database of the criteria through their capabilities such as the classification of forest and LULC, detection of changes, determination of land surface temperature, and editing and updating information for secondary data. At the same time, GIS is an integral part of this study because of its capabilities for providing many powerful functions. The collected maps were edited and updated using essential GIS tools. The advanced tools, such as spatial analysis, geostatistical analysis, density estimation, provided the ability to analyze and synthesize multiple layers, arranging the values of different categories in an efficient and usable way. GIS provided a strong tool to estimate the probability density, especially for determining the impact level and scale of various concerned targets for biodiversity conservation in Vietnam such as population, hydrology, natural disasters, schools and organizations responsible for forest protection.

This study provides an actual result of the present status of biodiversity conservation in the Pu Luong-Cuc Phuong region, which is one of the highest biodiversity areas in Vietnam. The determined criteria were applied to the Pu Luong-Cuc Phuong region, the largest area of tropical rainforest and evergreen forest in the North of Vietnam (GEF, 2002). It is an essential area for biodiversity conservation with many endangered species living on the karst-mountain (Baltzer et al., 2001; Barthlott et al., 2005). Three protected areas are located in Cuc Phuong National Park, Pu Luong Nature Reserve, and Ngoc Son-Ngo Luong Nature Reserve. The results, achieved from the field survey in 2017 and the previous reports of three protected areas, show an incomprehensive data set on the biodiversity status. Critically, there has been no spatial data which can identify the priority areas for biodiversity conservation in the three protected areas. It is a problem that has restricted the management of protected areas across Vietnam. The application of the criteria to define priority areas of biodiversity conservation in the Pu Luong-Cuc Phuong region is considered a pivotal step to identify the contemporary issues in the administration and management of the protected areas.

Finally, this study provides a fundamental framework that can apply to many regions and protected areas in Vietnam. The processes and steps to establish and apply the criteria to define priority areas for biodiversity conservation were analyzed and documented clearly in a step-wise manner that is essential for replications in other studies. The result of each part was calculated and described through the actual numbers in the synthesized tables and figures. The content of the study was arranged in a scientific process and divided into chapters such as the introduction, literature review, methodology, establishment of the criteria, application of the criteria. All of these create a framework that can be applied to other protected areas in Vietnam.

1.4. Thesis structure

The research was implemented to integrate Geographic Information System and Remote Sensing with multiple determined criteria to define priority areas for biodiversity conservation in Vietnam. The proposal was written in 2016, and data collection and fieldwork was conducted in 2017, then the collected data was analyzed, synthesized, and assessed in 2018, and finally writing the Ph.D. thesis in 2019.

This thesis is elaborated and organized in six chapters, as follows:

Chapter 1: This chapter introduces the problem statement and motivation for research to open the main research objectives and questions of this study. The problems were highlighted by showing the opportunities and constraints of establishing, monitoring, and managing the present protected areas that are considered one of the critical issues for biodiversity conservation in the world generally and in Vietnam particularly.

Chapter 2: This chapter is devoted to summarizing the theoretical background of the study based on a review of previous literature that shows the status of biodiversity conservation, the applied inventory methods, monitoring biodiversity and the establishment of new protected areas in Vietnam. Focused on defining priority areas for biodiversity conservation in Vietnam, the environmental Pressure-State-Response model is revised to deal with the establishment of the criteria. The literature on the establishment of criteria and application of GIS and RS in defining priority areas for biodiversity conservation is reviewed to suggest essential criteria and effective methods based on GIS and RS techniques.

Chapter 3: This chapter presents the study area and describes its terrain, climate, population, and biodiversity characteristics. The chapter further illustrates the research methodologies that were used in the study. The methods of Analytic Hierarchy Process, Remote Sensing, Geography Information System, and Climate Change Scenarios were introduced explicitly to achieve the research objectives. These methods are presented in order for the research process employed from the establishment of criteria to application of GIS and RS to mapping the criteria as well as synthesizing them.

Chapter 4: The data of the interview in 2017 were summarized to help select the responsible respondents for the analysis of pair-wise comparisons. Then, the Analytic

Hierarchy Process method was applied for calculating the weights of criteria with each pair-wise comparison. The values of the weights were identified based on the opinions of all individual respondents, and for the three main groups (PAs, GOs, and URIs).

Chapter 5: This chapter describes the application of the determined criteria to define priority areas for biodiversity conservation in the Pu Luong-Cuc Phuong region. The characteristics of each criterion were analyzed to find the major representable elements that can be mapped by using GIS and RS. Then, all the maps representing the criteria were synthesized based on their calculated weights for all respondents and for three main groups.

Chapter 6: The final chapter summarizes the achieved results of the thesis and is categorized into two main sectors. The first part sums up the main findings of the determined criteria and their weights for defining priority areas for biodiversity conservation in Vietnam. The second part presents the calculated results of priority areas and an outlook on potentials and perspectives for monitoring and assessment of biodiversity conservation in the Pu Luong-Cuc Phuong region.

Chapter 2. Literature review

2.1. Background information on Vietnam

Biodiversity conservation has been considered an essential task for sustainable development. Globally, biodiversity has degraded significantly in many regions as a result of rapid socio-economic development and weak management systems (Bini et al., 2005; Quyen & Hoc, 1998; MNRE, 2011b). Vietnam is located in the Indo-Burma region ranked as one of the top 10 biodiversity hotspots as well as the top five for threat in the world (CEPF, 2012). Vietnam is one of the priority countries for global conservation, with about 10% species worldwide, and the area accounts for only 1% of the land area of the world (PARC, 2002). The loss of biodiversity in Vietnam has been very severe. Several species are on the brink of extinction because humans have overexploited the natural resources in unsustainable ways (Nghia, 1999; Primack et al., 1999). Vietnam has been on the way to achieve the National Biodiversity Strategy to 2020 and vision to 2030 to cover 9% protected areas of the country's territory (MONRE, 2015).

Cuc Phuong National Park, the first national park in Vietnam - was established in 1962, marking a significant milestone of forest and biodiversity conservation in Vietnam (MARD 1998, MARD 2004, and VNG 2003). Moreover, the National Conservation Strategy (NCS) of Vietnam was introduced in 1985. Various institutions and legislation for biodiversity conservation and forest utilization have been created and issued by the Government of Vietnam such as Forest Protection and Development Law in 1991 (updated in 2004), Land Law in 1993 (updated in 1998 and 2003), Environmental Protection Law in 1993 (updated in 2005), Fisheries Law in 2003, and Biology Diversity Law in 2008 (VNG, 2008b). The first Vietnam Red Data Book was published in 1992 (updated in 2000 and 2007) (MONRE & VEA, 2010). To date, the system of natural protected areas of Vietnam comprises 164 PAs, including 30 National Parks, 69 Nature Reserves, 45 landscape protection areas, and 20 areas of empirical scientific research (MARD, 2007). Thus, PAs protection and management are of vital significance for biodiversity conservation in Vietnam (Bruner et al., 2001). However, the loss of biodiversity in Vietnam remains a critical issue.

Vietnam has been a member country of the international biodiversity conventions, which comprise three main objects: biodiversity conservation, sustainable use of the natural resource, and sharing benefits of genetic resources fairly and faithfully. However, the legislation documents of Vietnam have focused solely on biodiversity conservation (MONRE, 2004), without sufficient consideration of the latter two objectives. The establishment of special-use forests has been a positive and vital achievement for biodiversity conservation in Vietnam (MONRE & VEA, 2010).

According to Vietnamese legislation, a nature reserve is a natural land that has a high value of natural resource and biological diversity (VNG, 2010). The establishment of nature reserves is to protect and guarantee natural succession and serve biodiversity conservation and scientific studies. The specific conditions for nature reserve selection are the following:

- It must be a particular ecosystem in which remain the fundamental characteristics such as flora and fauna diversity. It is not impacted by or with limited impact from human activities.
- It has high importance for biogeography, geology, and ecology, as well as the valuable potential for research, education, landscape, and tourism.
- It also has various endemic species of flora and fauna, but which are in danger of extinction according to the IUCN Red List.
- The percentage of a natural ecosystem is at least 70 percent of the whole protected area to guarantee the conservation of an entire ecosystem.
- It must be guaranteed that the direct impacts of local people are prevented.

To implement a project of establishing a protected area, the project has to comply appropriately with the special-use forest system planning issued by competent state agencies, and the criteria of special-use forest (VNG, 2010). The process of establishing a special-use forest area needs to be based on Decree No.117/2010/ND-CP as follows:

- Assessing natural conditions, forest state, natural ecosystems, biodiversity values, gene source, historical and cultural values, landscape, scientific and practical researchers, environmental education, providing environmental services from the forest.
- Assessing forest management state, forest utilization, land-use, the water surface of the project.
- Assessing the state of livelihood, population, economy, and society.
- Identifying the objectives of establishing special-use forest following the criteria in Decree No.117/2010/ND-CP.
- Identifying boundary and area range of special-use forest on the relevant maps.

- Action plans, performance solution, management organization.
- Identifying capital investment estimates, separating investment capital following each period, regular funding for activities of protection, conservation, enhancing the income of local people, as well as investment effectiveness and efficiency.
- Organizing project implementation.

According to Vietnamese legislation, a protected area (PA) must be a specific ecosystem in which remain the fundamental characteristics such as the essential values of biogeography, geology, and ecology, as well as the valuable potential for research, education, landscape, and tourism (VNG, 2010). This system must be guaranteed that the direct impacts of local people are prevented. However, the loss of biodiversity has been continued due to both direct and indirect causes. Direct impacts include hunting, illegal logging, harvesting non-timber forest products, grazing, reclamation, forest fire (Dudley et al., 2006; Naughton-Treves et al., 2005). Indirect impacts consist of population growth, living habits of the local community, poverty, and inefficiency of forest legal protection as well as failure of several central and local policies (Dudley et al., 2006; Naughton-Treves et al., 2005b).

The identification and zoning of a protected area are based on habitat, landscape, priority species, and the discussion process with stakeholders as well as relevant experts. Forests have economic, social, and environmental values, and high conservation value of forests are identified through real meaning for its area (Tordoff, 2003). To define the threats influencing on biodiversity conservation, there is a need for a conservation strategy based on situational analysis and a biological assessment to formulate the priority landscape (Baltzer, 2000). The biodiversity assessment process has many limitations (Tordoff, 2003).

- The critical restrictions give insufficient information about biodiversity, which is unreliable and imprecise.
- The protected areas that stretch across a large area are struggling with management issues due to lack of staff as well as their limited capacity and knowledge about conservation.
- Poverty is the main cause of many conflicts between local people and the objectives of biodiversity conservation. There are many limitations of implementation of legislative and institutional frameworks on forest management, biodiversity

conservation, and environmental protection, that can result in the illegal exploitation of natural resources.

- The knowledge of local people and environmental management staff is limited regarding ecological issues.
- The cooperation of central and local level institutions in biodiversity surveying, environmental management, and capacity building is insufficient.
- Biodiversity data need to be centralized into an accessible information management system. The data have to be assessed quickly by environmental managers and policymakers.

One of the main limitations of the biodiversity assessment process in Vietnam is incomprehensive data on the conservation status of Vietnam's PAs. The data for biodiversity are usually identified through personal surveys, observation or interviews. Besides, there is a limited capacity of institutions and agencies that are responsible for forest management and biodiversity conservation. Therefore, this research's aim is to contribute to addressing current limitations related to the identification of priority areas for biodiversity conservation that will support the process of establishing new protected areas as well as contribute to the improvement of protected areas management.

2.2. Environmental Pressure-State-Response model

The Organization for Economic Co-operation and Development (OECD) proposed a framework with three main factors, including pressure, state, and response (OECD, 1993a). It is considered a necessary framework that can effectively combine environmental and economic indicators (Chen, 1996; Wolfslehner & Vacik, 2008). The framework is a strong tool to identify the impact of human activities on nature based on the information on causes, effects, and responses (Hammond & Institute, 1995; Wolfslehner & Vacik, 2008). The environmental Pressure-State-Response (PSR) model is created to identify the positive and negative indicators of biodiversity at regional and national scales over time (Lee et al., 2005). In this study, the original PSR model is adapted for defining the priority areas for biodiversity conservation. Three key factors, including Pressure, State, and Response, are considered as an important base to evaluate the connections and influences of the proposed indicators. It helps decision-makers and the public to solve problems that cover the environmental and social interface of biodiversity conservation (Figure 2.1).

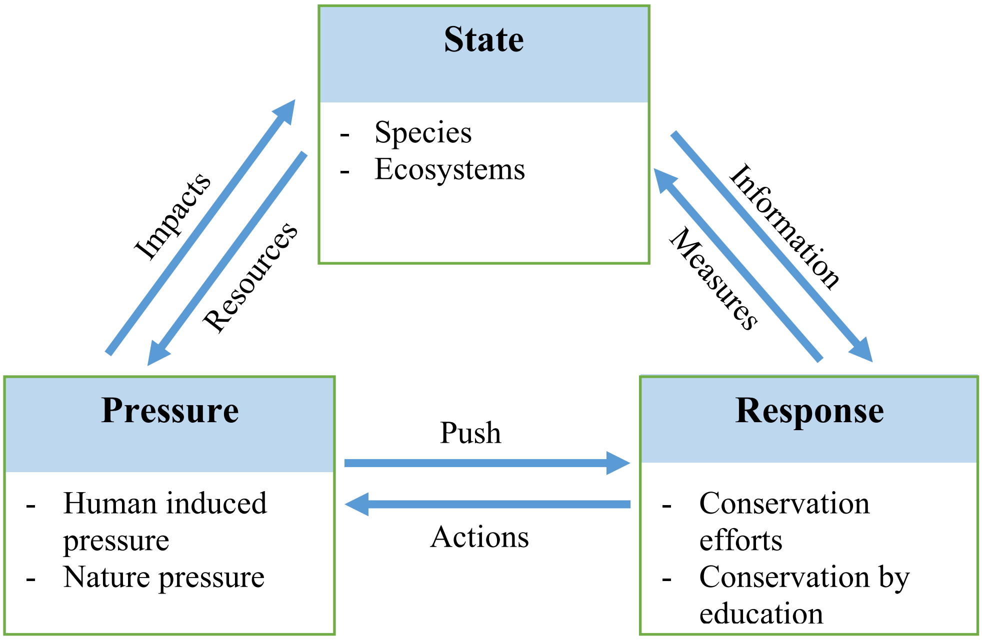


Figure 2.1: Adapted PSR Model for evaluating biodiversity conservation

a) ***Pressure refers to threats to species habitats such as habitat destruction, unsustainable hunting, and climate change.*** The rapid increase of population has been considered one of the critical pressures on biodiversity and natural resources due to the escalation of logging and hunting (Dudley et al., 2006; Naughton-Treves et al., 2005b; Sterling & Hurley, 2005), expansion of agricultural fields, shifting cultivation (Phua & Minowa, 2005), hydropower projects, urbanization (Evans et al., 2011; Poffenberger, 1998). The priority areas of biodiversity conservation are considered those least affected by the pressure of human activities (Gordon et al., 2005). The threat from human activities to biodiversity can be estimated through the indicators of distribution, quantity, density, and economic and societal demands (Saunders et al., 1998). Additional pressure on biological diversity is due to the disturbances of climate and habitat, which is considered as essential indicators (Hilton-Taylor & Stuart, 2009; Miller, 1994; Saunders et al., 1998; Sterling & Hurley, 2005). Several challenges of climate change for biodiversity were estimated with alarming consequences, potentially leading to mass extinction (Bellard et al., 2012; Thomas & al, 2004). Global climate change that is causing natural disasters or extreme climatic events is one of the significant threats to biodiversity (Hilton-Taylor & Stuart, 2009), including species (Evans et al., 2011) and ecosystems (Sivakumar et al., 2005).

b) ***State refers to species or site-specific data trends on populations and habitat.*** Species and ecosystems are two elements that represent the state of biodiversity (Gordon et al., 2005; Sterling & Hurley, 2005). Biodiversity conservation is often implemented and focused on species at a regional scale (Gordon et al., 2005). Ecosystem conditions are widely accepted to be the necessary data to identify the indicators of biodiversity (Franklin, 2010; Gordon et al., 2005; Phua & Minowa, 2000, 2005; Wulder et al., 2006). The condition of habitat is considered as a critical factor in assessing environmental issues such as the worldwide decline of forest habitats (Baillie et al., 2004; Gordon et al., 2005), biodiversity loss (Bunce et al., 2013; Firbank et al., 2003), high extinction rates (Evans et al., 2011) as well as destroying ecosystem services (Baillie et al., 2004). Vietnam's biodiversity is shaped by the complexity of geographic location, climate, topography, hydrology, and forest types, which impact on the distribution of species as well as on biotic communities (Gordon et al., 2005).

c) ***Response implies actions to recognize and preserve.*** Although the establishment of PAs is considered as an appropriate tool to maintain the biological diversity inside their boundaries (N. Dudley, 2008) as well as to battle the pressures of habitat loss and degradation (Hilton-taylor & Stuart, 2009). However, it was not sufficient for a long-time process of biodiversity conservation (Saunders et al., 1998). The sustainable management of biodiversity cannot be satisfied if stakeholders lack information and knowledge (SEAC, 1996). To remove the key impediment to sustainable management, it is necessary to provide the information, enhance the knowledge (Saunders et al., 1998), as well as improve awareness and provide funding (Sodhi et al., 2004) to the local communities for biodiversity conservation.

2.3. Defining criteria for biodiversity conservation

Biodiversity conservation is an important environmental issue, which aims to preserve the variety of species and communities as well as the genetic and functional diversity of species (Gordon et al., 2005; Saunders et al., 1998). According to Birdlife International, the priority areas of biodiversity conservation are Endemic Bird Areas (EBAs) (R. I. Miller, 1994). The functions of biodiversity conservation are entire to preserve species diversity, ecosystem diversity, soil and water conservation functions, and prevent potential threats (Phua & Minowa, 2000, 2005).

An essential step to evaluate biodiversity conservation value is the identification of biodiversity components or their functions, which are evaluable or significant (Hill, 2005). To understand and identify the elements of biodiversity conservation, it is necessary to understand the exact concept of biodiversity. Although many authors defined the idea of biodiversity, a popular definition of biodiversity that has been used in this research refers to the variety of life forms including genetic diversity, species diversity and ecosystem diversity (DeLong, 1996; IUCN et al., 1991; Noss & Cooperrider, 1994; Ricketts et al., 1999; United Nations, 1992; Wilson, 1993).

The evaluation of biodiversity conservation is a process that measures the value of many biodiversity components and at an array of scales (Hill, 2005). A critical aspect of biodiversity conservation is to evaluate and select the priority areas of biodiversity conservation, which are drawn out by using a criterion set for biodiversity and conservation (Bibby, 1998). According to Gordon et al. (2005), biodiversity value is determined by species richness, species endemism, rarity, outstanding ecological or evolutionary processes, and the presence of particular species. The criteria for conservation value are endangered species, species decline, habitat loss, fragmentation, large intact areas, high impact future threats, and low impact future threats (Gordon et al., 2005). Evaluation systems for biodiversity conservation typically consist of the measurement or description of criteria for biological and conservation value, which have been used for the evaluation of sites (Table 2.1).

The assessment of biodiversity conservation is an important task where conservationists and policymakers must carefully choose criteria to define potential areas for biodiversity conservation. The *Analytic Hierarchy Process* (AHP) is a helpful tool for handling complicated decision-making, and assist the decision-maker in determining priorities and making the best decisions for multiple-use planning of forest resources (Kangas, 1992; Kangas & Kuusipalo, 1993; Guillermo & Sprouse, 1989) as well as in environmental planning processes (Anselin et al., 1989; Kangas & Kuusipalo, 1993; S. Liu et al., 2013; Saaty & Gholamnezhad, 1982; Varis, 1989). The pairwise comparison of the AHP method helps to decrease the sophisticated level of decisions and captures both subjective and objective aspects of choice (Saaty, 1980). The AHP method is considered the most suitable tool to determine the weights of assessment factors, which will impact significantly on decision-making processes (Malczewski, 2004; Saaty, 1977; Saaty & Gholamnezhad, 1982; Zhang et al., 2015).

Table 2.1: The comparison of criteria for defining the conservation values used across several ENGOs

Organization and approach	Genetic	Species	Ecosystem	Biological value							Conservation value					
				Species richness	Species endemism	Rarity	Outstanding ecological or evolutionary	Presence of special species	Representation	Threatened species	Species decline	Habitat loss	Fragmentation	Large intact areas	High impact future threat	Low impact future threat
Alliance for zero extinction Aze sites		✓			✓					✓						
Birdlife international Endemic bird areas		✓	✓		✓			✓								
Birdlife international Important bird areas		✓	✓		✓			✓		✓						
Conservation International Biodiversity hotspots			✓		✓							✓				
Conservation International High biodiversity wilderness areas			✓		✓									✓		✓
Wildlife conservation society Range-wide priority setting		✓							✓					✓		✓
Wildlife conservation society Last of the wild			✓				✓		✓		✓	✓		✓	✓	✓
World Wildlife Fund Global 200		✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	

Source:(Gordon et al., 2005)

Although the AHP theory was initiated in the late1970s and used as a decision support tool, most applications of AHP are in areas outside forestry, agriculture, and natural resources (Schmoldt et al., 2001). However, there is a potential application of the AHP tool in natural resource and environmental management that contributes an important basis to develop further in these fields. Examples of published applications can be mentioned such as *decision making for forest planning* (Kangas et al., 1993; Mendoza & Sprouse, 1989; Pukkala, 2003; Pukkala & Kangas, 1996); *selection of risk factors for forest protection* (Jung et al., 2013; Mahdavi et al., 2012; Reynolds & Holsten, 1994; Vadrevu et al., 2010); *forest management* (Jalilova, Khadka, & Vacik, 2012; Kaya & Kahraman, 2011; Mendoza & Prabhu, 2000; Peterson, Silsbee, & Schmoldt, 1994; Schmoldt et al., 1994; Schmoldt & Peterson, 2000; Segura et al., 2014); *suitability analysis of land use* (Akinci et al., 2013; Banai-Kashani, 1989; Hutchinson & Toledano, 1993; Malczewski, 2004; Pourebrahim et al., 2011; Xiang & Whitley, 1994).

To make the setting of biodiversity conservation priorities more systematic and explicit, a combination of criteria, scoring, and ranking procedures have been developed during the last couple of decades (Margules et al., 2002; Smith & Theberge, 1986). In these processes, multiple criteria such as diversity, rarity, naturalness, and size, among others, have been determined and given scores based on literature review and participation techniques (Boteva et al. 2004, Phua & Minowa 2005, Valente & Vettorazzi 2008). These ratings have then been combined for each selected area. The areas have been ranked, and the highest priority has been given to the areas with the highest scores (Margules et al., 2002).

Moreover, the AHP method is integrated with GIS to analyze and assess land suitability, which helps to increase the effectiveness and accuracy in identifying potential areas (Zhang et al., 2015). The weight of each factor is identified by the AHP method, and GIS techniques are used to transform the elements and their weights into map data and then processes the data (Akinci et al., 2013; Zhang et al., 2015). The various indicators needed to identify and consider in making a spatial decision, which will be calculated through the overlay equation integrated into MCDA and GIS (Phua & Minowa, 2005).

2.4. Application of GIS and RS for biodiversity conservation

Dangermond (1986) has shown that: “Geographic Information System (GIS) is not a new science, but rather a technology which requires a considerable scientific knowledge base for many of its data management functions". Goodchild (1991) has listed nine research areas for GIS, including data collection and measurement, display of spatial data, data modelling, analytic tools, spatial statistics, data structures and indexes, algorithms and processes, decision theory and risk analysis, and reasoning and cognition.

GIS is a powerful tool referring to the computerized database management system for capture, storage, retrieval, analysis, and display of spatial data (Chakhar & Martel, 2003; Elez et al., 2013; Esri, 2010; Hossain & Das, 2010; Prakash & Technology, n.d.). GIS has been a component in modelling species habitat to link landscape patterns with a range of ecological and environmental variables for species (Boyd & Foody, 2011). Decision-makers have favored the integration of GIS and Multi-Criteria Decision Analysis (MCDA), managers, stakeholders, and interest groups to evaluate several alternatives and to reduce significances to one dimension or value based on multiple criteria (Gomes & Lins, 2002). MCDA has helped decision-makers in identifying alternatives based on multiple incommensurable factors and criteria as well as analyzing potential actions, aggregating those criteria by using decision rules to rank or rate the alternatives (Malczewski 1999; Figueira et al. 2005; Eastman 2009). For several years, MCDA methods of Carver (1991) and Malczewski (2006) have been used for spatial problems by associating them with GIS. Malczewski (2006) reviewed over 300 articles about the GIS-based multi-criteria decision analysis (GIS-MCDA) and proposed that remarkable progress in the quantity and quality of research in integrating GIS and MCDA was indisputable over the last 15 years. GIS-MCDA is a significant and relevant approach for a wide variety of fields. The GIS community recognizes the great benefits that can be gained by incorporating MCDA into a suite of GIS capabilities.

The GIS, its capability in handling spatial aspects, has been used effectively to select the priority areas for conservation based on the assessment of criteria that the most are spatial data (Phua & Minowa, 2005). The capability of GIS is undeniable and be demonstrated in many previous studies. It can be seen in the analysis of climate conditions and habitat of tropical legumes (beans)(Jones et al., 1997), planning priority areas for bird conservation based on environmental factors (Muriuki et al., 1997), solving forest conservation with multi-objectives (Keisler et al., 1997; Pereira & Duckstein, 1993), zoning potential areas for new protected areas by the GIS-based multi-criteria decision-making method (Phua & Minowa, 2005).

The images acquired by sensors on aircraft or space-borne platforms have been considered one of the significant sources of data, to derive vegetation maps (Fairbanks & McGwire, 2004; Gould, 2000; Hurlbert & Haskell, 2002; Johnson et al., 1998), to understand landscapes and regions (Forman, 1995), to monitor species habitat (Franklin, 2010), and to manage biodiversity (Foody & Cutler, 2006; Griffiths et al., 2000; Kerr et al., 2001; Nagendra, 2001). Remote Sensing (RS) is an important technology that processes the data, to investigate the characteristics of movement and behavior of the individual animal (Altmann & Altmann, 2003), to estimate potential areas containing endangered species (Franklin, 2010) or habitat suitability (Ferrier, 2002; Guisan & Thuiller, 2005), and to precisely map species distribution (Castro-Esau et al., 2006).

RS is considered one of the best tools to investigate, monitor, and analyze the environmental conditions of multiple scales (Franklin, 2010), especially for the ecosystem patterns of large regions (Gould, 2000). For images of high temporal and spatial resolution satellites and sensors are the crucial providers that help to explore the ability of remote sensing techniques to receive the near-real-time data of environment for assessment of vegetation and land use (Akinyede et al., 2015; Atzberger et al., 2013; Liang et al., 2012), and establishing maps of forest cover, biomass, and biodiversity in a global scale (Hansen et al., 2013; Levin et al., 2007). These outputs have been widely used to make informed decisions for environmental management (Fensholt et al., 2012; Mao et al., 2012; Notaro et al., 2010).

One of the root limitations for the biodiversity assessment process in Vietnam is an incomprehensive data set on the conservation status of Vietnam’s protected areas. The potential of using GIS and RS is to monitor, analyze, and assess the real condition of biodiversity and guide conservation work. It also estimates and visualizes the trends of biodiversity changes that help to improve the ability of the agencies to deliver biodiversity conservation.

Chapter 3. Research methodology

3.1. Study areas

Vietnam is located in Southeast Asia, ranging along the longitude from the 23^0 to 8^030'N. Vietnam occupies around 329,500 km^2 of the area and is bordered by China, Laos, and Cambodia on the north, northwest, and southwest, respectively. The rest of the country is bordered by the East Sea, which stretches 3,260 km along the eastern coast. Vietnam is divided into eight different ecoregions, including Northwest, Northeast, Red River Delta, North Central Coast, South Central Coast, Central Highlands, Southeast, and the Mekong River Delta.

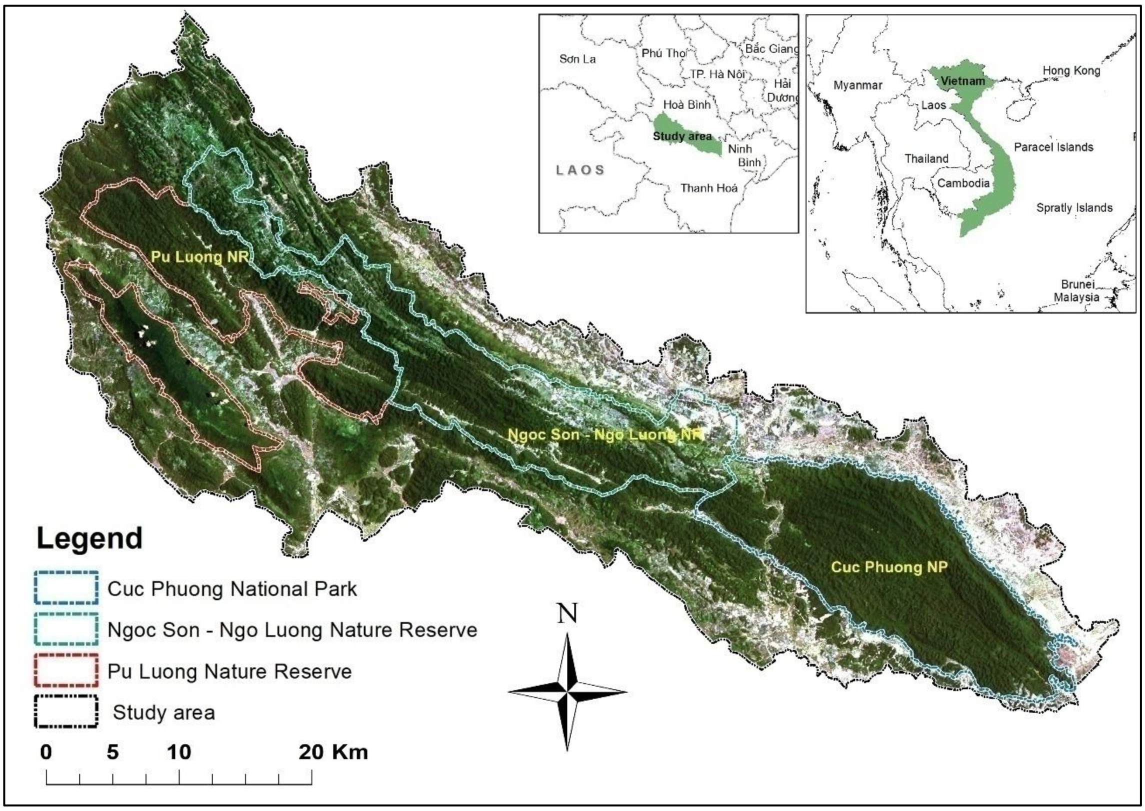


Figure 3.1: Location of three protected areas in the study area

This study was conducted to establish a criteria system to define priority areas of biodiversity conservation in Vietnam. GIS and RS were then integrated with the determined criteria to define priority areas for the Pu Luong - Cuc Phuong area in Northern Vietnam (Figure 3.1). Pu Luong - Cuc Phuong area, presents a globally important karst ecosystem with high levels of biodiversity and species endemism. There are currently three protected areas in the study area. Cuc Phuong National Park was established in 1962 as Vietnam's first national park, and it lies in the eastern part of the

Pu Luong Cuc Phuong area. Pu Luong nature reserve was created in 1999, and it covers the western part of the study area. The establishment of the Ngoc Son Ngo Luong nature reserve in 2004 formed a biodiversity corridor, connecting Cuc Phuong national park and Pu Luong nature reserve.

The study area is found in the geographical position as follows:

- From 20° 14' 15"to 20° 36' 00"North latitude.
- From 105° 1' 56"to 105° 44' 11"East longitude.

Table 3.1: Area statistics of the protected areas in the study area

Specific regions	**Area**	
	ha	**%**
Cuc Phuong National Park	22,792.5	15.4
Ngoc Son - Ngo Luong Nature Reserve	21,872.8	14.8
Pu Luong Nature Reserve	17,500.1	11.8
Other areas	85,831.0	58.0
Total	**147,996.4**	**100.0**

The study area covers 158.000 hectares, including Cuc Phuong national park, Ngoc Son – Ngo Luong nature reserve, and Pu Luong nature reserve, making up 15.4%, 14.8%, and 11.8% of the total area in the study area, respectively. The rest of the study area accounts for 58% (85,831 hectares) and lies outside the three current protected areas (Table 3.1).

Information regarding the study area, conservation status or condition of terrain, climate, population, and economy is described in the next sections.

3.1.1. Terrain

The study area is located in a mountainous region that contains two ranges of karst ecosystem running from the Northwest (Moc Chau district, Son La province) to the Southeast (Cuc Phuong commune, Ninh Binh province). The karst ecosystem has created a complex terrain that is divided into the Northwest region and the North Delta region.

The altitude ranges from 60 m at the Co Lung commune to 1,700 m on the highest peak of the Pu Luong nature reserve. Many points in the study area are located on steep slopes with more than 45^0. The average gradient of the whole region is around 30^0.

The karst ecosystem, which has existed thousands of years, contains lots of beautiful caves such as Con Moong, Nguoi Xua, Pho Ma Giang, Trang Khuyet, which are known as attractive destinations for ecological tourism as well as scientific research.

3.1.2. Climate

Pu Luong – Cuc Phuong region lies in the tropical climate under the influence of the monsoon and the weather of the Northwest region and Laos. It can be divided into two periods, a rainy season (from May to October) and a dry season (from November to April). The dry season is usually hot for a long period because of the combination of the deficient rainfall and the impact of the dry and hot wind from Laos. In the dry season, forest fires are often a threat to forest management.

The average annual air temperature in the study area is from 20^0C to 25^0C. Lowest and highest temperatures are 3^0C (in December or January) and 39^0C (in June or July), respectively. The range of daily temperature change is from 8^0C to 10^0C. The study area receives between 1,250 mm to 2,800 mm precipitation annually. The average annual air humidity is 82 % and can range between 75 % and 86 % (FFI, 2005).

3.1.3. Population

The study area is located across the eight districts of Lac Son (43,290 inhabitants), Mai Chau (13,338 inhabitants), Tan Lac (14,331 inhabitants), Yen Thuy (33,342 inhabitants), Nho Quan (12,689 inhabitants), Ba Thuoc (32,835 inhabitants), Quan Hoa (14,913 inhabitants), and Thach Thanh (17,260 inhabitants) and lies within the three provinces of Hoa Binh, Ninh Binh, and Thanh Hoa provinces. The Muong, Kinh, and Thai are the three main ethnic groups in the study site (FFI, 2005).

The population of three protected areas, including Ngoc Son–Ngo Luong NR, Pu Luong NR, and Cuc Phuong NP is 26,406, 18,309, and 8,590 people, respectively. Most of the population in Pu Luong NR and Ngoc Son–Ngo Luong NR are Thai (90.5%) and Muong (98%) (FPD, 2015; PLNR, 2013). An equal number of Kinh and Muong make up the communities in Cuc Phuong National Park. It is estimated that the population of this region will increase at a rate of 0.9% a year or higher (CPNP, 2011).

To date, educational and skill levels of local people living in the study area are still quite low. The main livelihood of local people has relied mostly on agriculture such as rice cultivation, livestock, and poultry, and industrial plantations. Only a small proportion of local population work in non-agricultural sectors, which are currently underdeveloped.

The income of local people is generally low, forcing local people to depend to a considerable extent on the remaining forests for their livelihood.

3.1.4. Biodiversity

Pu Luong–Cuc Phuong region is the largest area of tropical rainforest, as well as the evergreen forest that remains in the north of Vietnam (GEF, 2002). It is an essential area for biodiversity conservation with many species on the karst mountain (Baltzer et al., 2001; Barthlott et al., 2005). The landscape of the area creates a globally important area for plant diversity (WWF & IUCN, 1994). Pu Luong–Cuc Phuong is known as a hotspot of endemic and endangered species, especially Delacour's Langur Monkey (*Trachypithecus delacouri*) which has a global population of fewer than 300 individuals (Nadler et al., 2003). Three protected areas, including Cuc Phuong National Park, Pu Luong Nature Reserve, and Ngoc Son-Ngo Luong Nature Reserve have created a large forest corridor that improves significantly natural habitats of many endemic species that exist in Pu Luong-Cuc Phuong (FFI, 2005).

Cuc Phuong National Park is accounted for 1:1,500 of Vietnam's land area, while 1,983 plant species that were discovered this region, make up 17.27% of total plants in the country (CPNP, 2011). Many thousand-year-old plants reach from 45m to 75m in height and from 1.5m to 5m in diameter such as *Cinnamomum balansae* (45m high and 2.5m in diameter), *Parashorea chinensis* (70m high and 1.5m in diameter), *Dracontomelon duperreanum* (45m high and 2.5m in diameter), especially *Terminalia myriocarpa* (45m high and 25m crown diameter). The animals of Cuc Phuong National Park are also diverse. It is shown that Cuc Phuong national park has 89 mammal species, 307 bird species, 65 fish species, and around 2,000 insect species (FPD, 2015). Many species have been categorized as endangered or endemic species in the red list of International Union for Conservation of Nature (IUCN) and Vietnam Red Data Book (VNRB).

Pu Luong Nature Reserve is home to 1,109 species, 447 genera, 152 families belonging to 5 classes of vascular plants (PLNR, 2013). There are 84 mammal species, 162 bird species, 55 fish species, 28 reptile species, 13 amphibian species, and 158 butterfly species (Averyanow et al., 2003; Can, 2004; Monastyrskii, 2004; Thong, 2004; Yen et al., 2004).

Previous investigations have demonstrated a variety of animal and plant species in Ngoc Son Ngo Luong Nature Reserve (FPD, 2015). It is found that the number of plants contains 667 vascular species belonging to 372 genera, 140 families, and five classes.

There are 455 vertebrate animal species that belong to 93 mammal species (20.4%), 253 bird species (55.6%), 48 reptile species (10.5%), 34 frog species (7.5%), and 27 fish species (5.9%) (FPD, 2015).

3.2. Data collection

This study is based on the methods of primary data and secondary data collection (Hox & Boeije, 2005). The collected data were triangulated to increase their reliability. The secondary documents were compiled from many different sources such as paper maps, digital maps, annual reports from the protected areas, conservation project documents, statistic reports, satellite images, and other publications. The primary data were collected across Vietnam from March to July 2017 through a national survey by using a well-designed questionnaire. A detailed survey across three protected areas was conducted to collect information on the boundaries, land use status, and forest management types.

3.2.1. Questionnaire

In order to assess the preferences for criteria, the questionnaire was designed. The pairwise comparison was used to identify the importance levels between two criteria, which are presented as an assessment range. The respondents were requested to show their opinions for each pairwise, which of the criterion they think is more important. The questionnaire was designed in two forms for the direct interview, and the indirect interview via email, telephone calls, and other social media.

The rating scale was considered as a suitable method for this study. Following this, respondents were asked to express their opinion of biodiversity conservation in Vietnam, using a rating scale from 1 to 9. The rating scale questions were combined by corresponding groups and branches in Figure 3.2 as a matrix type. They are presented with questions, explanations, and figures showing the relationships among the criteria of each matrix. It helped to obtain the considerations of respondents about the importance level of each criterion as well as excluding inconsistencies in each pairwise comparison matrix.

The questionnaire was not only created to consult experts directly about the criteria, but it also explained the details to avoid misunderstanding and potentially incorrect responses. The form was created with four parts, including the introduction of research, information of respondent, assessment of respondent, and acknowledgement and references (Figure 3.2).

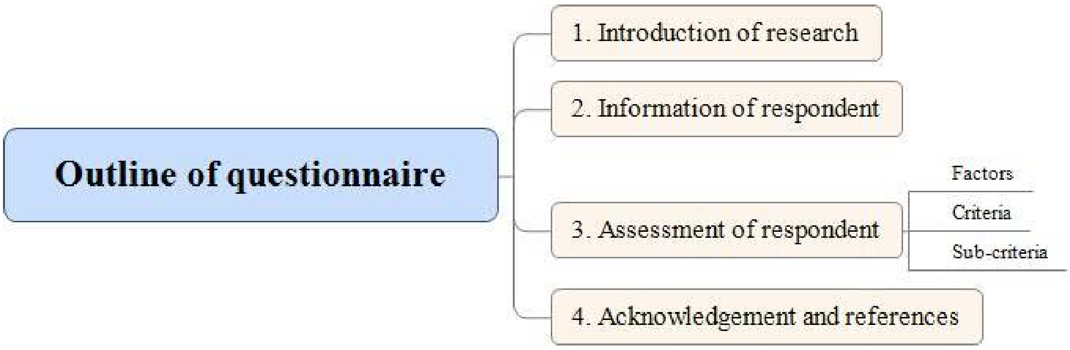


Figure 3.2: Outline of the questionnaire

The beginning of the questionnaire is an overview of the content, including a short introduction and two figures illustrating the questionnaire outline and criteria tree. The respondents are requested to answer eight questions on personal information such as full name, gender, age, email, mobile phone number, background, organization name, and address. After that, the respondents are provided with an explanation on how to answer the questions of the criteria that respondents will assess the important levels of factors, criteria, and sub-criteria following the nine levels from 1 (non-influence) to 9 (extreme influence). The diagrams were designed to describe the relationship between the criteria in each group of pairwise comparisons. They were added to each question of the questionnaire to help visualize and quickly explain to the respondents. It also helps to improve the trust level in an assessment of role of each criterion within the pairwise comparisons. The questionnaire is presented in appendix I.

3.2.2. Interview

Previous studies have pointed out the importance of expert method, which was used in their studies (Gordon et al., 2005). Specialist opinion significantly influences on habitat and species mapping, threat identification, data review, data compilation, as well as species status evaluation (Gordon et al., 2005). The data were mainly collected from interviewing face to face or via emails. Moreover, several field surveys in Cuc Phuong National Parks, Ngoc Son – Ngo Luong, and Pu Luong Nature Reserves were conducted to assess the values of biodiversity conservation that supported the analysis and synthesis of the collected data.

We used two forms of the interview, including face to face and email. An introduction of goals and explanation was delivered to interviewees. This helps interviewers understand all questions and provide more precise information. The paper-based questionnaire was used for face to face interview. Regarding the internet-based interview, each interviewee was provided with an online and PDF questionnaires via email with information on how to use these questionnaires. The use of three forms of questionnaire could help to increase the number of responses from interviewees.

3.3. Analytic Hierarchy Process

The selection of potential areas, high diversity, and endemic regions, facilitates to concentrate research and conservation efforts (Sterling & Hurley, 2005). The biodiversity is estimated by comparing the importance of the criteria that are known as the weights (Jyrki Kangas & Kuusipalo, 1993). From proposed indicators, the biodiversity conservation value of each site is calculated. Equation (3.1) is used to synthesize biodiversity conservation value for the whole study area.

$$\mathbf{C_k = \sum_{i=1}^{I} W_i X_i^k} \qquad (3.1)$$

where:

- *C_k is the biodiversity conservation value at the k_{th} intersection region.*

- *X_i^k is the score contained within the GIS layer of i_{th} indicators at the k_{th} intersection region.*

- *W_i is the weight of i_{th} indicator, which can be changed based on the critical level of each indicator.*

The steps of estimating a biodiversity conservation index are as follows:

a) *Criteria and their factors of biodiversity conservation will be selected from the literature review and expert interviews (AHP model includes objective, criteria, sub-criteria, and factors).*
b) *The grade of each factor will be transformed from measured data through the fuzzy set.*
c) *The weights of each factor will be assigned by the AHP method based on Saaty's scale and the pair-wise comparison matrix (Table 3.2).*
d) *Biodiversity conservation index will be calculated by a simple linear priority function (3.1)*

Table 3.2: Scale for pair-wise AHP comparisons

Intensity of Importance	Description
1	Equal importance
2	
3	Moderate importance
4	
5	Strong or essential importance
6	
7	Very strong or demonstrated importance
8	
9	Extreme importance

Source: (Fujita et al., 2000; Kouet al., 2012; Saaty & Vargas, 1991)

To use the results calculated by the AHP method, a critical aspect of the AHP is to check the consistency (Kou et al., 2012; Saaty, 1980; Saaty, 1991). Saaty proposed the consistency ratio (CR) to identify the consistencies of the pairwise comparison matrices. The test of consistency must be done when the number of criteria used in a pairwise comparison matrix is higher than two. When the number of criteria increases, the pairwise comparisons climb significantly, increasing inconsistencies and complicates the checking of consistencies.

A pairwise comparison matrix considered as consistency or inconsistency depends on the test of the Consistency Ratio (3.3). The test can pass when the Consistency Ratio is less than 0.1.

$$\mathbf{CI} = \frac{\boldsymbol{\lambda} - \mathbf{n}}{\mathbf{n} - \mathbf{1}} \tag{3.2}$$

$$\mathbf{CR} = \frac{\mathbf{CI}}{\mathbf{RI}} \tag{3.3}$$

where:

- *CR is Consistency Ratio (3.3)*
- *CI is Consistency Index (3.2)*
- *RI is the average Random Index based on Matrix Size (Table 3.3)*
- *n is the number of criteria used in a pairwise comparison matrix ($n \leq 10$)*
- *λ is the average of the elements of consistency vector*

Table 3.3: The average values of the Random Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45	1.49

Source: (Kou et al., 2012)

The procedure for checking the consistency includes the four steps as follows:

- *Step 1: Identify the λ of the pairwise comparison matrix.*
- *Step 2: Applying the third equation (3.2) to calculate the Consistency Index (CI)*
- *Step 3: Applying the second equation (3.3) to estimate the Consistency Ratio (CR).*
- *Step 4: The judgment of the consistency of the pairwise comparison matrix is performed through the comparison between the CR value with the consistency threshold (0.1).*

3.4. Remote Sensing

Images from satellites have been considered as an essential source to understand landscapes and regions (Forman, 1995), and estimate the trends of environmental modifications for management strategies (Franklin, 2010). Remote sensing can be applied to sustainable forest management, such as forest modelling, estimation of forest structure, classification of forest types, and forest change detection (Franklin, 2001). Classification of satellite images is an important method to detect and identify land cover or other attributes (Richards & Jia, 2005), as well as to extract and present information acquired from the images for use in management (Franklin, 2001).

The workflow of land cover classification through Landsat images can be divided into three main steps containing pre-processing, classification, and post-classification. Figure 3.3 shows the flowchart of the critical steps for using Landsat images as the data sources to classify land cover in this study.

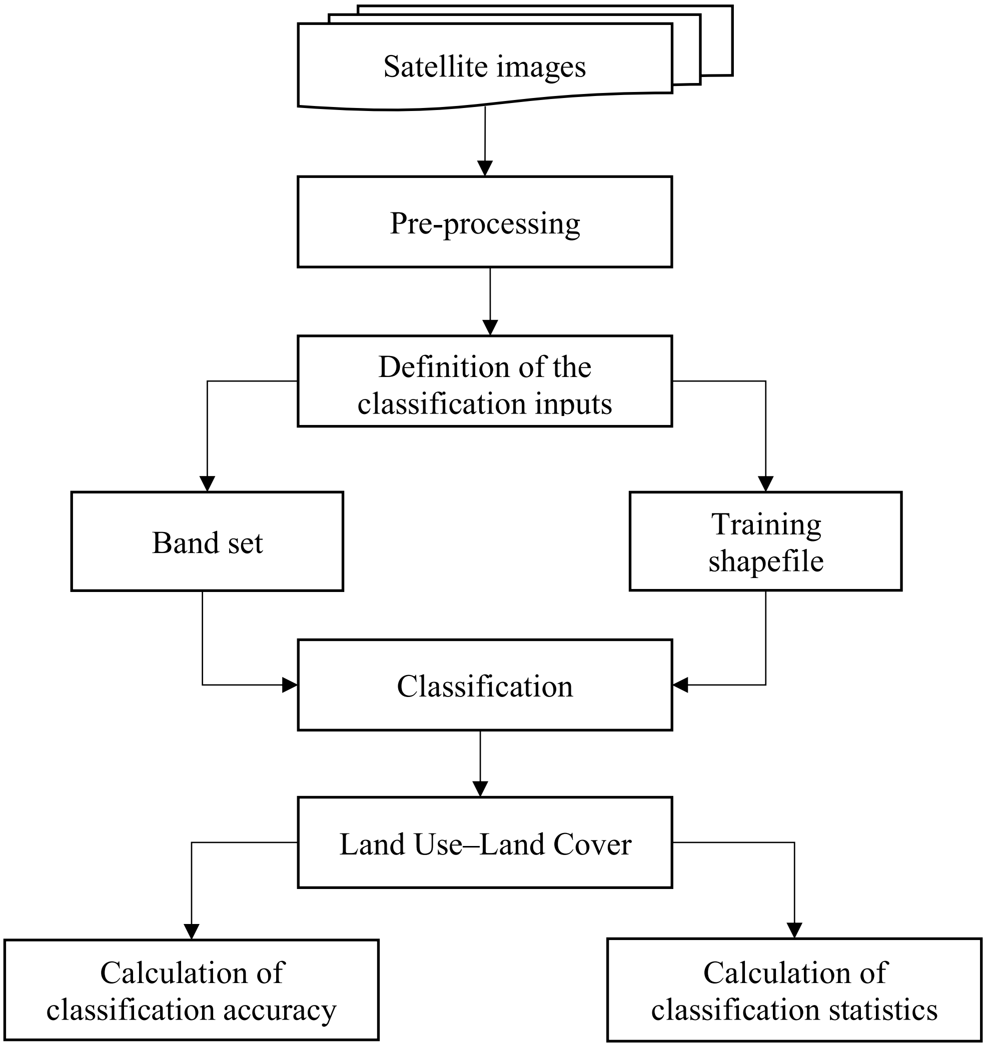


Figure 3.3: Land Use-Land Cover classification workflow for Landsat images

3.4.1. Pre-processing

To use satellite images for acquiring information, preprocessing is a crucial step to reduce the effects of topography and illumination (Ekstrand, 1996) and atmospheric attenuation (Chavez, 1996) by using pre-launch sensor coefficients (Mather, 2004; Mather & Koch, 2011).

The data used in this study contains Landsat 5 TM, Landsat 8 OLI, and Sentinel 2, which were acquired from the United States Geological Survey (USGS). Landsat 5 TM images were acquired through the Thematic Mapper (TM) sensor from July 1982 to May 2012. Landsat 8 satellite is equipped with the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) and was launched in February of 2013. The USGS has provided the surface reflectance data (Level 2 data products) of Landsat 5 and Landsat 8 through the Earth Explorer website. Landsat MTL files packaged inside Landsat images contain information about data processing and values necessary for enhancing Landsat data, which were applied through Dark Object Subtraction (DOS1) atmospheric correction method before use. The metadata files of Landsat 8 were also used to perform Pan-sharpening as well as to calculate the land surface temperature in the study area.

Sentinel-2 images have been acquired, processed, and generated by the European Space Agency (ESA). All Sentinel 2 data products are provided with Level – 1C in scaled Top of Atmosphere (TOA) reflectance by USGS. Therefore, the metadata files were used to apply DOS1 atmospheric correction before they can be used in this study.

Top of Atmosphere (TOA) Radiance

Landsat 8 images can be converted to TOA spectral radiance using the radiance rescaling factors provided in the metadata file (Landsat, 2016).

$$\mathbf{L_\lambda = M_L \times Q_{cal} + A_L} \qquad (3.4)$$

where:

- L_λ = Spectral radiance (W/(m^2 * sr * μm))
- M_L = Radiance multiplicative scaling factor for the band (RADIANCE_MULT_BAND_n from the metadata)
- A_L = Radiance additive scaling factor for the band (RADIANCE_ADD_BAND_n from the metadata).
- Q_{cal} = L1 pixel value in DN

Top of Atmosphere (TOA) Reflectance

To reduce the variability through a normalization for solar irradiance, the images in radiance are converted to reflectance(Landsat, 2016). This TOA reflectance is calculated by (3.5).

$$\boldsymbol{\rho_p = \frac{(\pi \times L_\lambda \times d^2)}{(ESUN_\lambda \times \cos\theta_s)}} \qquad (3.5)$$

where:

- L_λ = Spectral radiance at the sensor's aperture (at-satellite radiance)
- d = Earth-Sun distance in astronomical units (provided with Landsat 8 metadata file)
- $ESUN_\lambda$= Mean solar exo-atmospheric irradiances

- θ_s = Solar zenith angle in degrees, which is equal to $\theta_s = 90° - \theta_e$ where θ_e is the Sun elevation

Surface Reflectance

The disturbance of the reflectance at the ground by the atmosphere was considered (Moran et al., 1992). In which the land surface reflectance will be calculated by(3.6).

$$\rho = \frac{[\pi \times (L_\lambda - L_p) \times d^2]}{[T_v \times ((ESUN_\lambda \times \cos\theta_s \times T_z) + E_{down})]} \quad (3.6)$$

where:

- L_p is the path radiance
- T_v is the atmospheric transmittance in the viewing direction
- T_z is the atmospheric transmittance in the illumination direction
- E_{down} is the downwelling diffuse irradiance

Dark Object Subtraction Correction

The correction for Dark Object Subtraction (DOS) is based on the explanation of the complete shadow of some pixels due to atmospheric scattering (path radiance), as well as existing very few absolute black objects on the ground (Chavez, 1996). The algorithm for DOS correction is given by Sobrino et al., 2004.

$$L_p = L_{min} - L_{DO1\%} \quad (3.7)$$

where:

- $L_{min}$is the radiance obtained with that digital count value (DN_{min}) (Landsat, 2016)

$$L_{min} = M_L * DN_{min} + A_L$$

- $L_{DO1\%}$ is the radiance of Dark Object (Sobrino et al., 2004)

$$L_{DO1\%} = 0.01 * [(ESUN_\lambda * \cos\theta_s * T_z) + E_{down}] * T_v / (\pi * d^2)$$

The values of T_v, T_z, and $E_{down}$are different in each type of DOS technique, such as DOS1, DOS2, DOS3, and DOS4, in which DOS1 is the simplest technique offered (Moran et al., 1992).

- $T_v = 1$ $T_z = 1$ $E_{down} = 0$

Pan-sharpening

The panchromatic band (PAN) of Landsat 7 and Landsat 8 is used for the application of Pan sharpening methods to obtain the higher spatial resolution (15m) four multispectral bands (MS), which their original spatial resolution is 30 m. To combine MS and PAN, the Brovey Transform method was applied in the calculation (Johnson et al., 2012).

$$\mathbf{MS_{PAN}} = \frac{\mathbf{MS \times PAN}}{\mathbf{I}} \qquad (3.8)$$

where:

- I is intensity which can be calculated by different formulas for Landsat 7 and Landsat 8.
- Landsat 7: $I = \frac{(0.42 \times Blue + 0.98 \times Green + 0.6 \times Red + NIR)}{3}$
- Landsat 8: $I = \frac{(0.42 \times Blue + 0.98 \times Green + 0.6 \times Red)}{2}$

3.4.2. Supervised classification

Supervised classification, called a semi-automatic classification, is an essential technique in remote sensing to process the images for classifying the material on the ground, such as vegetation, soil, and water through the spectral signatures of the images. The method requires the users to select the Training Areas named Regions of Interest (ROIs) for each class of land use – land cover proposed by users. Then the classification algorithms that are used to calculate the spectral characteristics of ROIs and classify the whole image by comparing the spectral characteristics of each pixel to the characteristics of ROIs. There are a few popular classification algorithms, such as Minimum Distance, Maximum Likelihood, Parallelepiped, and Spectral Angle Mapping. The most common method of supervised classification is the Maximum Likelihood algorithm when the distribution of data is normalization (Ronald Eastman et al., 2009; Thenkabail et al., 2012).

Maximum Likelihood Classification

It is an algorithm related to the Bayes' theorem, which calculates the probability distributions for the classes to estimate land use-land cover type to which a pixel belongs (Richards & Jia, 2005). The algorithm requires a sufficient number of pixels for each reference region (ROI) to calculate the covariance matrix. Richards and Jia describe the Maximum Likelihood algorithm for the calculation of every pixel in 2006.

$$g_k(x)=\ln p(C_k)-\frac{1}{2}\ln\left|\sum_k\right|-\frac{1}{2}(x-y_k)^t\sum_k^{-1}(x-y_k) \quad (3.9)$$

where:

- C_k = land cover class k;
- x = spectral signature vector of an image pixel;
- $p(C_k)$ = probability that the correct class is C_k;
- $|\Sigma_k|$ = determinant of the covariance matrix of the data in class C_k;
- Σ_k^{-1}= inverse of the covariance matrix;
- y_k = spectral signature vector of class k.

3.4.3. Post-processing

Table 3.4: Error matrix for accuracy assessment in classification

Map \ Reference	Class 1	Class 2	…	Class k	Total
Class 1	$\mathbf{a_{11}}$	a_{12}	…	a_{1k}	a_{1+}
Class 2	a_{21}	$\mathbf{a_{22}}$	…	a_{2k}	a_{2+}
…	…	…	…	…	…
Class k	a_{k1}	a_{k2}	…	$\mathbf{a_{kk}}$	a_{k+}
Total	a_{+1}	a_{+2}	…	a_{+k}	n

To define the reliability level of land use-land cover classification, accuracy assessment will be performed to find and measure the errors. An error matrix in Table 3.4 is calculated and presented as a comparative table between classified information (map) and reference data (ground truth data) using sample areas (Congalton & Green, 2008).

where:

- k is the number of classes identified in the land cover classification.
- n is the total number of collected sample units.
- a_{ii} are the number of samples correctly identified, while the other items are classification error.

3.4.4. Land surface temperature

Top of Atmosphere Brightness Temperature

The data can be converted from spectral radiance to top of atmosphere brightness temperature using the thermal constants that provide in the metadata file (Landsat, 2016).

$$\mathbf{T} = \frac{\mathbf{K2}}{\mathbf{Ln}\left(\frac{\mathbf{K1}}{\mathbf{L_\lambda}}+\mathbf{1}\right)} \quad (3.10)$$

where:

- T = TOA Brightness Temperature in Kelvin.
- L_λ = Spectral radiance (Watts/(m^2 * sr * μm))
- K1 = Thermal conversion constant for the band (K1_CONSTANT_BAND_n from the metadata)
- K2 = Thermal conversion constant for the band (K2_CONSTANT_BAND_n from the metadata)

Land Surface Temperature

Top of Atmosphere Brightness Temperature can be converted to Land Surface Temperature (LST), using the following equation (Weng et al., 2004).

$$\mathbf{LST} = \frac{\mathbf{T}}{\left(\mathbf{1}+\left(\lambda\times\frac{\mathbf{T}}{\mathbf{C_2}}\right)\times\mathbf{ln}(\varepsilon)\right)} \quad (3.11)$$

where:

- λ = Wavelength of emitted radiance is listed inTable 3.5.
- $C_2 = \frac{H\times C}{S} = 14388\ \mu m\ K$
- H = Planck's constant = $6.626*10^{-34}$ Js
- S = Boltzmann constant = $1.38*10^{-23}$ J/K
- C = Velocity of light = $2.998*10^{8}$ m/s
- $\varepsilon = 0.004\times\left(\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right)^2 + 0.986$
- NDVI = Normalized Difference Vegetation Index

Table 3.5: Centre wavelength of Landsat bands

Satellite images	Band	λ (μm)
Landsat 4, 5, and 7	6	11.45
Landsat 8	10	10.8
Landsat 8	11	12

3.4.5. Visual interpolation

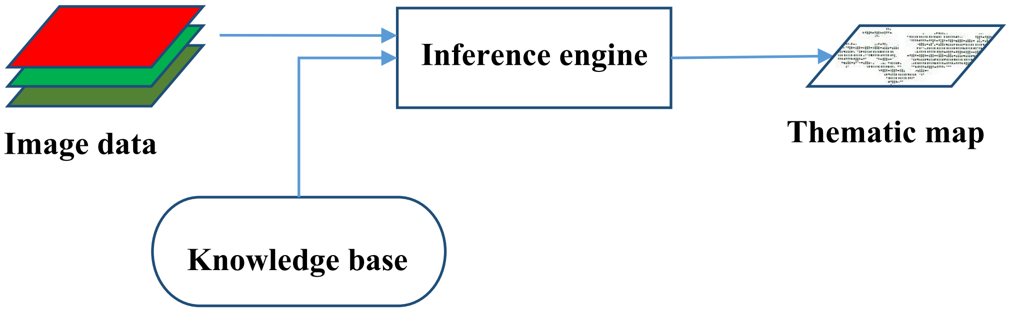


Figure 3.4: Knowledge-based image analysis system
Source: (Richards & Jia, 2005)

One of the essential characteristics of digital image data is that it can be classified by automatic information extraction or by humans through visual inspection (Richards & Jia, 2005). The visual interpolation is a method which is based on the experiences of the completed surface as well as perceptual knowledge about elements' properties of expert analysts (Lowe, 2012; Nakayama & Shimojo, 1992; Park & Nikamanon, n.d.; Richards & Jia, 2005). The method is useful for spatial assessment with high-level decisions through the inference engine, which is associatively connected between images and surfaces (Figure 3.4). Visual image interpretation techniques are usually used after the digital processing to improve the accuracy for detection and identification of land cover or other (Richards & Jia, 2005). The method was used to verify the results of digital processing. It is an essential part of this research that enables us to infer any hidden or misclassified objects.

3.4.6. Time series analysis

Time series analysis is considered a powerful tool to detect, monitor, analyze, as well as predict changes (Franklin, 2001). Application of the time series analysis by remote sensing data plays a vital role in various research fields, ranging from economics to engineering, such as land use - land cover change, climate change, forest change in seasonal and inter-annual (Bounoua et al., 2015; Dao Minh et al., 2017; Fernández-Manso et al., 2012; Franklin, 2001).

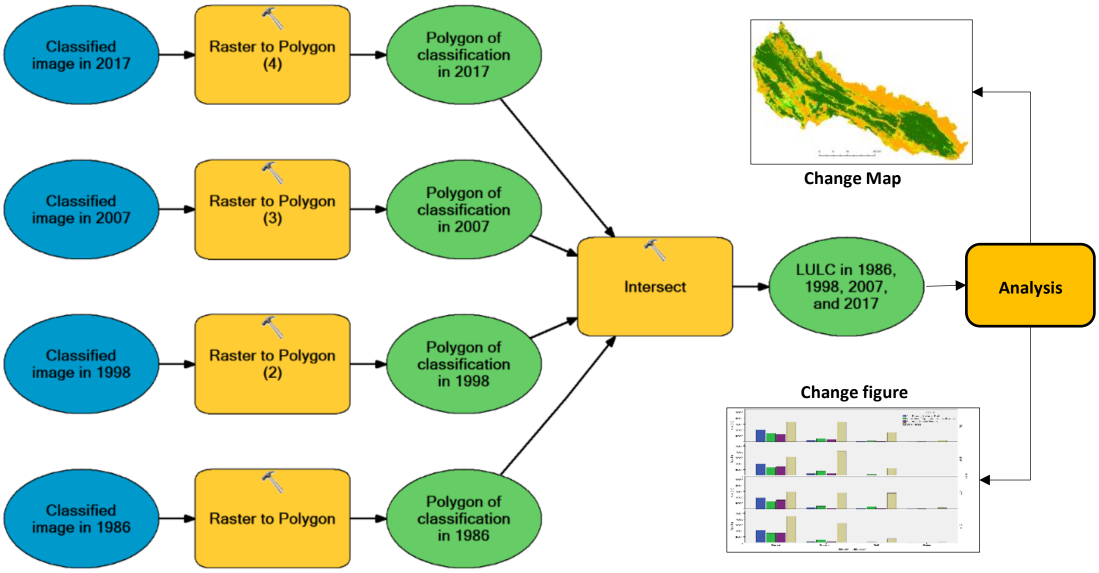


Figure 3.5: Change detection model for classified images in this study

The analysis requires data collected from different periods. The change map can be obtained through several different methods. In this study, the multi-temporal satellite images were classified with the same determined categories before they were overlaid for detecting changes (Figure 3.5).

3.5. Geography Information System

3.5.1. Data conversion

The demand for spatial data is increasing sharply by existing numerous issues as well as the rapid development of computer technology that has created the diversity of database, design, platform, and format (He et al., 2011; Montgomery & Schuch, 1993). Therefore, data conversion methodologies are particularly essential to enable the effective use of the available data from various data formats, geolocations, and scales.

Figure 3.6 illustrates the principal tasks and their relationships within the data conversion process. Data sources are in several different formats, including data files, maps, records, and field inventory, and other types of information. In the data conversion process, collected data have been converted into a standard format, and the proposed database contains the relevant data. The conversion methodology will be identified based on the original formats and the requested format as well as the designed database based on the required information of each layer in this study.

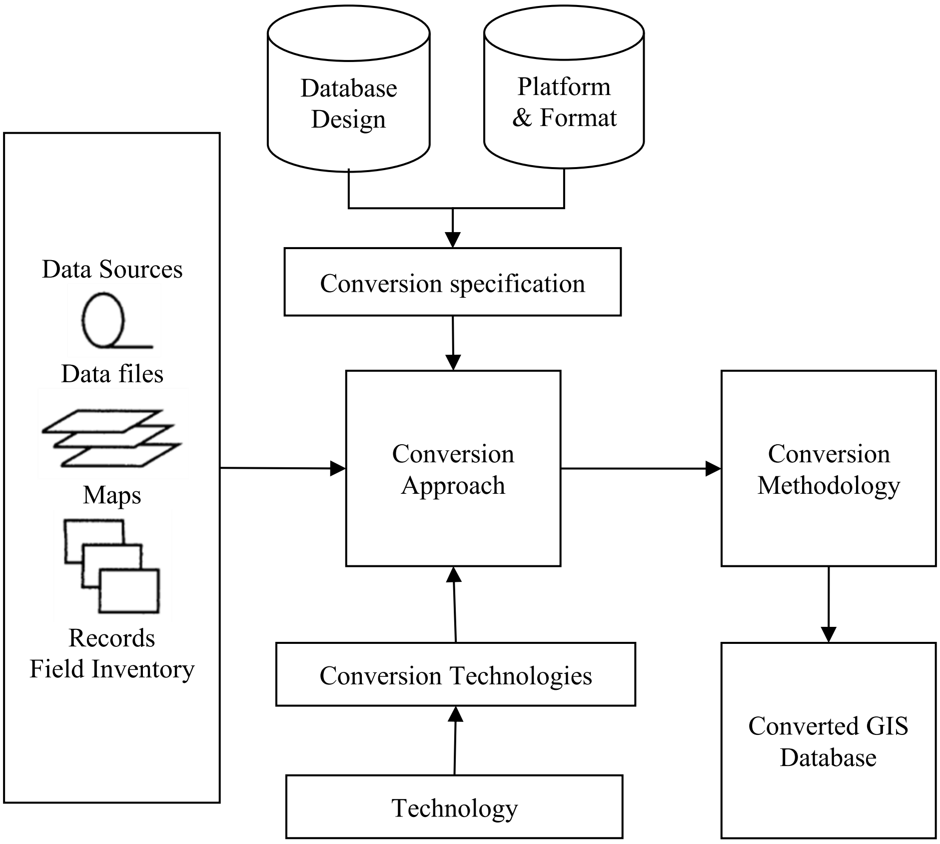


Figure 3.6: Data conversion process

(Modified from Montgomery &Schuch, 1993)

3.5.2. Overlay analysis

Overlay analysis with various layers has been the most effective application of GIS to obtain essential results (Walke at al. 2012). Assessment of the conservation suitability will require the integration of a multidisciplinary database. All collected thematic maps, which could influence biodiversity conservation, are entered into the GIS system to create a thematic database with various parameters. The biodiversity database is created from the overlay process of the defined layers. The final map of biodiversity value is achieved from the spatial overlay of factors as well as the calculation and analysis of attribute data for each intersection region in the study area (Figure 3.7).

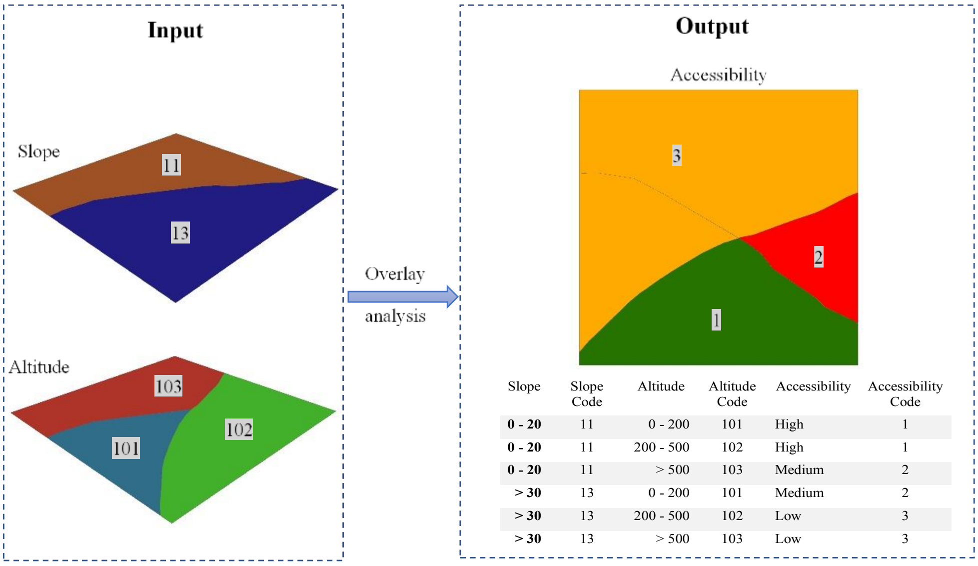


Figure 3.7: Overlay operation with spatial and attribute data
Source: (Author's work)

3.5.3. Kernel Density Estimation

Kernel Density Estimation method that is considered the most popular non-parametric method is applied to estimate the probability density function of a random variable (Scott, 2015; Simonoff, 2012; Wand & Jones, 1994). It is an essential tool in the analysis of data (Silverman, 1998; Botevet al., 2010; Dehnad, 1987; Scott, 2015).

The Kernel Density Estimator is defined as an unknown continuous probability density function (***f***) on x with n independent realizations $X_n = \{X_1, X_2, \ldots, X_n\}$ (Silverman, 2018). The formula of Kernel Density Estimator is described as followed:

$$\hat{f}_h(x) = \frac{1}{n}\sum_{i=1}^{n} K_h(x - x_i) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \quad (3.12)$$

where:

- K is the Kernel function, a non-negative function, to determine the shape of the bumps.
- h is the window width, called the bandwidth or smoothing parameter.
- X_i is location

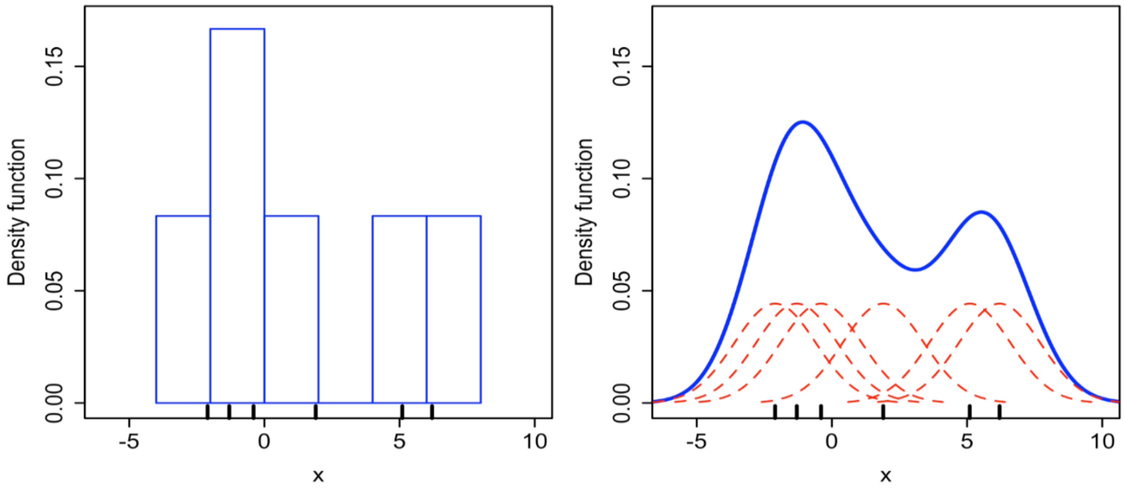
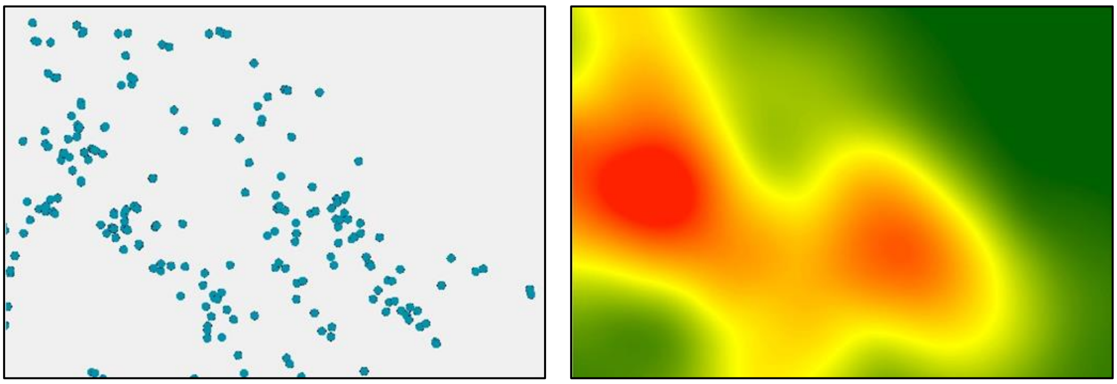


Figure 3.8: A comparison between the Histogram and Kernel Density Estimation

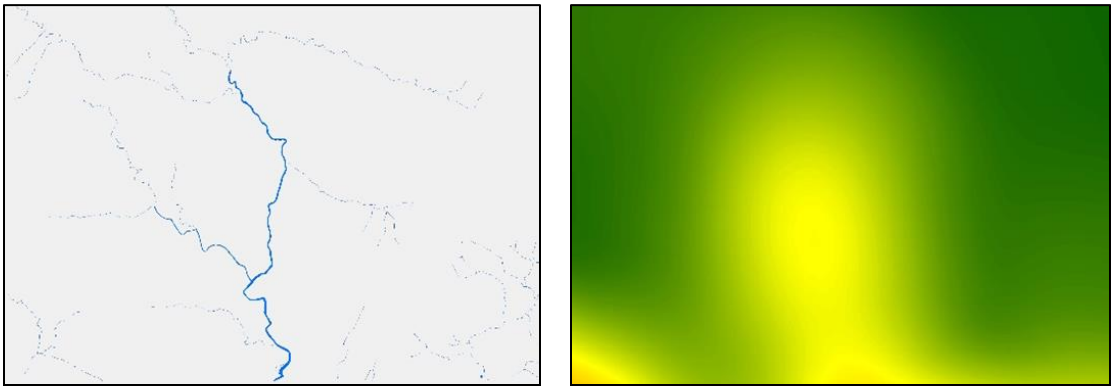
Source: (Scott, 1979)

The Kernel Density algorithm estimates the density of features in a neighborhood around those features. In Figure 3.8, the Kernel Density method can estimate the histogram closely, but its results are presented with smoothness or continuity (Scott, 1979). The GIS tools of the method have been designed to calculate for only point and line features (Figure 3.9).

In our research, the Kernel Density tool of ESRI ArcGIS 10.1 is applied to define the density of the hydrological system, points of natural disaster, population, impacts of education, and law using corresponding weights. The field supports identifying the impact levels of some features more than others.



a. Distribution of points and Kernel Density surface



b. Lines of hydrology and Kernel Density surface

Figure 3.9: Applications of Kernel Density Estimation for point and line features

Source: (Author's work)

3.5.4. Jenks Natural Breaks

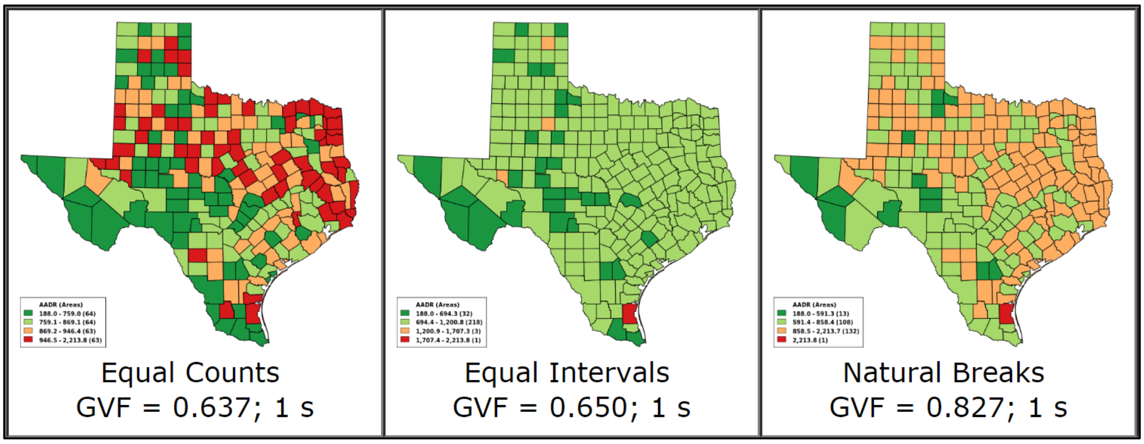


Figure 3.10: Comparison between Jenks Natural Breaks and other methods

Source: EHDP.com

The Jenks Natural Breaks classification algorithm that is also named the Jenks optimization method is used to arrange values of different categories in the best way. The method helps to decrease the variance within classes and maximize the variance between classes (Jenks, 1967). The data are divided into groups whose boundaries are determined to show where relatively significant differences in the data values exist. According to Expert Health Data Programming (EHDP.com), the Jenks Natural Breaks method can find the best way to split up the ranges. Many comparisons among Jenks Natural Breaks with other methods such as Equal Counts, and Equal Intervals with the same data were performed for a series of commonly made maps. Overall, the Jenks Natural Breaks algorithm is better in almost all the tests with the highest value of GVF

(Goodness of Variance Fit) (Figure 3.10). The method was applied to identify the best thresholds to split the ranges that groups into the different levels of priority areas or pressure areas in this study.

3.6. Climate change scenarios

Table 3.6: Regional climate models for calculating climate change scenarios

ID	Model	Developed by	Methods	Resolution (km)	Location (^{0})
1	CLWRF	Several organizations such as NCAE, NCEP, FSL, AFWA, etc.	1. NorESM1-M	30	3.5–27 N 97.5–116 E
2	PRECIS	Hadley Meteorological Centre United Kingdom	1. CNRM-CM5 2. GFDL-CM3 3. HadGEM2-ES	10	6.5–25 N 99.5–115 E
3	CCAM	Commonwealth Institute of Science and Industry Australia	1. ACCESS1-0 2. CCSM4 3. CNRM-CM5 4. GFDL-CM3 5. MPI-ESM-LR 6. NorESM1-M	20	6.5–30 N 99.5-119.5E
4	RegCM	International Centre for Theoretical Physics, Italy	1. ACCESS1-0 2. NorESM1-M	20	6.5–30 N 99.5–119.5 E
5	AGCM/ MRI	Japan Meteorological Research Institute	1. NCAR-SST 2. HadGEM2-SST 3. GFDL-SST 4. Combination of SSTs	20	Global

Source: (MONRE, 2016)

The estimated maps of climate change in Vietnam were used to identify the priority areas for biodiversity conservation in the study area. The climate change scenarios were calculated based on five Regional Climate Model (RCM). They consist of Atmosphere General Circulation Model (AGCM) developed by Japan Meteorological Research Institute; Providing Regional Climates for Impacts Studies (PRECIS) developed by Hadley Meteorological Centre of United Kingdom; Conformal-Cubic Atmospheric Model (CCAM) developed by Commonwealth Institute of Science and Industry in Australia; Regional Climate Model (RegCM) provided by International Centre for Theoretical Physics in Italy; and Weather Research And Forecasting Model (WRF) modified for Regional Climate Modelization (CLWRF). Sixteen methods for calculating the climate change scenarios in Vietnam were applied through these five models (Table 3.6).

Application of the five regional climate models with the sixteen methods helps to provide more objective information, which can increase the accuracy as well as the reliability of the estimated result (Solomon et al., 2007; Weigel et al., 2008).

Chapter 4. Establishment of criteria

The synthesized criteria were combined with the environmental Pressure-State-Response model to identify key processes that significantly impact on biodiversity conservation over time (Chanson et al., 2010; Lee et al., 2005). A detailed model to define the priority areas for protected areas in Vietnam was developed in this study based on the combination of the criteria of biodiversity conservation and the environmental Pressure-State-Response model shown in Figure 4.1.

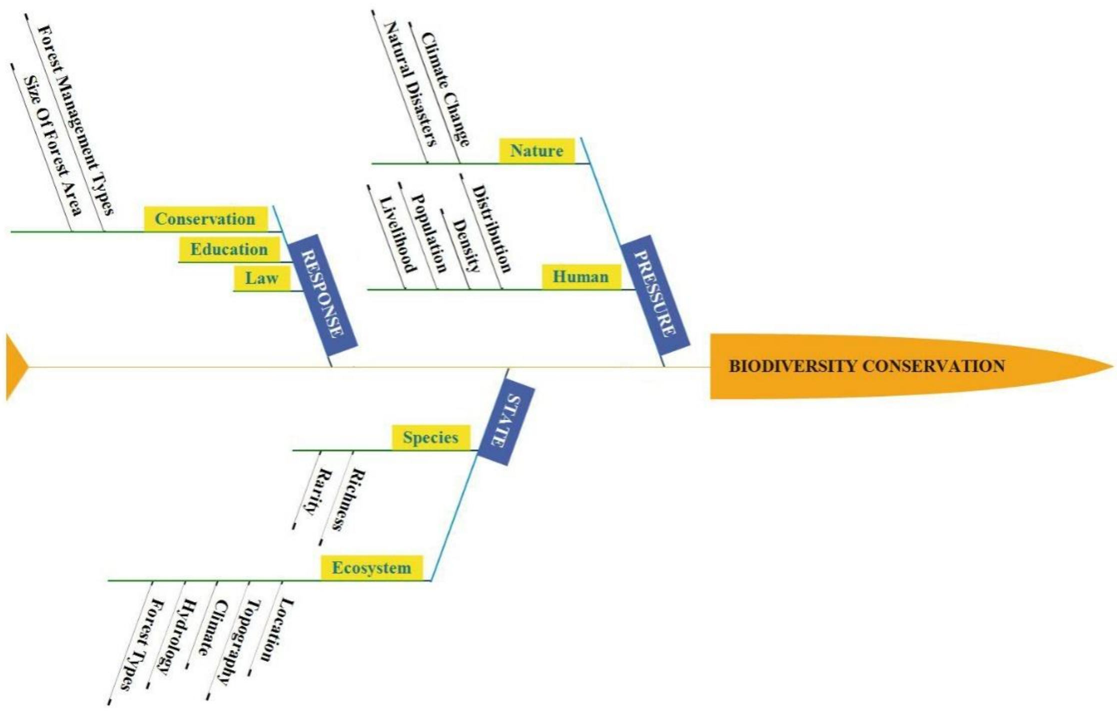


Figure 4.1. Criteria system to define priority areas for biodiversity conservation

Figure 4.1 illustrates a set of criteria to define priority areas of biodiversity conservation in Vietnam. Three main principles of the environment, including pressure, state, and response, were used to develop all criteria which have impacts on biodiversity conservation. The criteria tree of biodiversity conservation in Vietnam was formulated to illustrate the relationships and arrangements between the indicators.

A hierarchy model with four levels was established based on the Analysis Hierarchy Process (AHP) method to calculate the weight of the criteria (Figure 4.2). The first class is the main aim of this study, the evaluation of biodiversity conservation. The second class is three factors (pressure, state, and response) achieved based on the environment model. Then the third class is composed of the seven criteria (species, ecosystems, nature, human, conservation, education, and law). Finally, the fourth class is composed of 15 sub-criteria (richness; rarity; location; topography; climate; hydrology; forest types; climate change; natural disasters; distribution, density, and quantity of population; livelihood; forest management types; size of forest area).

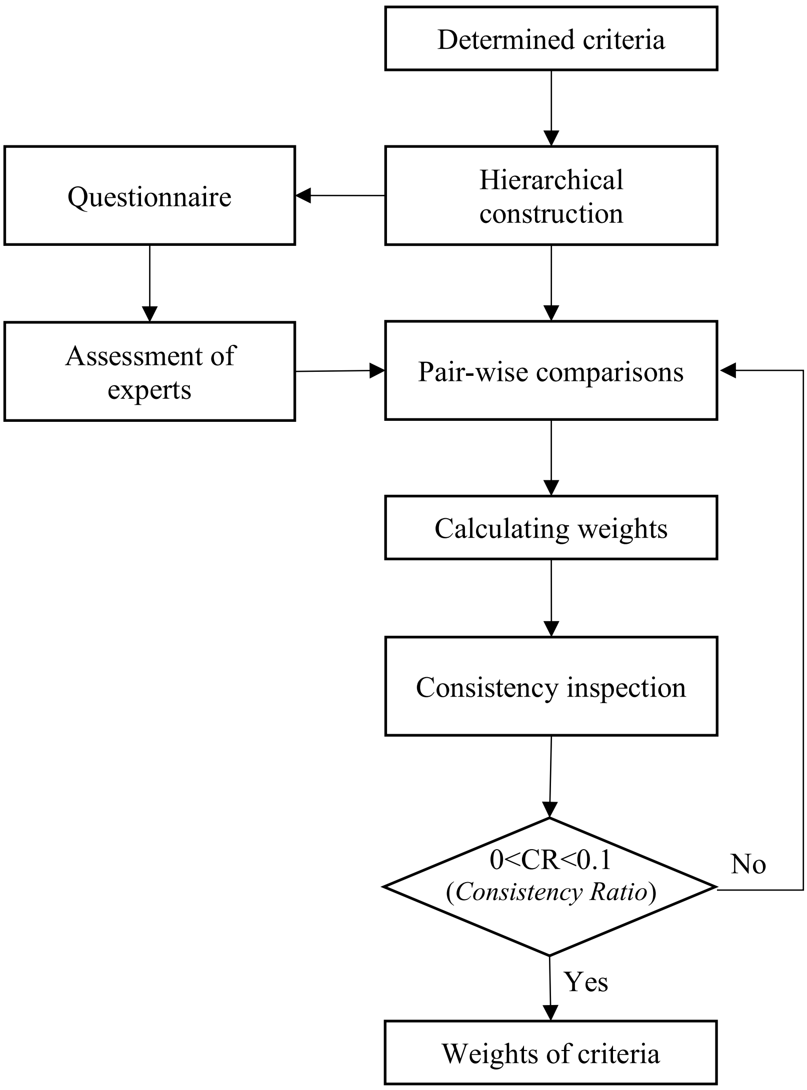


Figure 4.2. Calculating weights of criteria based on the AHP method

The response of experts achieved through the interviews was synthesized to construct a set of pair-wise comparison matrices that reflect the relative importance of the indicators within each matrix. According to the number of criteria, sub-criteria, and factors (Figure 4.1), 27 pairwise comparisons were formulated. Then the process of calculating weights and Consistency Ratio (CR) was performed. Through the consistency inspection ($0<CR<0.1$) shows the reasonable consistency of the pair-wise comparison matrix. The judgment is performed for the calculated weights of the corresponding matrix.

4.1. Summary of responses

The questionnaires were delivered to all potential respondents, and completed responses were received from 185 respondents. The range of age is from 20 years to 70 years; 53 % of respondents are older than 30 years. Of the young respondents (20 to 23 years old), 30% were last-year students of universities who have been trained deeply in biodiversity conservation and forest management. The remaining respondents are working for organizations or agencies relating to biodiversity and conservation. The number of males is double the number of females, accounting for 69% of 185 respondents. Of these respondents, 133 (69.2%) are interviewed directly, and the rest (30.8%) were interviewed indirectly via emails. They were from 37 different organizations located throughout Vietnam (Figure 4.3).

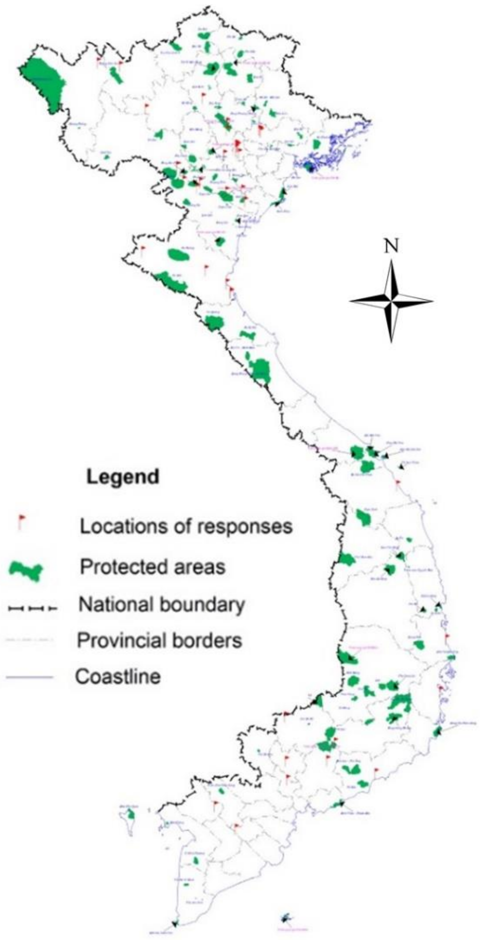


Figure 4.3. Locations of respondents

The respondents are working for various organizations, which can be grouped into five categories, including in Protected Areas, Government Organizations, NGOs, Universities and Research Institutes, and Others. Three highest response rates of 50.41%, 34.6%, and

10.26% were from Universities and Research Institutes, Protected Areas, and Government Organizations. The Vietnam National University of Forestry, Cuc Phuong National Park, Pu Luong Nature Reserve and Ngoc Son – Ngo Luong Nature Reserve were four main places with the highest rate to the questionnaire with 39.5%, 10.8%, 9.7%, and 5.4% respectively (Appendix II - Table II. 1).

Appendix II - Table II. 2 shows the assessments of 185 respondents for criteria, sub-criteria, and factors, which are divided into nine different levels. The ranges of the requirements fluctuate from 6 to 8 degrees in which "Ecosystem," "Nature" sub-criteria, and "Location" factor have the most extensive range. It points out existing various opposite opinions in assessing the importance level of three measures. Excluding the "Nature" sub-criterion with two levels of difference between mode and median are 8 and 6, respectively, the majority are close or equal between themselves. If Mode and Median results are used to identify the opinion of all respondents, it is difficult to compare among pairwise because of retaining the equilibrium of the essential levels assessed within each group of criteria.

Moreover, these values do not represent the collective opinions of respondents. The ultimate purpose of this study is to compare each pair of standard groups. The synthetic values from all responses for each criterion are not appropriate to calculate the weight set of the whole criteria system of biodiversity conservation in Vietnam. Therefore, the processing is performed through analyzing and synthesizing the attitude of all respondents, respectively, to each pairwise.

Two outlier detection methodologies were applied to find out data points of outliers in the collected data. 77 and 49 data points were showed by the interquartile range and the standard deviation, respectively. The numbers of respondents synthesized from the data points are 38 and 22, which were numbered following the number column in Appendix II - **Error! Reference source not found.**. The interquartile range showed that " Response," "Human," and "Forest type" criteria obtained the highest data points of outliers with 9, 11, and 15 respondents. On the other hand, 3 data points of outliers were the maximum number showed by the standard deviation method for "Conservation," "Hydrology," and "Climate change" criteria (Appendix II - Table II. 2). However, the most outliers calculated by the standard deviation also include the outliers of the interquartile range. The outliers consist of around half of the respondents and are students of several universities.

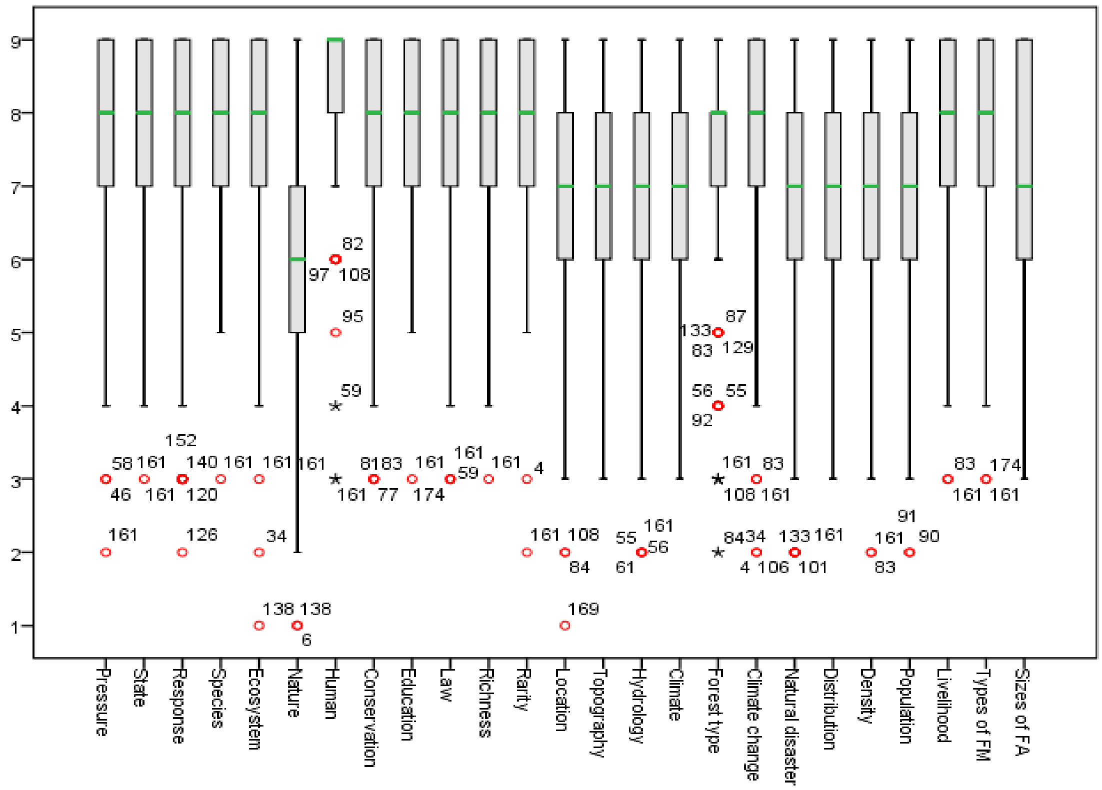


Figure 4.4. Boxplot for responding all criteria of biodiversity conservation

A visual display of data values is presented to observe and understand the whole of the interview data from the distribution, the range of each criterion to the data points of outliers (Appendix II - Table II. 3). The number of respondents was used to label outliers and extreme cases on the boxplot (Figure 4.4). Various names are shown in the figure, yet the most outliers of respondents just existed on 1 or 2 criteria, and most respondents are students indicated in Figure 4.4. Significantly, two titles, labelled more several times than other, are the number 83 and 161 in which 7 and 17 data points of outliers belonged to the corresponding respondents. The outlier points of number 83 and 161, one student and one technician respectively, calculated by both outlier detection methods are remarkably equivalent. Therefore, it needs to remove the respondents mentioned before processing the next step of the study.

4.2. Statistic of pairwise comparison

Since the 1950s, numerous methodologies of psychology named multidimensional scaling (MDS) have been studied and applied in analyzing similarity and preferential choice data. Nevertheless, the solution has not yet been found to deal with the problem of gaining the perfect-voting in multidimensionality (Poole, 2005). The Condorcet Winner considered as majority rule games choose the winner, which is preferred in every one-to-one comparison with the other choices (Poole et al., 2000).

As shown in the heading of the questionnaire, the data of the pairwise comparison was not gathered directly. The pairwise value was calculated by comparing two criteria in one pairwise of each respondent and synthesizing as in Appendix II - Table II. 3. The scale of integers ranging from 1 to 9 is applied to assess their importance levels (Saaty, 1980; Saaty & Vargas, 1991). For example, A and B are two criteria in one pairwise comparison. It includes three possible situations; they are A higher than B (A>B), A equal to B (A=B), and A less than B (A<B). The intensity of importance is 1 represented for the second case (A=B). Consequently, each pairwise can be presented by 8 cases of A>B, one case of A=B, and 8 cases of A<B (Appendix II - Table II. 3).

The number of pairwise comparisons was synthesized for each pairwise from all the respondents (183 people after removing 2 cases of outliers). Twenty-seven pairwise comparisons and 17 instances of themselves are described entirely in Appendix II - Table II. 3. According to majority rule (Condorcet Winner), the total of respondents selecting the same situation of A>B, A=B, and A<B for each pairwise comparison was calculated to compare together.

The acceptable risk was demonstrated in the formula of error estimation from Cochran in 1977. The chance is commonly called the margin of error, which has been used by researchers as the limit for willingness to accept (Cochran, 1977). The acceptable margin of error is 5% and 3% for categorical data and continuous data, respectively (Krejcie & Morgan, 1970). The appropriate precision for prevalence researches is 5% by experience (Bartlett et al., 2001; Mandallaz, 2008; Naing et al., 2006). This percentage of difference (PD) is used to show the reliability of comparison among the number of respondents who chose A>B, A=B, or A<B. The rules were used to identify the appropriate level of one pairwise comparison as following:

- 5% of the difference was used to select the majority to belong to A>B, A=B, or A<B.
- If the number of A>B and A<B is similar or higher than under 5% out of total respondents, the situation of A=B is the priority option.
- If the highest number of three situations (A>B, A=B, and A<B) are higher than others above 5% out of total respondents, this situation is the opinion of the majority.

- The case of the statistical model is used in this situation, A>B or A<B accounts for the majority.
- If the number of A>B is similar to the A<B, and they are more significant than the A=B. Such A and B have equal importance. The situation of A=B is the collective opinion of all respondents.
- If one of A>B or A<B is less than the A=B, and another is similar to the A=B. The trend of majority opinions inclines to the number identical to the A=B.

Appendix II - Table II. 3 shows 27 pairwise comparisons corresponding to the criteria system. A and B represented two criteria in each pairwise comparison. Three situations of A>B, A=B, and A<B were calculated about the total number of respondents. Various pairwise comparisons obtained the amounts existing the significant difference among of three situations such as Nature - Human, Location - Hydrology, Location - Forest Type, Topography - Forest Type, Hydrology - Forest Type, Climate Change – Nature Disaster, Distribution – Livelihood, Density – Population, Density – Livelihood, Forest Management Types – Size of Forest Area. The rest gained the quantities are similar to three situations, the PD value was used to judge which one is greater or they are equal together.

The critical levels of two criteria are alike within seven pairwise comparisons, including State – Response, Species - Ecosystem, Conservation - Law, Education - Law, Hydrology - Climate, Distribution - Density, Density – Population. Most respondents chose the case of A=B in comparison to A>B and A<B. Besides, it points out a unique case of pairwise comparisons that obtained a similar number of respondents that chose the situations of A=B and A<B. It is the pairwise comparison of distribution and quantity with the same amount of responses accounting for 37% of the situations and 26% of the rest (A>B). It can be seen that the trend of the majority is tilted towards the status of A<B.

4.3. Weights of criteria based on all respondents

4.3.1. Factors

The cases of A>B and A<B in the pairwise comparisons between “Sate” and “Response” as well as “Pressure” and “Response” are quite similar with 2% of the difference (32% and 30%; 33% and 35% respectively). It showed the equalization in the pairwise comparisons. In contrast, the comparison of “State” and “Pressure” existed the slope, which bent to pressure with 38% of respondents choosing this. The first different level of A<B accounts for 24% of all responses. Therefore, the value for “State” and “Pressure” pairwise

comparison is 1/2 to establish the pairwise comparison matrix (Table 4.1) of three factors for defining the priority areas of biodiversity conservation in Vietnam.

Table 4.1. Pairwise comparison of factors

	State	Pressure	Response
State	1.00	0.50	1.00
Pressure	2.00	1.00	1.00
Response	1.00	1.00	1.00
Sum	**4.00**	**2.50**	**3.00**

Table 4.2: Standardized matrix of factors

	State	Pressure	Response	Weight
State	0.25	0.20	0.33	**26%**
Pressure	0.50	0.40	0.33	**41%**
Response	0.25	0.40	0.33	**33%**
Sum	**1.00**	**1.00**	**1.00**	**100%**

The value of each cell in a pairwise comparison matrix of Table 4.1 was used to calculate the standardized matrix of criteria. The matrix includes the weight column, which shows the weight of "State," "Pressure," and "Response" factors with 26%, 41%, and 33%, respectively (Table 4.2).

Table 4.3: Consistency test of factors

Compositions	Values
n	3
RI	0.520
λ	3.054
CI	0.027
CR	0.052
Consistency	**Yes**

These weights were combined with the pairwise comparison matrix to calculate the average of the elements of the consistency vector ($\lambda = 3.054$). The number of factors used in the pairwise comparison matrix in Table 4.1 is 3. Hence the average Random Index found in Table 4.3 is 0.520. Then, two formulas (3.2) and (3.3) are used to calculate the Consistency Ratio (CR). The derived value is 0.052 less than 0.1 of the consistent ranking (Table 4.3). Therefore, it results in the pairwise comparison matrix of the criteria being entirely consistent, and the weights in Table 4.2 can be used.

4.3.2. Criteria

4.3.2.1. State

"Species" and "Ecosystem" criteria are two elements that are under the "State" factor. One pairwise comparison between "Species" and "Ecosystem" was established and synthesized from all the respondents to calculate the weight of them. Although the situation of A=B accounted for 38% just higher 2% than A<B with 36%, it did not reach the acceptable margin (5%) to select the situation of A=B as the majority of opinions. It means that "Species" and "Ecosystem" criteria were not equal in the level of importance. The first level of difference was selected with the situation of A<B. The pairwise comparison matrix for the criteria is illustrated in Table 4.4.

Table 4.4: Pairwise comparison of criteria of state

	Species	**Ecosystem**
Species	1.00	0.50
Ecosystem	2.00	1.00
Sum	**3.00**	**1.50**

Table 4.5: Standardized matrix of criteria of state

	Species	**Ecosystem**	**Weight**
Species	0.33	0.33	**33%**
Ecosystem	0.67	0.67	**67%**
Sum	**1.00**	**1.00**	**100%**

The results of the weights are 33% and 67% for "Species" and "Ecosystem" that belong to the "State" factor (Table 4.5). Besides, the calculation of the Consistency Ratio was not necessary for the matrix with just one pairwise comparison.

4.3.2.2. Pressure

The "Pressure" factor of biodiversity conservation identified with two criteria: "Nature" and "Human." The result of the consultation was evident with many respondents (83%) choosing the "Human" criterion as the essential element in the "Pressure" factor. However, the numbers of responses for the critical levels of 1/2, 1/3, 1/4, and 1/5 were reasonably parallel with 22%, 14%, 19%, and 13%, respectively. To represent the majority of respondents, the level of 1/3 was an optimal choice in this condition. The pairwise comparison matrix is established, as shown in Table 4.6.

Table 4.6: Pairwise comparison of sub-criteria of pressure

	Nature	Human
Nature	1.00	0.33
Human	3.00	1.00
Sum	**4.00**	**1.33**

Table 4.7: Standardized matrix of sub-criteria of pressure

	Nature	Human	Weight
Nature	0.25	0.25	**25%**
Human	0.75	0.75	**75%**
Sum	**1.00**	**1.00**	**100%**

The results in Table 4.7 show that the importance of the "Human" sub-criterion is higher three times than the "Nature" sub-criterion with just 25% of the weight. The calculation of the Consistency Ratio is not necessary for the comparison matrix with only one pairwise comparison between "Nature" and "Human."

4.3.2.3. Response

Three criteria, including "Conservation," "Education," and "Law" were identified as the main elements of the "Response" criterion. They created three corresponding pairwise comparisons, which are shown in Table 4.8. Two pairwise comparisons of "Conservation

– Law” and “Education – Law” achieved the same of the most responses in a situation of A=B with 44% and 48% respectively, while the comparison between “Conservation” and “Law” was the majority in the situation of A<B. The position of the pairwise comparison is 1/2, accounting for the majority of A<B situation with 22%.

Table 4.8: Pairwise comparison of sub-criteria of response

	Conservation	**Education**	**Law**
Conservation	1.00	0.50	1.00
Education	2.00	1.00	1.00
Law	1.00	1.00	1.00
Sum	**4.00**	**2.50**	**3.00**

Table 4.9: Standardized matrix of sub-criteria of response

	Conservation	**Education**	**Law**	**Weight**
Conservation	0.25	0.20	0.33	**26%**
Education	0.50	0.40	0.33	**41%**
Law	0.25	0.40	0.33	**33%**
Sum	**1.00**	**1.00**	**1.00**	**100%**

The pairwise comparison matrix is established, according to Table 4.8, 26%, 41%, and 33% are the weights of “Conservation,” “Education,” and “Law” sub-criteria calculated from the standardized matrix in Table 4.9.

Table 4.10: Consistency test of sub-criteria of response

Compositions	**Values**
n	3
RI	0.520
λ	3.054
CI	0.027
CR	0.052
Consistency	**Yes**

The average Random Index is 0.520, shown in Table 3.3, with three criteria used. The consistency vector was calculated for identifying the average (λ) of the elements of its self. The average gained was 3.054. The results of processing consistency were 0.027 and 0.052 for the Consistency Index (CI) and Consistency Ratio (CR), respectively. The value of the Consistency Ratio was less than 0.1 of the consistency limit. Therefore, it results in the pairwise comparison matrix of the criteria being entirely consistent, and the weights in Table 4.9 can be used.

4.3.3. Sub-criteria

4.3.3.1. Species

The situation (A<B) reached 40% in a pairwise comparison between "Richness" and "Rarity" sub-criteria. 12% and 8% are the different values higher than the situations of A>B and A=B, respectively. The A<B situation received the highest responses in the first level of moderate importance, with 22%. Thus, the pairwise comparison matrix between "Richness" and "Rarity" is presented in Table 4.11.

Table 4.11: Pairwise comparison of factors of species

	Richness	**Rarity**
Richness	1.00	0.50
Rarity	2.00	1.00
Sum	**3.00**	**1.50**

Error! Not a valid bookmark self-reference. shows that the "Rarity" sub-criterion was moderately more critical than the "Richness" sub-criterion in the "Species" criterion. The values of weights were 33% of "Richness" and 67% of "Rarity". The calculation of the Consistency Ratio was not necessary for the comparison matrix with just two sub-criteria, including "Richness" and "Rarity."

Table 4.12: Standardized matrix of factors of species

	Richness	**Rarity**	**Weight**
Richness	0.33	0.33	**33%**
Rarity	0.67	0.67	**67%**
Sum	**1.00**	**1.00**	**100%**

4.3.3.2. Ecosystem

Five main elements of "Location," "Topography," "Hydrology," "Climate," and "Forest type" are represented in the "Ecosystem" criterion. The pairwise comparisons among them were calculated to identify the importance levels for the "Ecosystem". Seven out of ten comparisons obtained the clear difference among three situations of A>B, A=B, and A<B such as "Location – Topography," "Location – Hydrology," "Location – Climate," "Location – Forest type," "Topography – Forest type," "Hydrology – Forest type," and "Climate – Forest type." "Location" and "Forest type" factors were reasonably different from each other and other sub-criteria. The rest of pairwise comparisons have the parallel numbers between two out of three situations consisting of "Topography – Hydrology," "Topography – Climate," and "Hydrology – Climate."

Table 4.13: Pairwise comparison of sub-criteria of ecosystem

	Location	**Topography**	**Hydrology**	**Climate**	**Forest type**
Location	1.00	0.50	2.00	0.50	0.50
Topography	2.00	1.00	2.00	1.00	0.50
Hydrology	0.50	0.50	1.00	0.50	0.33
Climate	2.00	1.00	2.00	1.00	0.50
Forest type	2.00	2.00	3.00	2.00	1.00
Sum	**7.50**	**5.00**	**10.00**	**5.00**	**2.83**

In most comparisons, it is clear to judge the importance level for each pairwise comparison. Although the "Forest type" sub-criterion was moderately more important than "Hydrology," the numbers of respondents at the first level (1/2) and the second (1/3) were the same with 23% and 20% respectively. However, in the majority method, the second level (1/3) was more appropriate for all respondents. The pairwise comparison matrix of the factors for "Ecosystem" is described in Table 4.13.

The standardized matrix was created from the pairwise comparison matrix to calculate the weights of the all sub-criteria of the "Ecosystem" criterion that is shown in Table 4.14. There are three groups of weights. The lowest one includes "Location" and "Hydrology" sub-criteria with 14% and 10%, respectively. The medium group consists of "Topology" and "Climate" with the same percentage (21%). The "Forest type" was in the highest group gained more concentrate than others with 34%, nearly more two times than the lowest group.

Table 4.14: Standardized matrix of sub-criteria of ecosystem

	Location	Topography	Hydrology	Climate	Forest type	Weight
Location	0.13	0.10	0.20	0.10	0.18	**14%**
Topography	0.27	0.20	0.20	0.20	0.18	**21%**
Hydrology	0.07	0.10	0.10	0.10	0.12	**10%**
Climate	0.27	0.20	0.20	0.20	0.18	**21%**
Forest type	0.27	0.40	0.30	0.40	0.35	**34%**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

The number of elements (n) creating the pairwise comparison matrix was 5. Thus the average Random Index (RI) in Table 3.3 was 1.11. The consistency vector was constructed to identify the average (λ = 5.088) of the elements.

Table 4.15: Consistency test of sub-criteria of ecosystem

Compositions	Values
n	5
RI	1.110
λ	5.088
CI	0.022
CR	0.020
Consistency	**Yes**

The equations of AHP were used to gain the Consistency Ratio (CR). It was 2% less than 10% of the consistency condition (Table 4.15). It showed that the results of processing AHP were consistent.

4.3.3.3. Nature

The "Nature" criterion impacts biodiversity conservation by two sub-criteria, "Climate change" and "Nature disaster". 55% of respondents identified the vital role of the “Climate change” sub-criterion more than “Nature disaster.” The first level (2) and second level (3) of the situation (A>B) were quite similar to 21% and 18% respectively, the opinion of the most respondents belonged to the second one. Therefore, the pairwise comparison matrix of “Climate change” and “Natural disaster” factors was presented in Table 4.16.

Table 4.16: Pairwise comparison of factors of nature

	Climate change	**Natural disaster**
Climate change	1.00	3.00
Natural disaster	0.33	1.00
Sum	**1.33**	**4.00**

The results of weights in **Error! Not a valid bookmark self-reference.** presented the most critical sub-criterion of the “Nature” criterion that was “Climate change” with 75% of weight more significant three times than “Natural disaster”. The number of criteria creates the pairwise comparison matrix in Table 4.16 was 2. Thus, the calculation of the Consistency Ratio (CR) was unnecessary.

Table 4.17: Standardized matrix of factors of nature

	Climate change	**Natural disaster**	**Weight**
Climate change	0.75	0.75	**75%**
Natural disaster	0.25	0.25	**25%**
Sum	**1.00**	**1.00**	**100%**

4.3.3.4. Human

The pairwise comparison matrix of the “Human” sub-criterion included six assessments among four factors, such as “Distribution,” “Density,” “Population,” and “Livelihood.” Five evaluations of “Distribution – Density,” “Distribution – Livelihood,” “Density – Population,” “Density – Livelihood,” and “Population – Livelihood” were quite evident with 9%, 25%, 33%, 39%, and 39% respectively.

The pairwise comparison of "Distribution – Population" was unique, with the same percentage (37%) of respondents choosing equal importance. "Distribution" was less important than "Density." The appropriate level of each comparison was determined by majority rule (Condorcet Winner), and the results are presented in Table 4.18. The pairwise comparison matrix was standardized to achieve the weights of the entire sub-criteria of the "Human" criterion. While the "Distribution" sub-criterion was the least important with 15%, "Livelihood" accounts for 43% and stays at the top. The same weights belong to "Density" and "Population" sub-criteria with 19% and 23%, respectively (Table 4.19).

Table 4.18: Pairwise comparison of factors of human

	Distribution	**Density**	**Population**	**Livelihood**
Distribution	1.00	1.00	0.50	0.33
Density	1.00	1.00	1.00	0.50
Population	2.00	1.00	1.00	0.50
Livelihood	3.00	2.00	2.00	1.00
Sum	**7.00**	**5.00**	**4.50**	**2.30**

Table 4.19: Standardized matrix of factors of human

	Distribution	**Density**	**Population**	**Livelihood**	**Weight**
Distribution	0.14	0.20	0.11	0.14	**15%**
Density	0.14	0.20	0.22	0.21	**19%**
Population	0.29	0.20	0.22	0.21	**23%**
Livelihood	0.43	0.40	0.44	0.43	**43%**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

The average Random Index (RI) was 0.890, found in Table 3.3, with four factors participated. The Consistency Index (CI) was 0.015, then the value calculated for the Consistency Ratio (CR) was 0.017 (Table 5.20). It demonstrated that the pairwise comparison matrix of the sub-criterion of the "Human" criterion was consistent.

Table 4.20: Consistency test of factors of human

Compositions	Values
n	4
RI	0.890
λ	4.046
CI	0.015
CR	0.017
Consistency	**Yes**

4.3.3.5. Conservation

There are two sub-criteria regarding the "Conservation" criterion that comprise "Forest management types" and "Size of forest area." To assess the role of these sub-criteria in "Conservation," a pairwise comparison between the two sub-criteria was used. The synthesized result in Appendix II - Table II. 3 pointed out that "Forest management types" sub-criterion, accounting for 41%, was more important than "Size of forest area," with 29% of the responses from interviewees. "Forest management types" (19%) was considered more important than "Size of forest area" (15%). The difference was just 4%. Thus the opinion majority stays at the second level (3). The values are presented in Table 4.21.

Table 4.21: Pairwise comparison of factors of conservation

	Forest management types	Size of forest area
Forest management types	1.00	3.00
Size of forest area	0.33	1.00
Sum	**1.33**	**4.00**

Table 4.22: Standardized matrix of factors of conservation

	Forest management types	Size of forest area	Weight
Forest management types	0.75	0.75	**75%**
Size of forest area	0.25	0.25	**25%**
Sum	**1.00**	**1.00**	**100%**

The results of weight of "Forest management types" and "Size of forest area" sub-criteria were 75% and 25%, respectively, that are illustrated in Table 4.22. The number of criteria in the pairwise comparison matrix was two. Thus, the calculation of the Consistency Ratio (CR) was unnecessary.

4.3.4. Weights of criteria

The weights of the factors, criteria, and sub-criteria for identifying the priority areas of biodiversity conservation in Vietnam were calculated using data from respondents. The values of the Consistency Ratio (CR) of the pairwise comparison matrices were lower than Consistency Ranking (10%). Thus, the matrices were consistent, and the calculated weights were appropriate to use. The assignment of percent values of factors, criteria, and sub-criteria were computed and showed in Figure 4.5.

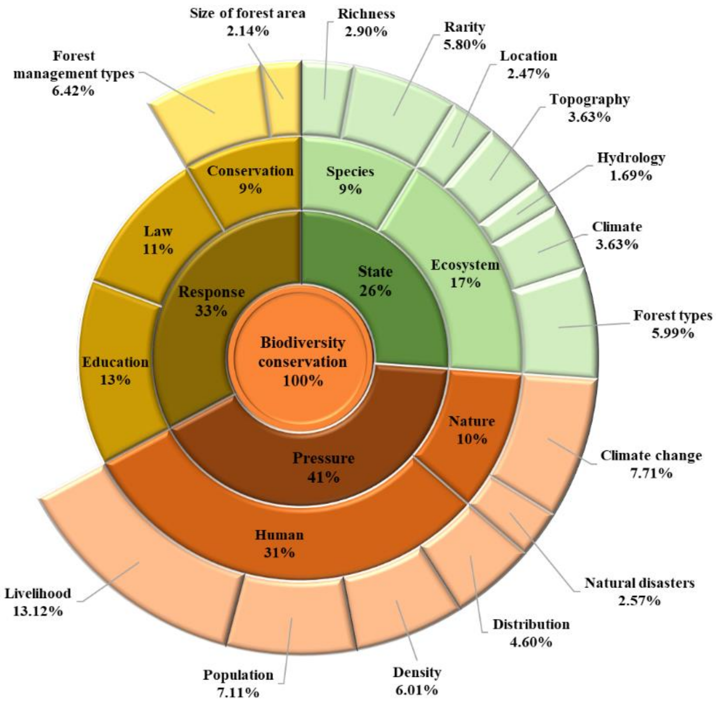


Figure 4.5: Weights of criteria based on all respondents for identifying priority areas of biodiversity conservation in Vietnam

Figure 4.5 illustrates the assignment of four levels of criteria system in this study. The first level, in the center of the figure, is the ultimate purpose (100%) of assessing the influences of the criteria on biodiversity conservation in Vietnam. The second level is three factors that used the environmental model to measure biodiversity conservation. The factors account for 26%, 41%, and 33% of "State," "Pressure," and "Response," respectively. The third level demonstrates a massive difference among seven criteria, with

31% of "Human," then it is 17% of "Ecosystem," the rest is distributed relatively similar. Except for "Education" and "Law" (24%), the fourth level illustrates 15 sub-criteria of five sub-criteria. The "Livelihood" sub-criterion is highest with 13.12%. The mediate group consists of "Forest management types," "Rarity," "Forest types," "Climate change," "Density," and "Population," fluctuating from 5.8% to 7. 71% while the rest of eight of 15 sub-criteria accounts for 23.84%.

4.4. Weights of criteria based on groups

Beside the data of all respondents, the calculation of weights for the groups was considered as an essential task. It helped provide an overview to understand the difference between each group about the importance levels of the criteria to define priority areas for biodiversity conservation in Vietnam. The respondents were classified according to their agencies into five groups, including Government Organizations, Protected Areas, Universities and Research Institutes, NGOs, and Other Companies (Appendix II - Table II. 1). Two groups of NGOs and Other Companies comprised around 2.5%. Therefore, the assessment of the groups is only performed for Government Organizations, Protected Areas, Universities, and Research Institutes with 10.26%, 34.59%, and 50.41%, respectively. The processed data for each group are presented in appendix II.

4.4.1. Protected Areas group

The respondents who are working at protected areas (PAs) are important elements of the national survey. Their opinions and experiences help to assess precisely role of the criteria set in biodiversity conservation. The respondents of PAs, located mostly in the North of Vietnam, account for 34.59% of the total of 51 respondents (26.27%) were interviewed directly (Appendix II - Table II. 1).

The data of respondents from PAs were filtered separately to calculate the weights of the entire presented criteria in the questionnaire. The consistent tests were applied to the pairwise comparison matrices. The weights were synthesized and described in detail, as shown in figure 4.6. It can be seen that almost all the distribution of weights in PAs is relatively similar to the distribution calculated by the respondents. Exceptionally, the "Richness" and "Rarity" sub-criteria obtained the same percentage (50%) for each instead of 33% and 67% in synthesizing all respondents, respectively (appendix II).

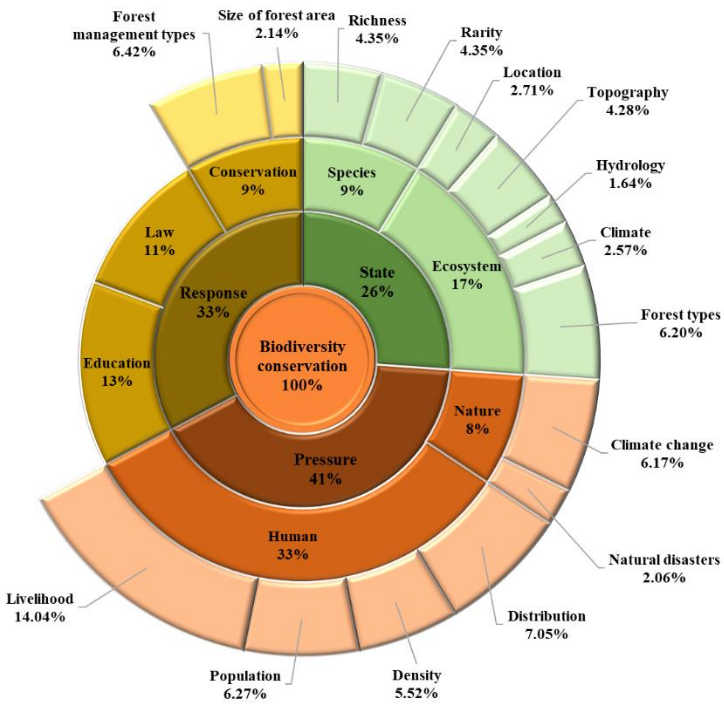


Figure 4.6: Weights of criteria based on Protected Areas group for identifying the priority areas of biodiversity conservation in Vietnam

4.4.2. Government Organizations group

Government Organizations represent the state to implement the laws and the policies of the country. Although the group only accounts for 10.26% of the total number of respondents, they represent the opinion of the Vietnam Government. Notably, the respondents from government agencies of forestry, including Forest Protection Department and Forest Protection Station, which fulfil the tasks of investigation, monitoring, and management of forests in the local regions accounted for 7.56% (14 respondents). The data of the Government Organization group is synthesized to calculate the weights for its criteria (Figure 4.7).

The pairwise comparison matrices were shown to be consistent when they passed the consistency test with a Consistency Ratio (CR) lower than 10%. The results show a pretty similarity to the Protected Areas group as well as the result of all the respondents in the second level. The sub-criteria in the third level assessed are reasonably different. The distribution of weight among “Education,” “Law,” and “Conservation” changed. The biodiversity conservation by “Law” is the most important accounting for nearly 50% of weight, while the results of other groups, as well as the result of all the respondents, show that most of their consideration focused on “Education” sub-criterion (appendix II).

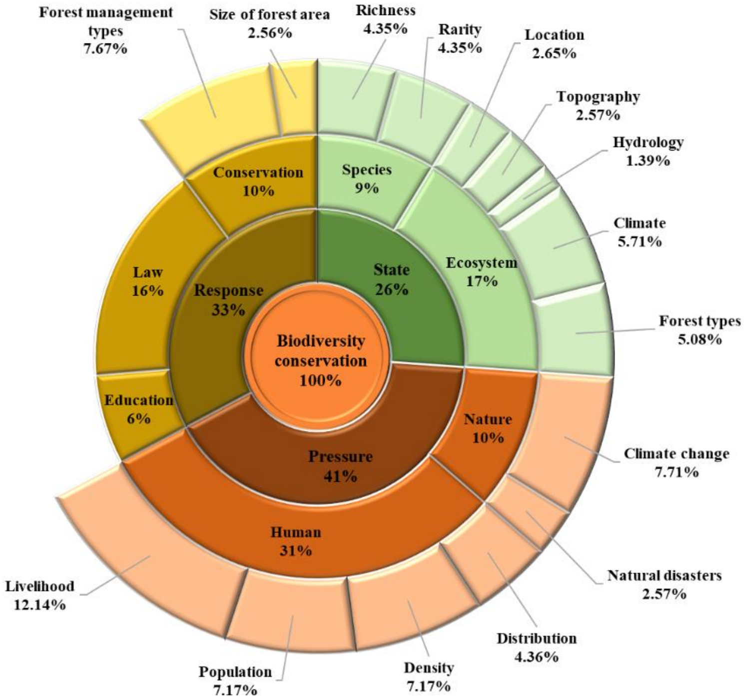


Figure 4.7: Weights of criteria based on Government Organization group for identifying the priority areas of biodiversity conservation in Vietnam

4.4.3. Universities and Research Institutes group

The group with the highest response rate is the Universities and Research Institutes (URIs) group, with 50.41%. It includes six universities, five research institutes, and four research centers (Appendix II - Table II. 1). The Vietnam National University of Forestry (VNUF) had a 39.46% response rate; all the respondents were questioned directly. The VNUF is one of the best universities on forestry in Vietnam and has trained numerous officers and employees in various fields of forestry such as silviculture, forest protection, biodiversity conservation, forest planning and inventory, and forest economy. Therefore, the consultation of professors, scientists, researchers, lecturers, and students in the university is significantly important to assess the criteria for biodiversity conservation in Vietnam.

The pairwise comparison matrices are established by the data from 92 respondents of the URIs group (49.86% of the total number of respondents). The Consistency Ratio (CR) is used to check the consistency of the matrices. All the pairwise comparison matrices obtained the accepted consistency tests appropriate to the standard of Consistency Radio (10%). The weight set calculated by the respondents of universities and research institutes is presented in figure 4.8.

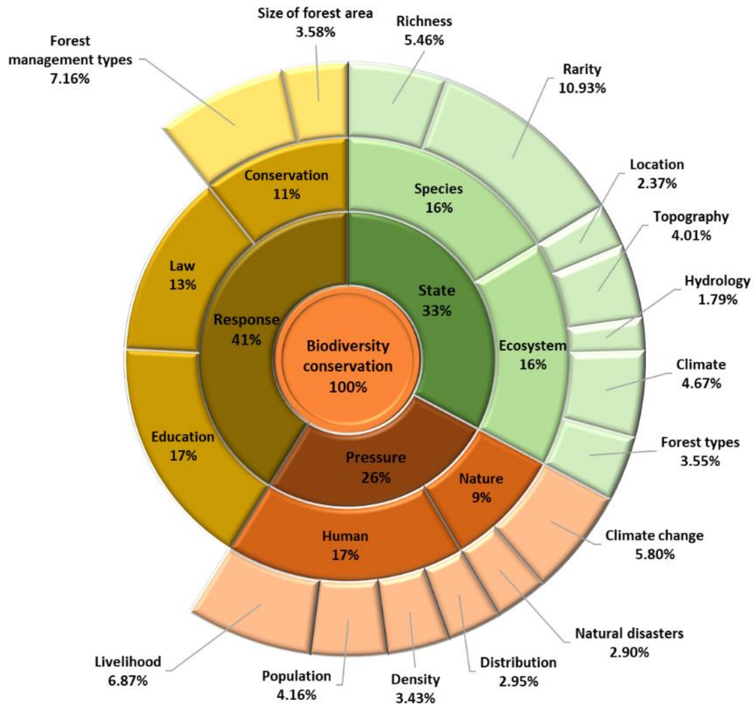


Figure 4.8: Weights of criteria based on the Universities and Research Institutes group for identifying the priority areas of biodiversity conservation in Vietnam

There is a significant change in the assignment of the weights when it is compared with the case of all respondents. In the second level, the "Response" factor has 41% of weight replacing "Pressure" as the top criteria and, in fact, pushed it to bottom with 26% of the weight. The third level witnesses the adjustment of the ratio between "Species" and "Ecosystem" when they are equal in the importance level instead of the "Ecosystem" criterion is assessed as more critical than "Species" with all respondents. The ratio of the sub-criteria in the fourth level is firmly unchanged. Remarkably, the "Climate" factor climbed to a peak of 28% impact on to "Ecosystem" criterion. While "Forest type" sub-criterion fell from 34% to 22% of importance level in the assessment of the universities and research institutes (Appendix II).

The result shows that there are differences of opinion between all the respondent groups while considering the importance of the criteria in defining priority areas for biodiversity conservation in Vietnam. In the aspect of the factors, the most considerable difference is inevitably accredited to the URIs group. While the PAs and GOs group are similar and thus form the collective opinion of all the respondents, it is both clear and essential factor to consider the difference in responses that reflect the opinion of specific sectors. The URIs group, representing the field of research and training, focuses significantly on the "Response" factor. Other groups concerned with the pressure on biodiversity conservation are those working in planning, policy, decision making, and direct management of biodiversity conservation.

Chapter 5. Application of Criteria

5.1. Mapping criteria

Based on the environmental Pressure-State-Response model, this study has shown that priority areas for biodiversity conservation could be identified by three factors: State, Pressure, and Response. Then seven criteria and 17 sub-criteria and their weights were developed and calculated to support the zoning of priority areas (appendix II). In this chapter, I applied GIS and RS to establish a database for determined criteria to define priority areas for biodiversity conservation in Vietnam. To combine the criteria into the overall indices of biodiversity conservation, the score was used to measure the criteria (Bedward et al., 1991). Each criterion was generated a GIS layer that was scored according to its importance level that was considered as a weight (Phua & Minowa, 2005). In this research, scoring procedures used five ordinal values, including very low, low, medium, high, and very high rankings for priority levels of each criterion to scores of 1, 2, 3, 4, and 5.

5.1.1. Species

The significant effects of external factors on the ecosystem in general, as well as biodiversity, are shown in Figure 5.1 that comprise land-use, history, migration, and climate. Historical factors and levels of species migration are considered significant in defining the diversity and types of functional groups in a region (Schulze & Mooney, 2012).

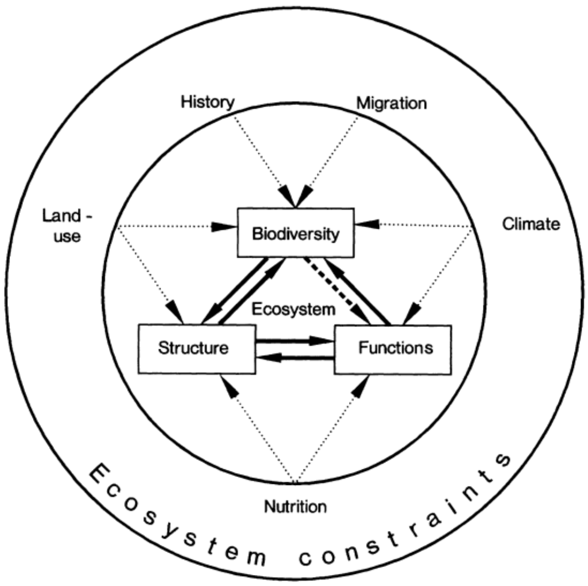


Figure 5.1: Interactions between internal and external factors of an ecosystem
(Schulze & Mooney, 2012)

Vegetation is one of the most widely used indirect indicators of the distribution of terrestrial plant and animal species (Austin, 1991). There is a significant increase in applying empirical remote-sensing models to define plant species richness at various scales and environmental conditions (Franklin, 2010). A strong relationship was found between image NDVI and plant species richness (Coops et al., 2004; John et al., 2008; Levin et al., 2007; Waring et al., 2006). The vegetation maps derived from classification methods for satellite images have been considered as predictors of species richness (Fairbanks & McGwire, 2004; Gould, 2000; Hurlbert & Haskell, 2002; Johnson et al., 1998).

The complex geology and climate, as well as the geographical location of Vietnam, has created a particular ecosystem with high biodiversity. The World Atlas of Biodiversity indicates the high ranking of Vietnam in the world for species richness (Groombridge et al., 2002). However, the changes in living conditions and environment are vital causes that influenced the biological richness in Vietnam (Sterling & Hurley, 2005). The accumulation of productivity over a long period (>10 years) is considered as a positive impact on richness (Fargione et al., 2007; Reich et al., 2012). Thus, the higher levels of species richness are often found in the forest areas that provide sufficient living environments for many species.

Many studies have shown that habitats or environmental conditions are considered as an indicator of the existence of species (Feddes & Dam, 2004; Franklin, 2010; Moore, 2008). Prediction of species distribution based on the existence of their habitat is used to identify the priority areas for conservation as well as field surveys (Franklin, 2010). Therefore, one of the primary methods to conserve species is the protection of their habitats (Gordon et al., 2005). It has shown that the occurrence of rare and sensitive species is determined within their range of appropriate habitats (Miller, 1994).

5.1.1.1. Richness

To define priority areas for species richness, a time series analysis method was performed using satellite images to find out how long the forest areas in the study area have existed (Figure 5.2). Multi-temporal satellite images of Landsat 5 and 8 were used as input data. The pre-processing was applied to reduce the effects of topography and atmosphere on the Landsat images. Four types of land use – land cover with forest, grassland, soil, and water were classified by the images taken in 1986, 1998, 2007, and 2017 using the Maximum Likelihood method. Then a technique of accuracy assessment was conducted to check the precision of the classified images before they were used for time series analysis.

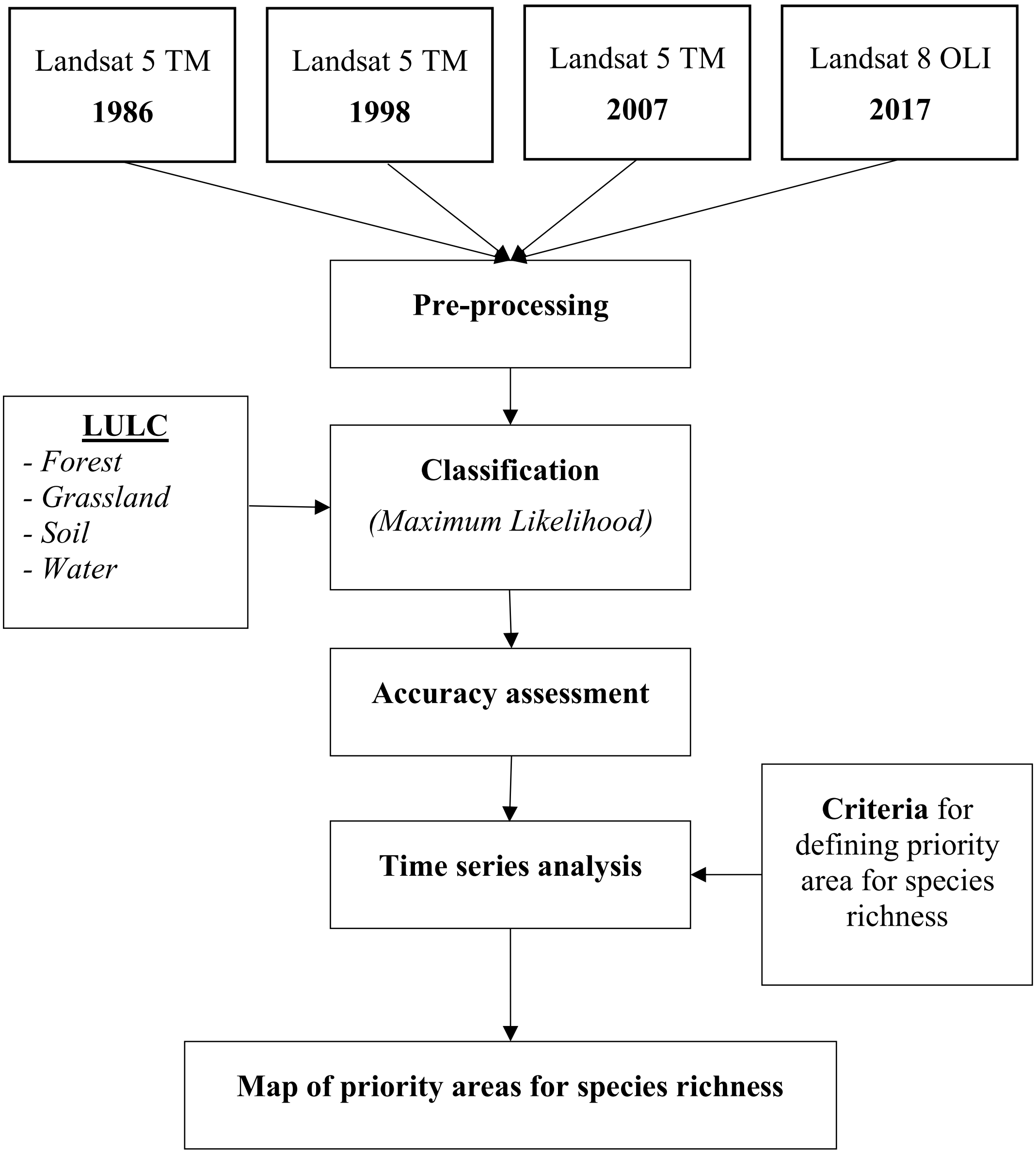


Figure 5.2. Framework for mapping priority areas of species richness

To monitor land use and land cover changes, the Landsat images are considered as a unique option to provide a temporal series of imageries. The multi-spectral images were used for the analysis, including three Landsat 4-5 TM images (1986, 1998, and 2007), and one Landsat 8 OLI image (2017). Their details are presented in Table 5.1.

These images were applied in various image pre-processing operations of geometric correction, ETM + gap filling, image enhancement, interpretation, and DOS1 atmospheric correction (via ***Semi-Automatic Classification Plugin of QGIS)*** before they were used in next steps.

Table 5.1: Images used to define the priority areas regarding the richness of species

No	Acquisition date	Path/ Row	Cloud cover (%)	Satellite image	Resolution
1	01-07-1986	127/ 46	2	Landsat 5 TM	30
2	18-07-1998	127/ 46	3		
3	08-05-2007	127/ 46	0		
4	11-07-2007	127/ 46	15		
5	04-06-2017	127/ 46	9	Landsat 8 OLI	30

The Landsat 4-5 TM image acquired on 11th July 2007, was covered by 15% cloud. It was therefore combined with the image taken on 8th May 2007 to create an image without cloud cover for 2007, which has enabled a better understanding of forest cover (Figure 5.3).

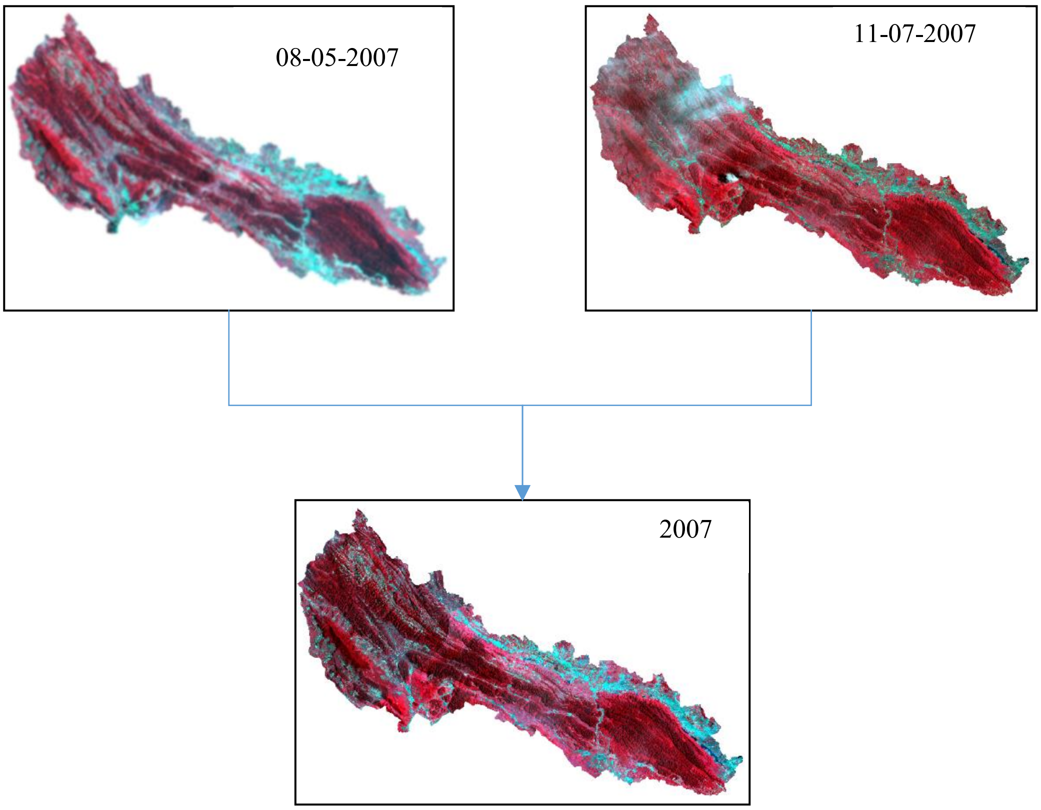


Figure 5.3: Combination to gain the appropriate image in 2007

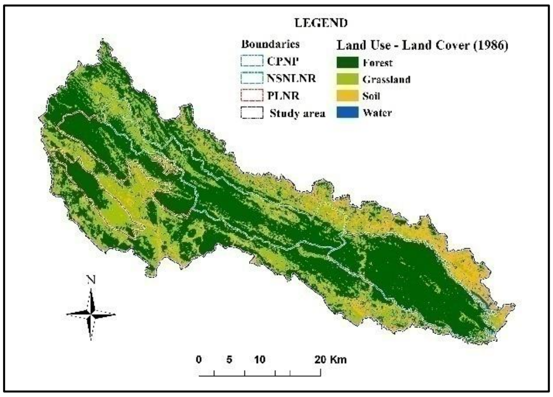
The data on LULC maps, statistics maps of forest, interview results, and field surveys are the fundamental basis on which to establish the four groups of training samples, including Forest, Grassland, Soil, and Water (Appendix III - Figure III. 1). The secondary data of statistics maps in protected areas, as well as in the provinces, were used for selecting the training samples of classification to process and check the accuracy of classified images.

Training sample regions were delimited by polygons selected to represent for each LULC type. To increase the accuracy of selecting training samples, the visual interpretation method was integrated with the data collected and investigated during the field surveys from March to July 2017.

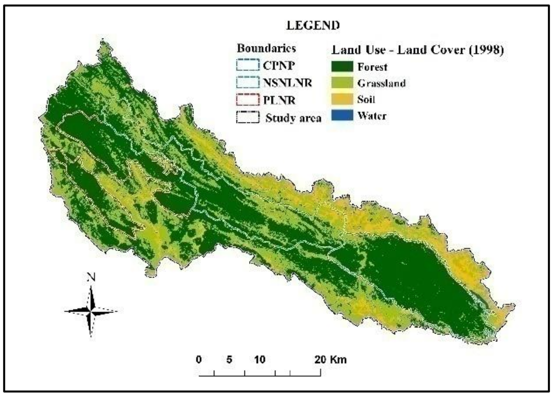
Many studies have shown that the increase of species richness in one region depends on the stability level of the forest area over time (Fargione et al., 2007; Gould, 2000; Griffiths et al., 2000; Kerr et al., 2001; Kuusipalo, 1984; Myers, 1988; Oindo & Skidmore, 2002; Phillips et al., 2008; Reich et al., 2012; Rocchini et al., 2006; Sterling & Hurley, 2005; Tilman, 1982; Wang et al., 2016; Wickham et al., 1997). Forest is a significant factor in biodiversity conservation since it provides appropriate habitats for many species. It means that the level of species richness is higher in areas continually covered by forest for a more extended period. Therefore, satellite images acquired by Landsat sensors were selected to monitor the forest changes throughout the study area in 1986, 1998, 2007, and 2017. The images were classified using the Maximum Likelihood method of Supervised Classification with four land-use types, namely forest, grassland, soil, and water.

The Semi-Automatic Classification Plugin developed by Luca Congedo of QGIS 3.2.2 was used to detect the forest changes for the whole study area. DOS1 atmospheric correction was applied to all the Landsat images. The Landsat-8 image in 2017 was subjected to pan-sharpening to achieve a higher resolution image supporting visual interpolation in selecting the training samples as well as in assessing the accuracy of the classified image. The training samples were selected for four types of Land Use Land Cover (LULC) maps, including forest, grassland, soil, and water, by drawing polygons around representative sites (Appendix III - Figure III. 2).

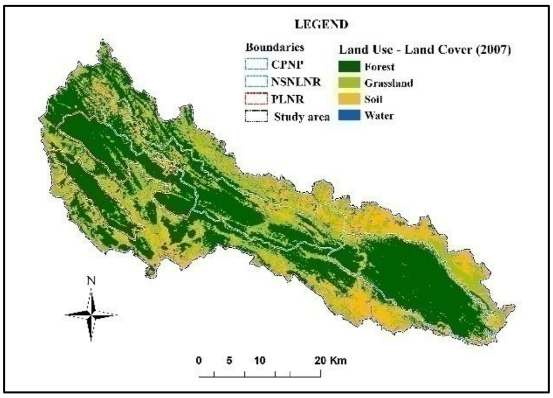
The satellite images were classified by applying the Maximum Likelihood method of supervised classification to achieve thematic raster layers. Then, all collected data were used as reference sources to assess classification accuracy for these images, including ground-trusting points, achieved documents, time series of forest statistic maps, LULC maps, and topographic maps. As a result, an error matrix was formulated for the classified images, as shown in appendix III - Table III. 1. Our results showed that the overall accuracy of classified images in 1986, 1998, 2007, and 2017 is 97%, 95%, 96%, and 92%, respectively. The classified images were integrated with visual interpretation to improve classification accuracy and reduce misclassifications. Figure 5.4 indicates the LULC maps based on supervised classification and image interpretation in 1986, 1998, 2007, and 2017.



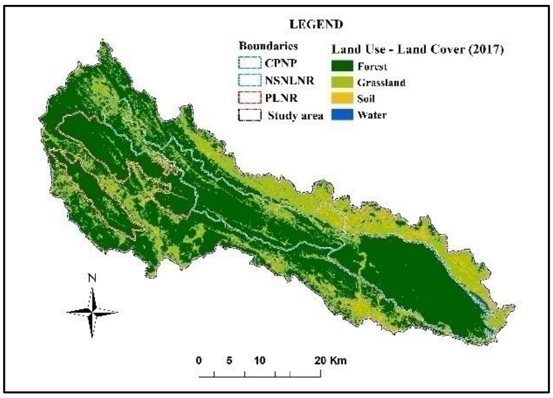
a. Land use and land cover map in 1986



b. Land use and land cover map in 1998



c. Land use and land cover map in 2007



d. Land use and land cover map in 2017

Figure 5.4: Land use and land cover maps in Pu Luong – Cuc Phuong (1986, 1998, 2007, and 2017)

Based on the classified images, we used time-series analysis to assess LULC changes of three protected areas and surrounding areas in the selected site. There is no substantial change observed in the forest area of Cuc Phuong National Park (CPNP) from 1986 to 2017. Forest areas of Pu Luong Nature Reserve (PLNR) experienced a stable increase in periods between 1986 and 2017. Although Ngoc Son Ngo Luong Nature Reserve (NSNLNR) was established in 2004, the management board of NSNLNR was only set up in 2006. Thus, illegal logging continued after the establishment of NSNLNR. Our results have shown a decline in forest area (7%) in NSNLNR from 1986 to 2007 (Figure 5.5). However, there is a significant increase in forest areas in NSNLNR from 58.9% in 2007 to 73.9% in 2017 as a consequence of the implementation of forest protection policies by the Vietnamese Government (Appendix III - Table III. 2).

The diversity of plants depends significantly on the disturbance in the past (Moore, 2008). Therefore, the priority levels of richness for biodiversity conservation are determined by monitoring the forest cover from 1986 to 2017.

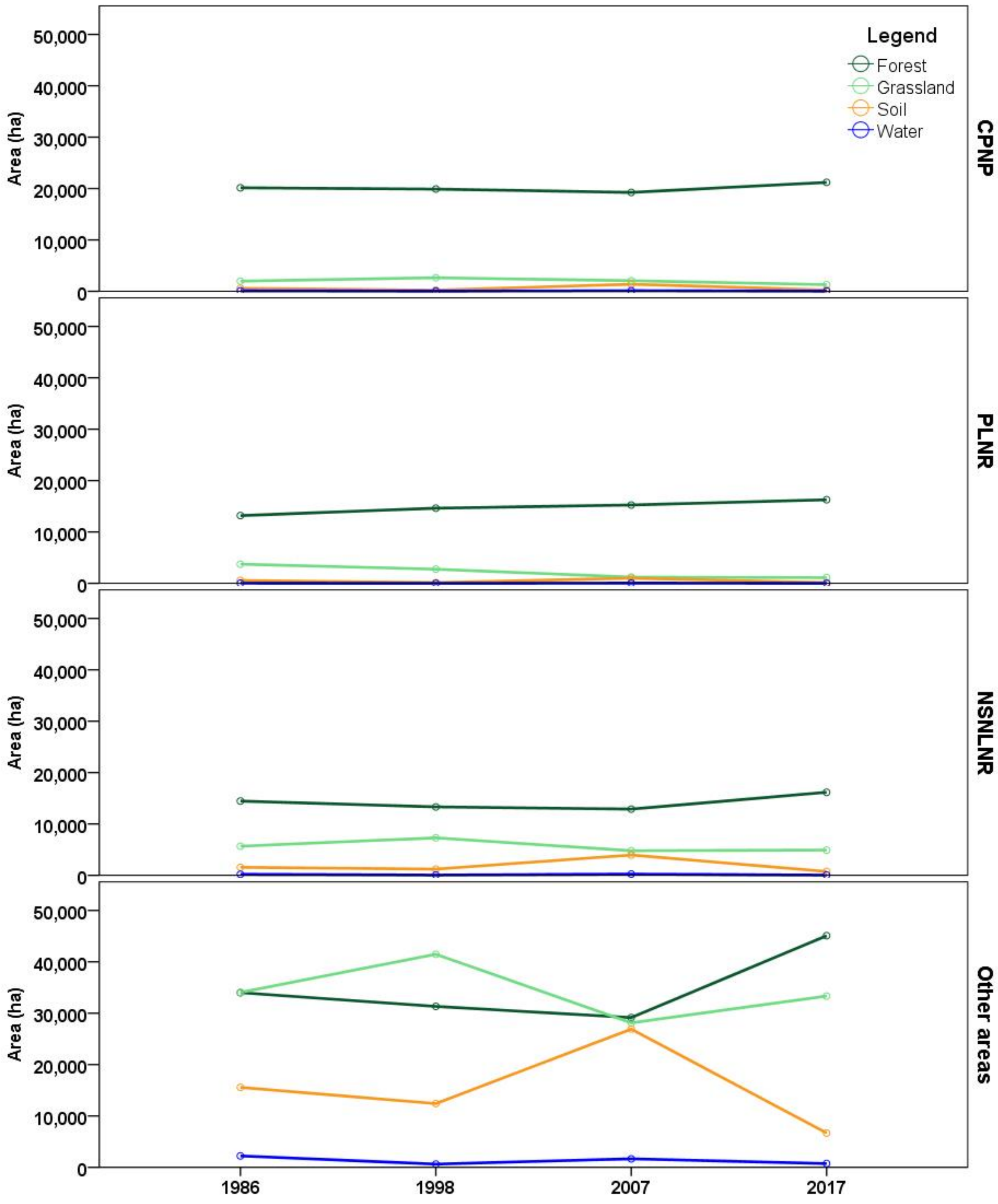


Figure 5.5: LULC changes in specific regions from 1986 to 2017

Table 5.2 shows five levels of priority based on species richness that relies on existing forest cover in investigated periods (1986, 1998, 2007, 2017). The level of priority depends on the longevity of the forest area that exists in 2017. The areas covered by the forest continually during 1986 and 2017, are categorized as the highest level of priority for richness. The lowest level is attributed to the areas without the forest cover in 2017.

Table 5.2: Criteria for defining priority areas for species richness

Levels of priority	Land Use – Land Cover			
	2017	2007	1998	1986
4	Forest	Forest	Forest	Forest
3	Forest	Forest	Forest	Others
2	Forest	Forest	Others	
1	Forest	Others		
0	Others			

Four LULC maps were established for 1986, 1998, 2007, and 2017. Then, time series analysis was used to overlay and determine the levels of priority for richness based on five categories of priority, as shown in Table 5.2. There are five levels of priority for species richness, including very low, low, medium, high, and very high (Figure 5.6).

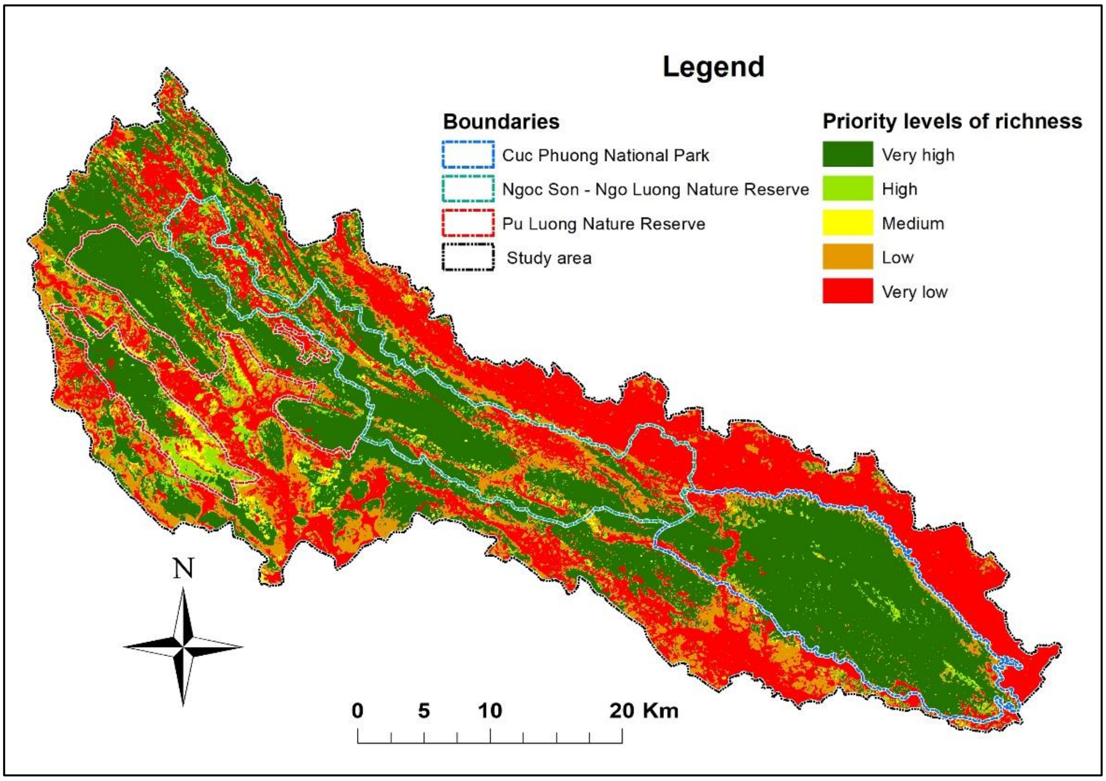


Figure 5.6: Priority levels of richness in the study area

The results indicate that 49.7% of the total study area is categorized as very low and low levels of priority for richness, with 39.2% lying outside of the three protected areas. 43.2 % of the total study area is considered as a very high level of priority for richness, with 28.2% located in the three protected areas. For each protected area, the areas of the very high level of priority for richness were calculated. The results have shown that the proportion of very high priority areas for CPNP, PLNR, and NSNLNR are 80.9%, 70.3%, and 50.7%, respectively (Figure 5.7)(Appendix III - Table III. 6).

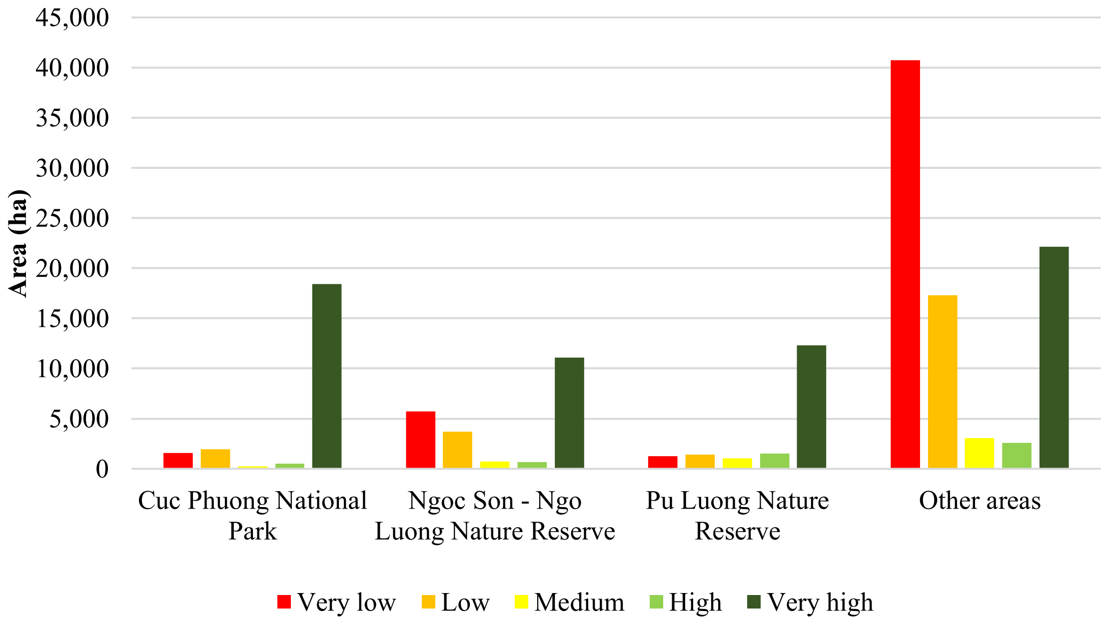


Figure 5.7: Assessment of priority levels of richness in the study area

5.1.1.2. Rarity

Many rare species that were found in the study area and listed in the IUCN Red List and Vietnam Red Data Book (VNRB) were analyzed in terms of their preferred habitats as well as living conditions. The list of rare animals and plants, as well as the characteristics of their habitat and ecology, is shown in appendix III - Table III. 3. To define the distribution of the rare species, several maps were required based on the analyzed characteristics such as evergreen forest, topography, hydrology, geology, forest types, and valley.

Topography and valley layers were established by the Digital Elevation Model (DEM) image, acquired on 17 October 2011 by Aster sensor. The hydrological map of the study area was collected from the layers of rivers and streams shown on existing maps of the Thanh Hoa, Ninh Binh, and Hoa Binh provinces and updated through Sentinel-2 image acquired on 9th of April 2018. The data of forest types were acquired by image classification, as described in Figure 5.44. The time series analysis was applied to the classified images over five different months of the year to identify the areas of evergreen forest (Figure 5.8).

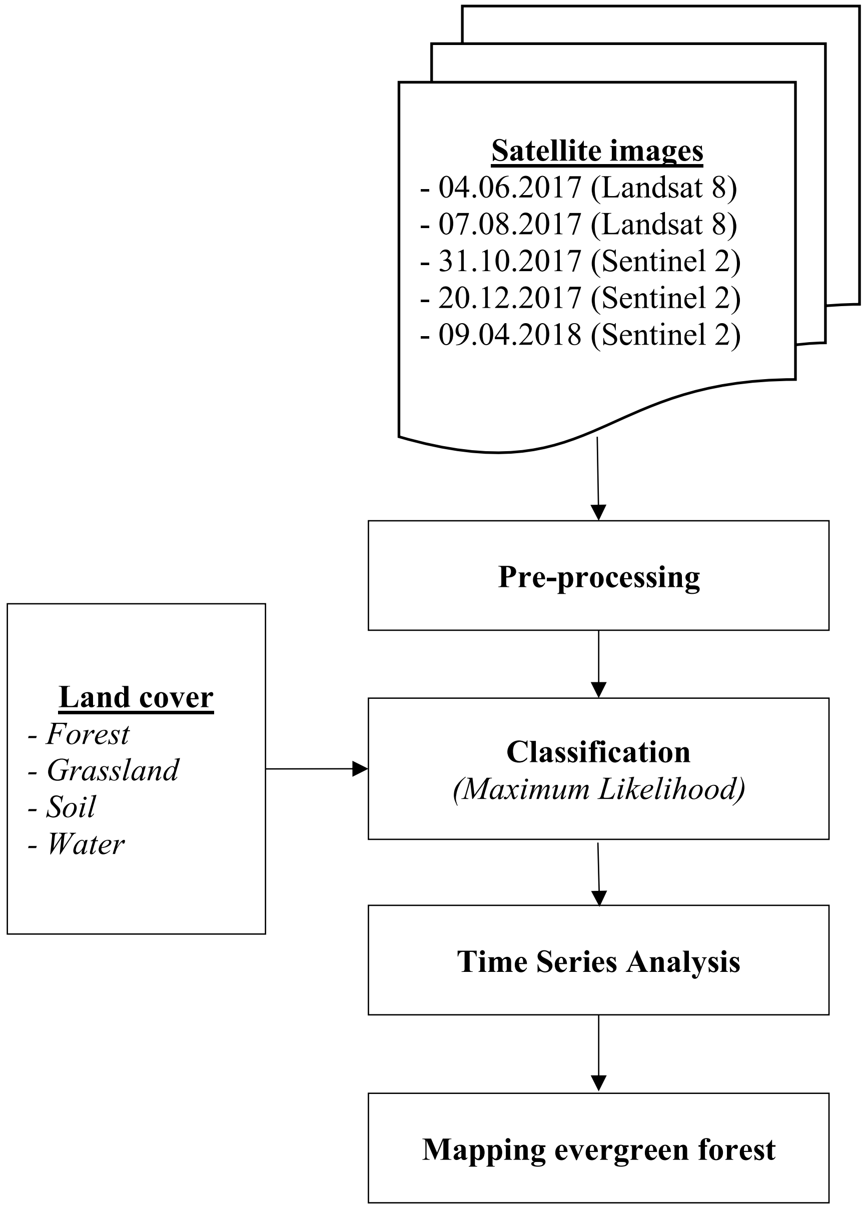


Figure 5.8: Framework for mapping evergreen forest in the study area

The distribution of each rare species was zoned based on the overlay analysis method, which was applied for the required maps (Figure 5.9). Then the maps of all rare species distribution were combined and classified into priority levels depending on the number of rare species that could theoretically exist in those areas. Evergreen forest is covered with leaves throughout a year for photosynthesis (Moore, 2008). Thus, land use and land cover maps of the study area in June, August, October, December 2017, and April 2018 were overlaid to identify the evergreen forest. In order to create the LULC maps, 2 Landsat 8 images and 3 Sentinel 2 images shown in Table 5.3 were used for classification.

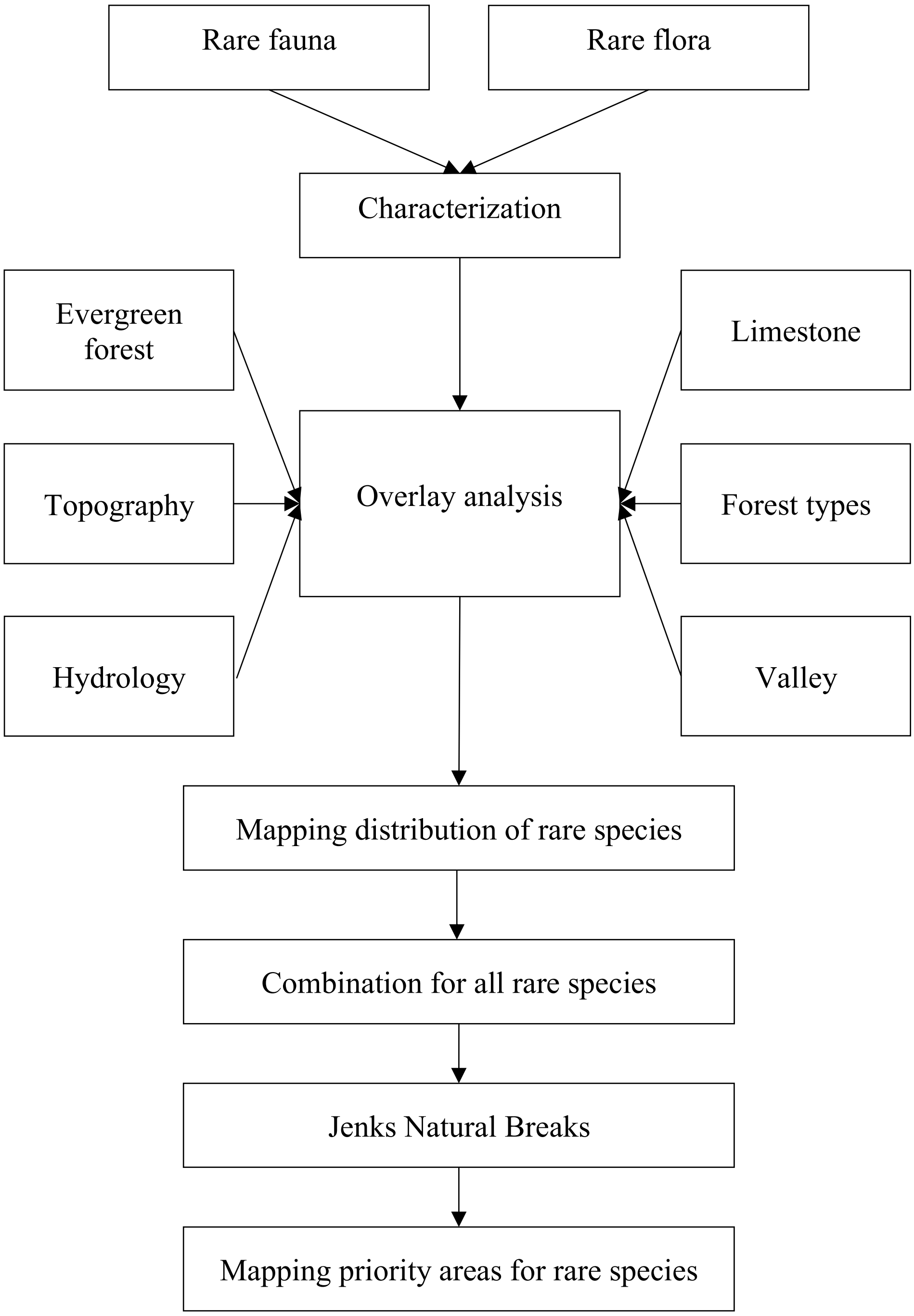


Figure 5.9: Framework for mapping priority areas of rare species

The classification method of Maximum Likelihood was applied for the five images. Training samples in the five months were selected from the data collected in the field survey in 2017 as well as additional information in 2018 (Appendix III - Figure III. 3). The accuracy assessment was performed with the appropriate results (Appendix III - Table III. 4).

The DEM image was acquired on 17th October 2011 by the Aster sensor. The image helps to show topography throughout the study area. The habitat characteristics and ecology of rare species, such as altitude, slope, and elevation zones, were extracted from the DEM. The data from the field survey, the LULC maps, and the statistic maps of forest were synthesized to establish the other data illustrating characteristic habitats of rare species (appendix III - Figure III. 4).

Table 5.3: Satellite images used to establish the map of evergreen forest

No	Acquisition date	Cloud cover (%)	Satellite image	Resolution
1	04-06-2017	9	Landsat 8 OLI	15, 30
2	07-08-2017	15	Landsat 8 OLI	15, 30
3	31-10-2017	9	Sentinel 2	10, 20
4	20-12-2017	0		
5	09-04-2018	0		

Of the species listed in the VNRB and IUCN Red List, six rare animals and 28 rare plants were found in the study area. Then, we analyzed and selected ecology characteristics and distributions of these rare species to identify the database for mapping. Eight maps were established to display the mainly environmental conditions in the study area (appendix III - Figure III. 4). Based on the eight maps on environmental conditions and ecological characteristics of all the rare species found in the area, we formulated maps based on the distribution of each rare species by applying spatial analysis (appendix III - Figure III. 5, Figure III. 6).

Then, maps of distribution on all the 34 rare species identified were overlaid to identify the areas within the study area that have a high probability of containing rare species. The levels of priority for rarity depend on the density of rare species found in the investigated area. It means that the areas where suitable habitat for many rare species exists will be classified as the high and very high priority areas regarding the rarity of species. By applying the Jenks Natural Breaks method of classification, we identified five levels of priority for rarity, including very low, low, medium, high, and very high (Figure 5.10). The raster of priority levels was filtered by the majority method in ArcGIS 10.1 before the image was converted into vector format to analyze and synthesize the priority area for the protected areas as well as the study site.

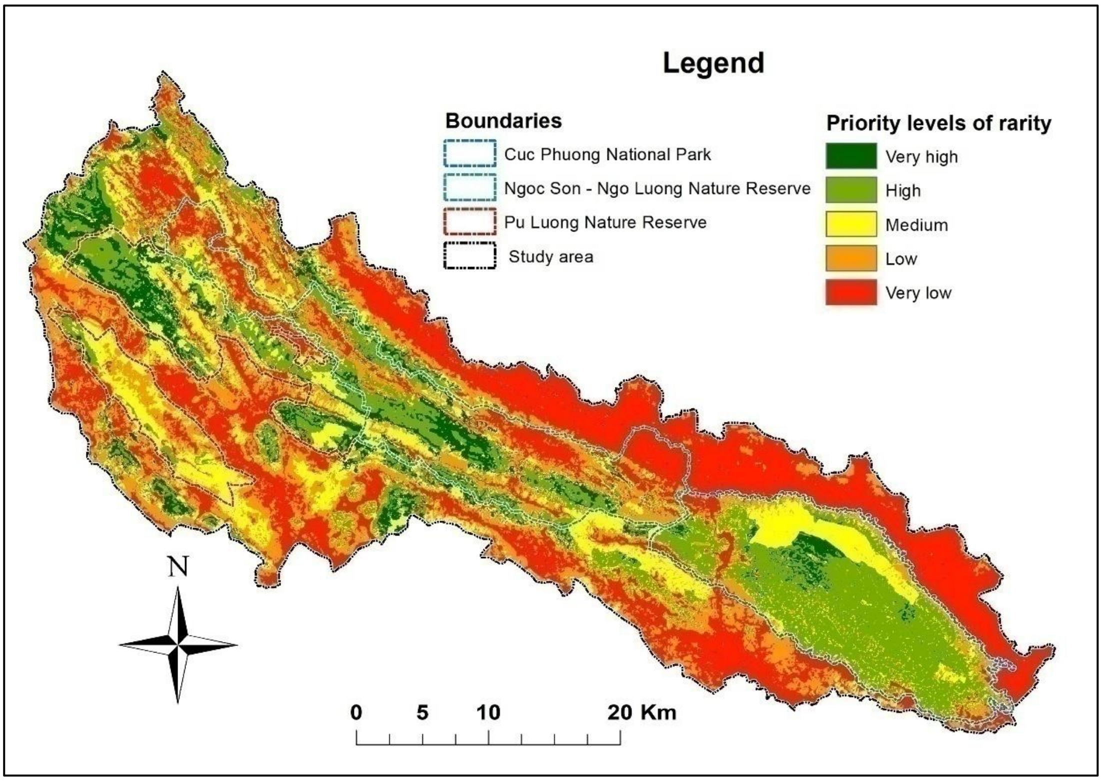


Figure 5.10: Priority areas of rarity in the study area

The results show that 27.9% of the total study area is categorized as very high or high levels of priority for rarity, with 19.8 % lying inside the three protected areas (appendix III - Table III. 7). Outside the three protected areas, 8.1% of the land was identified as having a very high or high priority for rare species. These results show justification for protecting outside areas, which are classified as very high or high levels of priority for rarity.

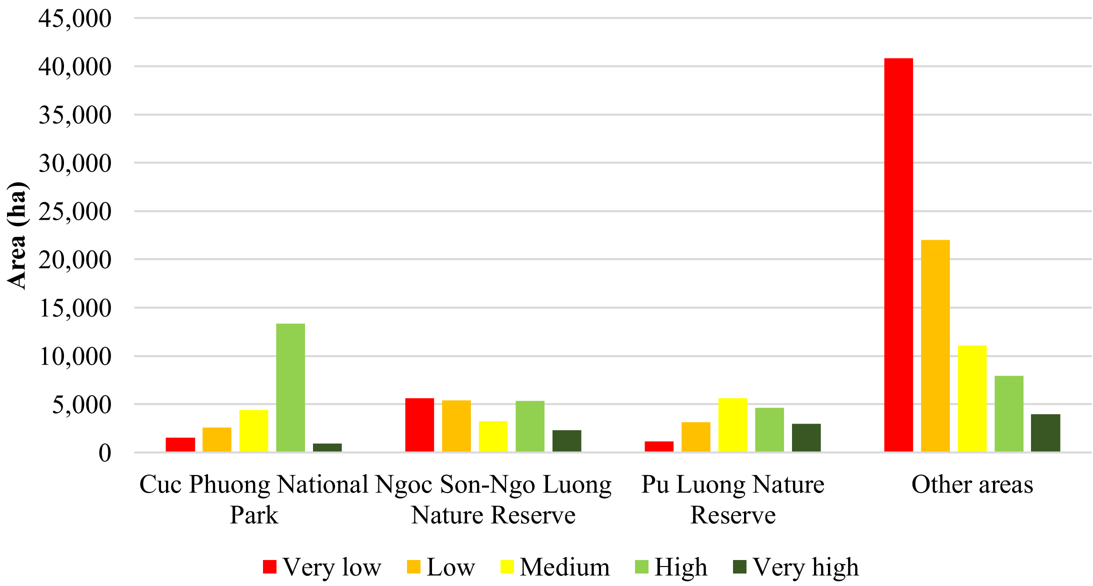


Figure 5.11: Assessment of priority levels of rarity in the study area

We also estimated the area at very high and high levels of priority based on rarity criteria for each protected area. Our findings have indicated that the proportion of areas at very high and high priority in CPNP, PLNR, NSNLNR are 62.6%, 43.2%, and 34.9%, respectively (Figure 5.11).

5.1.2. Ecosystem

5.1.2.1. Location

Previous studies show that the highest level of biodiversity in Vietnam was found in three mountainous regions, including the north-eastern area, Hoang Lien Range, and Truong Son Range (Pu Luong Nature Reserves is located in the northern Truong Son range) (Averyanov et al., 2003; Sterling & Hurley, 2005). The Annamites, karst limestone formations, and the Hoang Lien Mountains are considered as significant ecoregions for many endemic species (Carew-Reid et al., 2011).

Karst ecosystem is one of the prioritized ecosystems for biodiversity conservation due to its structure and sensitivity (Furey & Infield, 2005; Vermeulen & Whitten, 1999). The karst areas are a sensitive ecosystem containing several endemic species. It will be complicated to restore the species within the karst ecosystem if they are lost (Mickleburgh et al., 2002; Mittermeier et al., 2007). Therefore, the higher priority was given to the areas within limestone ecosystem.

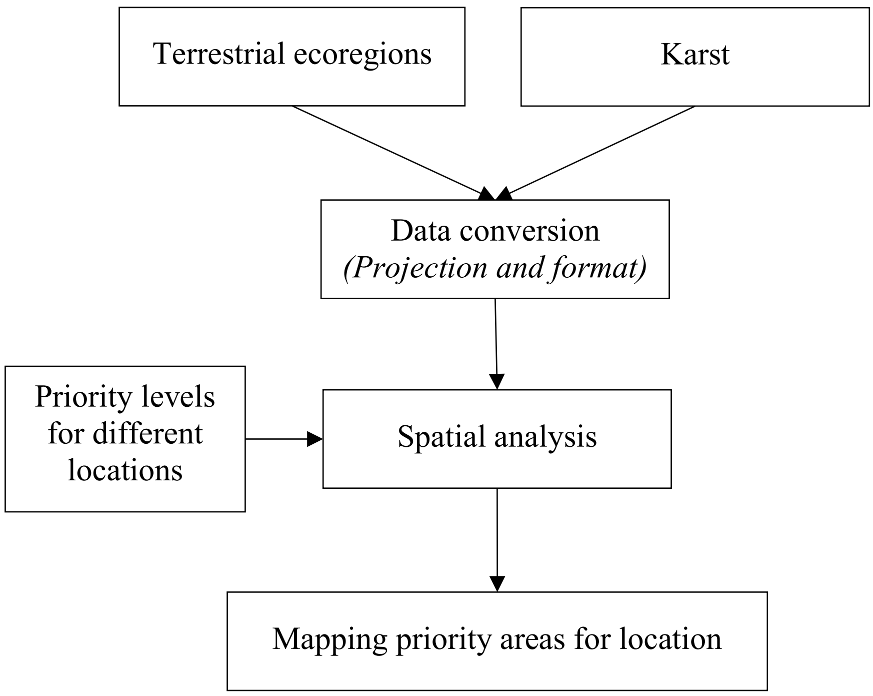


Figure 5.12: Framework for mapping priority areas of location

Maps of terrestrial ecoregions and karst were used as input data to create the map of priority areas for our research. The original data were converted into the common projection type and format before using the spatial analysis method to define priority areas for biodiversity conservation (Figure 5.12).

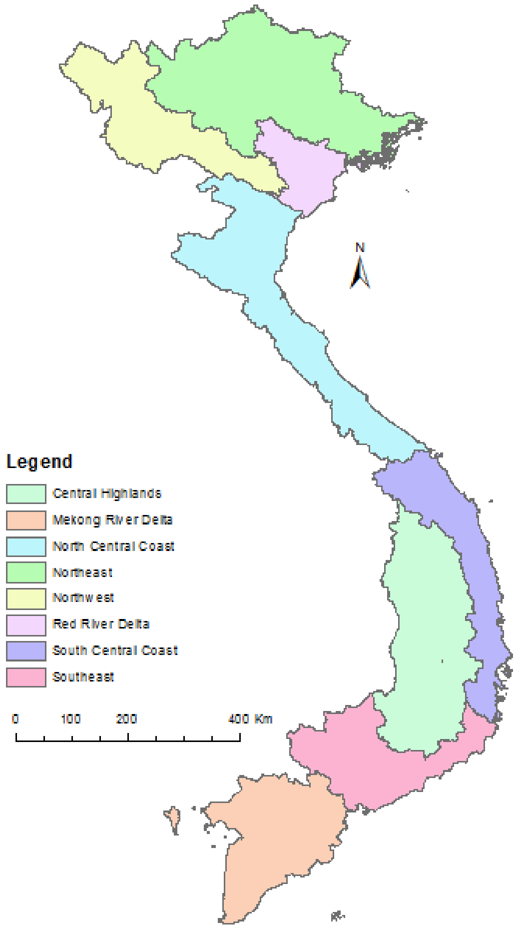


Figure 5.13: Terrain regions in Vietnam

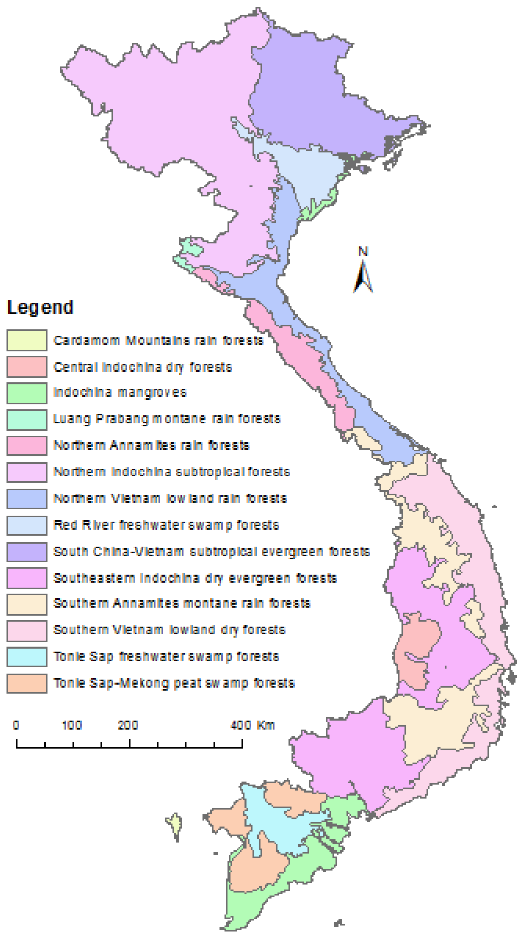
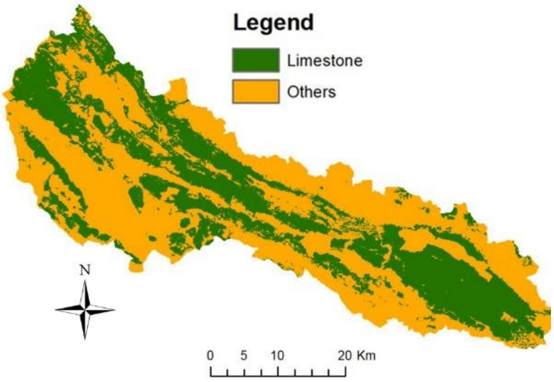
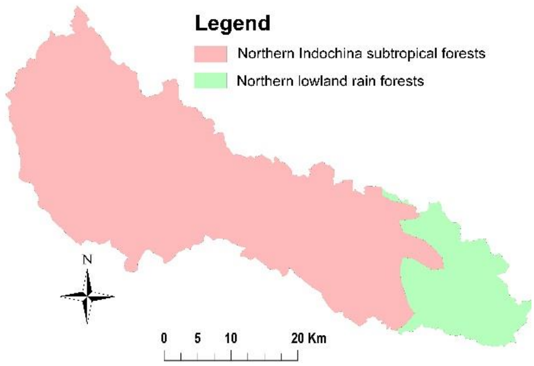


Figure 5.14: Terrestrial ecoregions in Vietnam

Vietnam is divided into eight terrain regions, including Northeast, Northwest, Red River Delta, North Central Coast, Sound Central Coast, Central Highlands, Southeast, and Mekong River Delta (Figure 5.13). The terrain regions were defined by the different characteristics of topography as well as regional climates. They meant as administrative boundaries. Therefore, it is necessary to obtain a precise map of terrestrial ecoregions for the study area. The terrestrial ecoregions map (Figure 5.14) based on WWF's ecoregions was downloaded from the Nature Conservancy (http://maps.tnc.org). It is a website developed by the Nature Conservancy's North American Region science team in partnership with the Technology and Information System group.



a. Karst limestone regions



b. Terrestrial ecoregions

Figure 5.15: Karst limestone regions and terrestrial ecoregions in the study area

The identification of priority areas regarding location criterion is based on WWF's ecoregions and karst limestone formations in the study area. To synchronize the priority levels of location with the other criteria for synthesizing all criteria, the weights for different locations were suggested in Table 5.4. Karst regions in the study area were extracted from the established maps, such as topography and forest statistic maps. The overlay analysis method was used to process two data layers, including terrestrial ecoregions and karst regions (Figure 5.15).

According to terrestrial ecoregions maps from the World Wide Fund for Nature (WWF), Vietnam includes 14 ecoregions with different biodiversity levels. In Pu Luong Cuc Phuong, there are two typical ecoregions, namely Northern Indochina subtropical forests and Northern lowland rain forests. Many previous studies have shown that northern Indochina subtropical forests have a high level of biodiversity (Averyanov et al., 2003; Sterling & Hurley, 2005).

Table 5.4: Proposed weights for different locations in the study area

No	Category	Priority levels
1	Northern Indochina subtropical forests + karst limestone formations	4
2	Northern Indochina subtropical forests	2
3	Karst limestone formations	2
4	Others	0

Besides, the limestone ecosystem is one of the priority ecosystems for biodiversity conservation due to its structure, biodiversity, and sensitivity (Furey & Infield, 2005; Vermeulen & Whitten, 1999). Therefore, we suggested the priority levels of different locations in the study site (Table 5.4).

Based on the suggested priority levels for locations, we established a distribution map of priority areas of location for biodiversity conservation in the study area (Figure 5.16). There are three levels of priority for location criterion, including high, medium, and low. It is shown that limestone regions within the study area are categorized as a high priority. Areas of low priority are found in the eastern part of the study area, which is settled by local communities and used for agricultural cultivation.

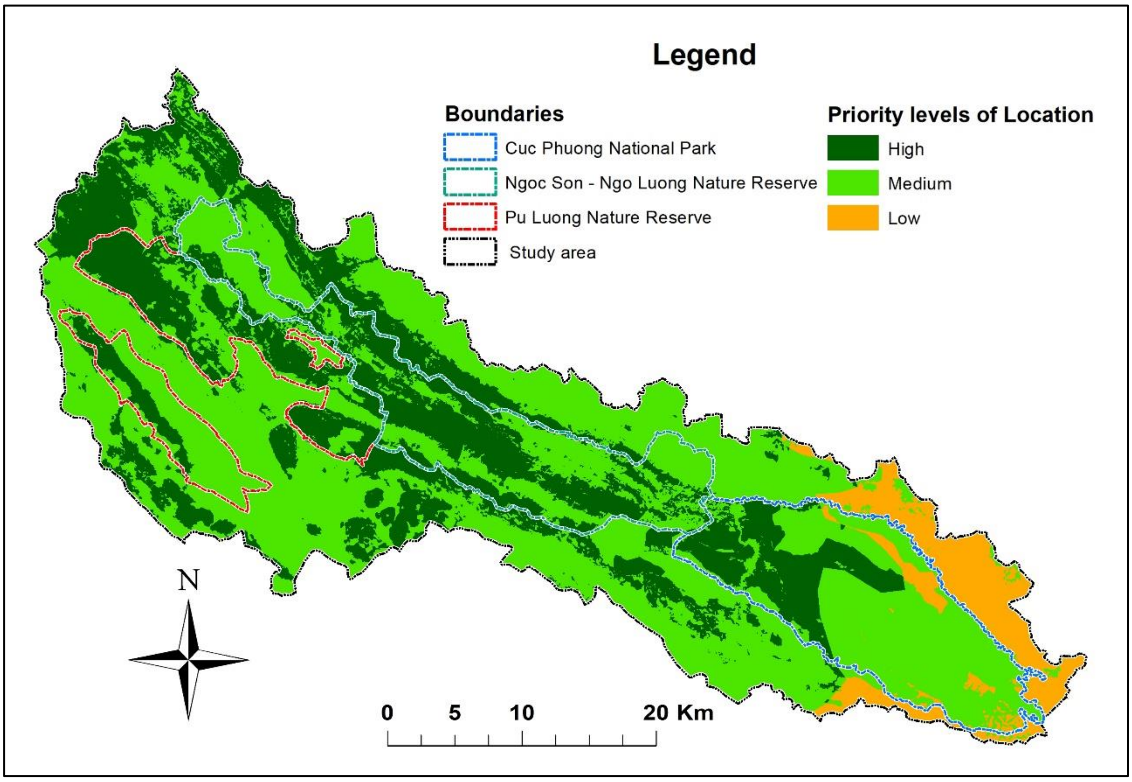


Figure 5.16: Priority areas of location in the study area

Then, area statistics for priority levels for location criterion are presented in appendix III - Table III. 8. The results have shown that 4.2% of the total study area is classified as a high priority in CPNP. Areas at high priority in NSNLNR and PLNR are 7.5% and 6.5%, respectively. The areas of high priority based on location criterion for each protected area were also estimated. The findings have indicated that the areas of high priority for CPNP, NSNLNR, and PLNR account for 27.4%, 50.5%, and 55%, respectively (Figure 5.17).

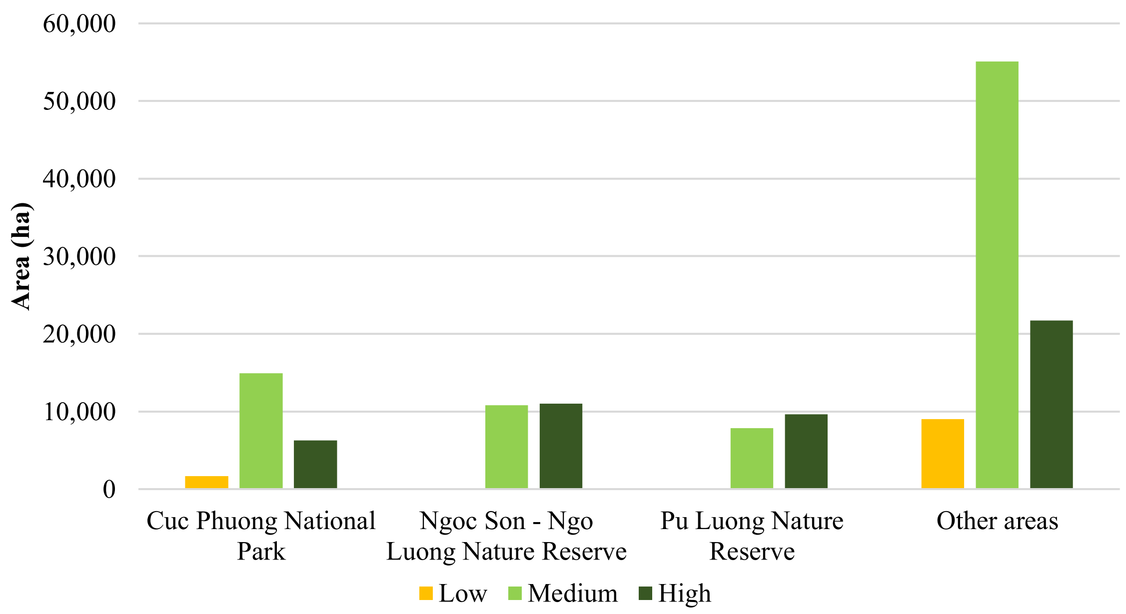


Figure 5.17: Assessment of priority levels of location in the study area

In comparison with the two nature reserves, CPNP has a low proportion of areas of high priority because CPNP is located in the transitional region between Northern Indochina subtropical forests and Northern lowland rain forests. Also, 14.7% of the total area of high priority is distributed outside the three existing protected areas. It suggests a need for establishing other priority areas for biodiversity conservation in the study area.

5.1.2.2. Topography

A negative relationship has been found in many ecosystem regions between elevation and diversity of species (Benayas, 1995; Moore, 2008; J G Pausas, 1994; Stevens, 1992). Uplands of deciduous forests and lowland of tropical forests provide significant habitat for many threatened animals and have very high plant diversity, respectively. The areas of the evergreen forest below 800-1000m average sea level (asl) are short dry season regions with high rainfall, which are suitable for maintaining the highest diversity of tree species (Carew-Reid et al., 2011).

A significant positive correlation is recognized between altitudinal distribution and forest cover. The forest loss has happened extensively at lower elevations much more so than at higher elevations (Tordoff, 2003). It leads to a significant reduction of the habitat in the lowland forest below 300m asl. It is because the large areas have been narrowed down by the overexploitation caused by human activities. Therefore, it is necessary to retain and preserve the lowland forest below 300m (Tordoff, 2003).

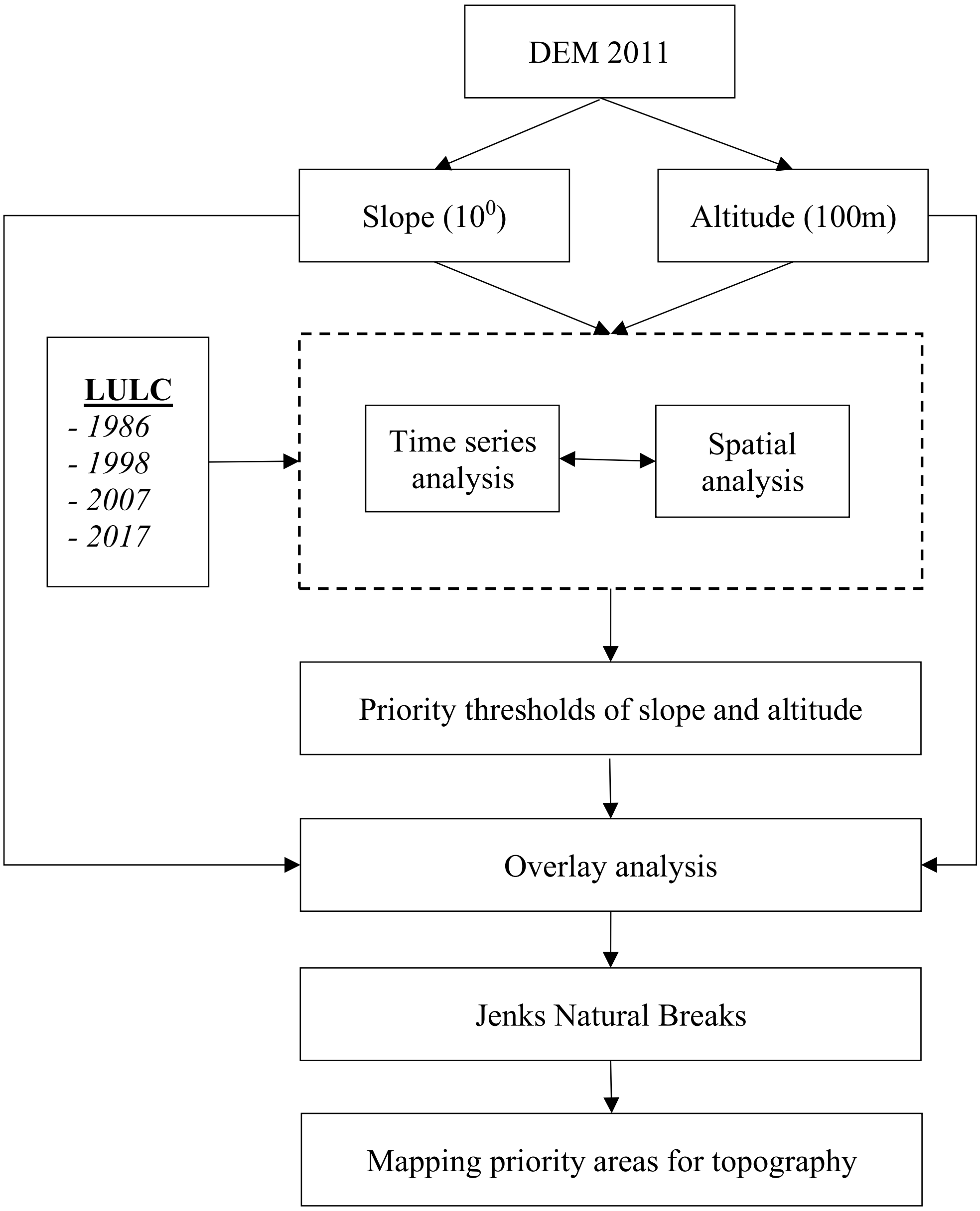


Figure 5.18. Framework for mapping priority areas of topography

Regarding the topography criterion, the workflow for mapping priority areas for biodiversity conservation consists of two periods (1) identifying priority thresholds and (2) establishing a map for topography criterion. Slope and altitude are two main elements of topographical assessment in our research. They were interpolated through Digital Elevation Model data using steps of 10 degrees of slope and 100 meters of altitude. The temporal and spatial analyses were applied for topographical data and land use – land cover in 1986, 1998, 2007, and 2017 to monitor, assess, and find out the thresholds of topography in the study area, which are essential for biodiversity conservation (Figure 5.18).

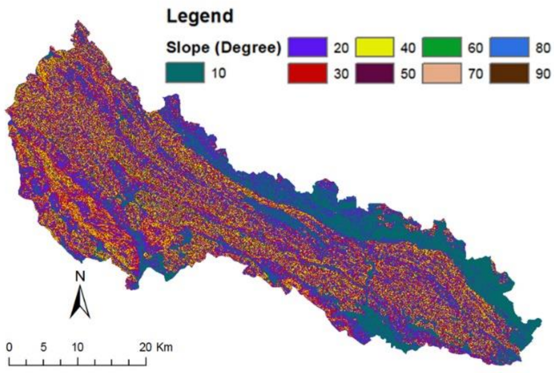


Figure 5.19:10⁰-slope map

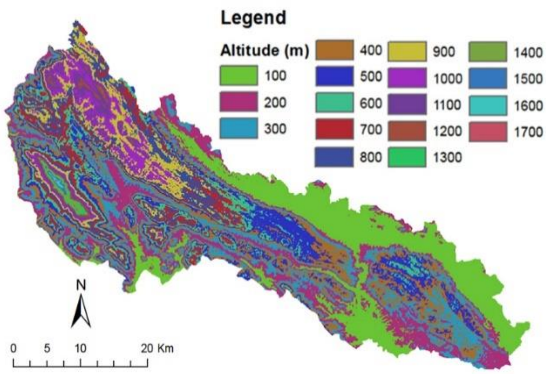


Figure 5.20:100m-altitude map

The thresholds were used to classify three levels for both slope and altitude. Then they were overlaid together to analyze and reclassify the whole topographical element. Jenks Natural Breaks method established a map of priority areas of topography for biodiversity conservation with five levels of priority (very low, low, medium, high, and very high). The LULC maps in 1986, 1998, 2007, and 2017 were overlaid on the 10^0-slope map and 100m-altitude map to define the priority areas of topography for biodiversity conservation. The DEM image, acquired on 17 October 2011 by Aster sensor, is used as a fundamental basis for extracting the slope and altitude data. Then they were overlaid on the land use - land cover maps from 1986, 1998, 2007, and 2017 to identify how levels of slope and altitude influence change to the area of forest in the study site. The data of slope in each 10^0 step and altitude each 100m were estimated by DEM image acquired. They are shown as in Figure 5.19 and Figure 5.20.

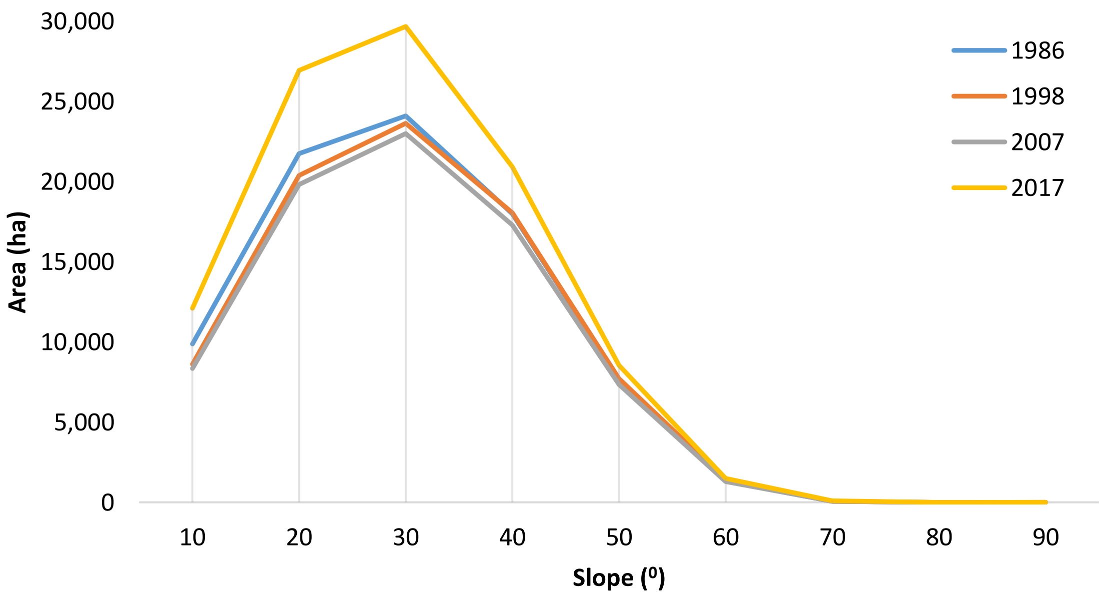


Figure 5.21: Change in forest areas at different slopes from 1986 to 2017

Appendix III - Table III. 5 shows that the forest area of the study site changed significantly from 1987 to 2017. The establishment of Pu Luong Nature Reserve in 1999 and Ngoc Son Ngo Luong Nature Reserve in 2004 are the main promotion to rocket up the forest area in the period (2007 to 2017). The forest cover decreased sharply from 1986 to 1998 and slightly from 1998 to 2007 in slope and altitude under 30 degrees (Figure 5.19) and 500 m (Figure 5.20), respectively.

The steady decline of forest area is found on the slope lower than 30^0 from 1986 to 1998, with thousands of hectares of forest loss. The areas on the slope (30^0–50^0) were also deforested significantly from 1998 to 2007 (Figure 5.21). While forest areas covering on the altitude lower than 500 m were felled/cleared from 1986 to 2007, with the majority being at an elevation lower than 200 m (Figure 5.22), the reversal of this situation can be found beginning in 2007 when a large forest area has been planted and restored (Appendix III - Table III. 5). It was due to improved biodiversity protection in the Pu Luong and Ngoc Son – Ngo Luong Nature Reserves, which were established in 1999 and 2004, respectively. Therefore, topographic information is an essential aspect of identifying vulnerability to human activities, which historically have harmed lowland slopes of a low gradient.

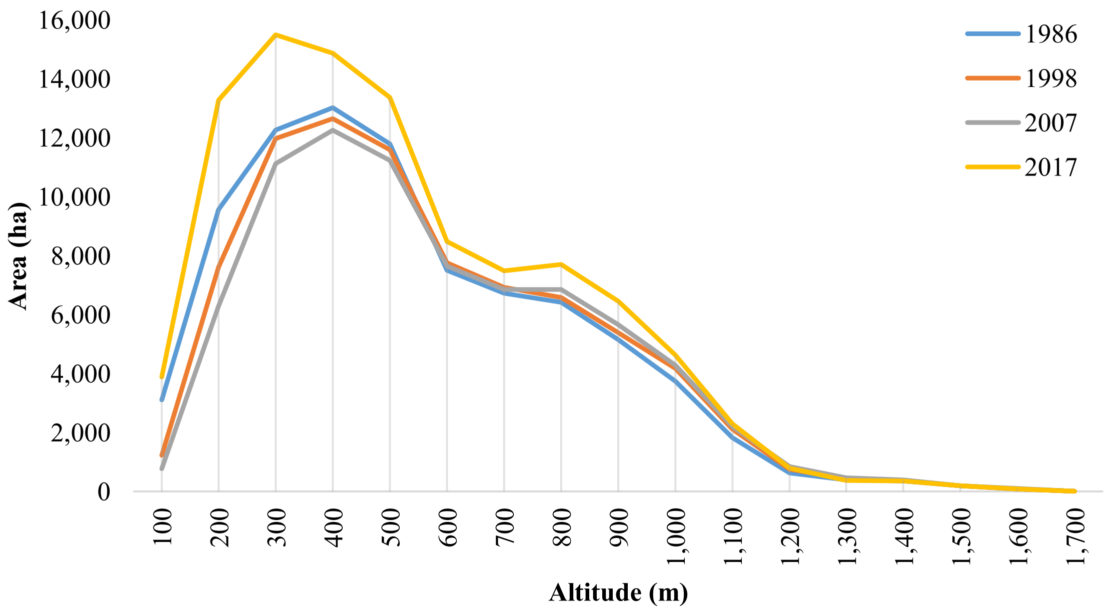


Figure 5.22: Change in forest areas at different altitudes from 1986 to 2017

The thresholds were used to establish the priority levels of slope and altitude for biodiversity conservation, as presented in Table 5.5. The synthesis from priority areas of slope and altitude helped to gain the results of priority areas of topography for biodiversity conservation in the study area.

Table 5.5. Priority levels of slope and altitude for biodiversity conservation

No	Slope zones (^{0})	Priority levels	No	Altitude zones (m)	Priority levels
1	0 - 20	2	1	0 - 200	2
2	20 - 30	1	2	200 - 500	1
3	> 30	0	3	> 500	0

Based on our analysis of forest area changes in 4 years: 1986, 1998, 2007, and 2017 in different topographies, priority levels were suggested for biodiversity conservation in topography (Table 5.5). This study focused on two main elements of topography, including slope and altitude. Concerning the slope of the topography, there are two priority levels determined for biodiversity conservation, i.e., 0 – 20^0 and 20 - 30^0 since this is where forest area changes are recorded at the highest level. When it comes to the altitude, two priority levels for biodiversity conservation are from 0 to 200 m and from 200 m to 500m.

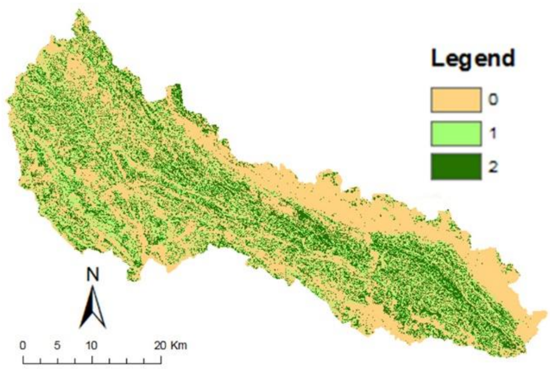


Figure 5.23: Priority areas of slope

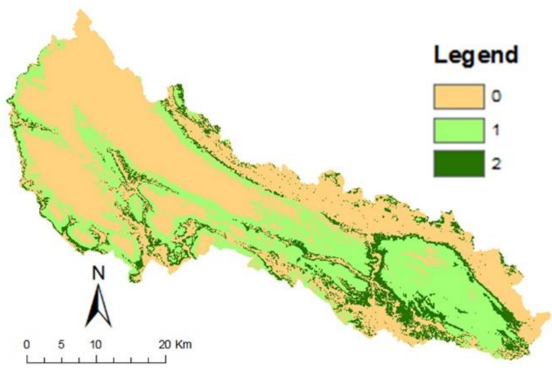


Figure 5.24: Priority areas of altitude

Two maps were established on priority levels for biodiversity conservation regarding slope and altitude in the study area, as shown in Figure 5.23, and Figure 5.24, respectively. Then these two maps were overlaid to identify priority areas and their levels for topography criterion (Figure 5.25). The results have shown five priority levels for topography from very low, low, medium, high, to very high.

The areas at different priority levels were calculated in three protected areas and outside areas. The results have shown that 7% of the total area is classified as very high or high priority levels in CPNP. 2.4% and 0.7% of the total area is determined as very high or high priority levels in NSNLNR and PLNR, respectively (Appendix III - Table III. 9).

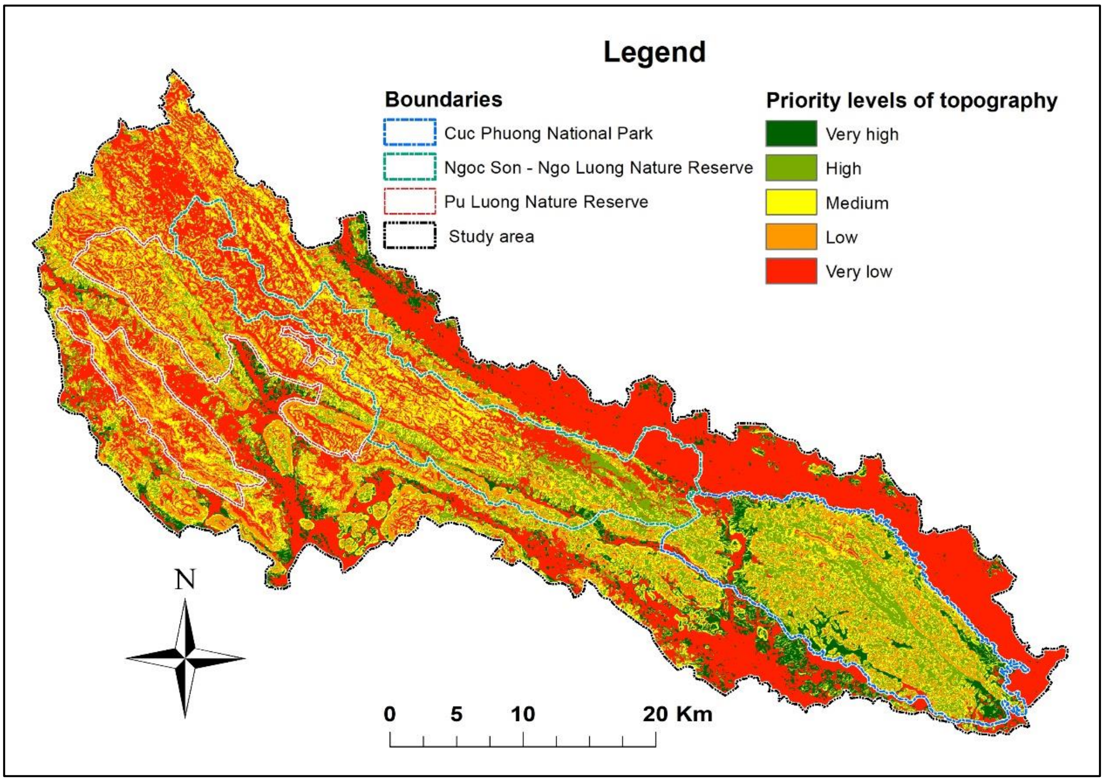


Figure 5.25. Priority areas of topography in the study areas

The areas at different priority levels for each protected area were also measured. Of the three protected areas, CPNP has the highest area classified at very high or high priority levels (45%). The area at very high or high priority levels is 16.5% and 6% for NSNLNR, and PLNR, respectively (Figure 5.26).

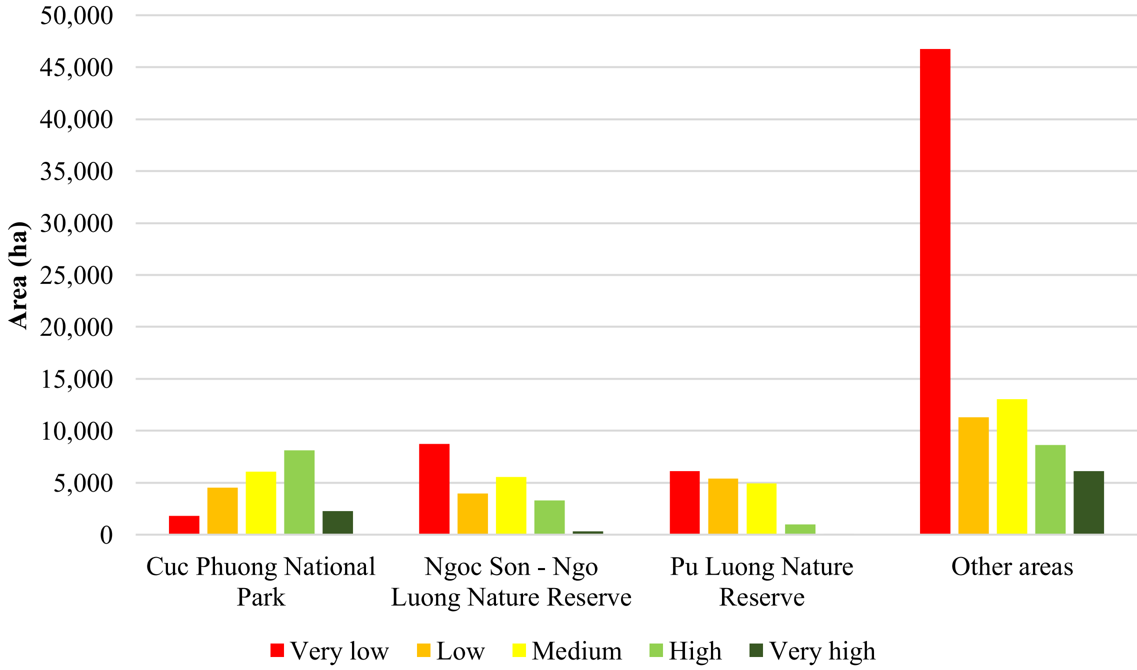


Figure 5.26: Assessment of priority levels of topography in the study area

5.1.2.3. Climate

Vietnam has a high diversity of species due to its complex geology and diverse climate. Many systems of hilly and mountainous topography create localized temperature and humidity at different elevations as well as landscape levels, which affects the distribution of species (Sterling & Hurley, 2005). Until 2015, the data from 150 hydro-meteorological stations (Figure 5.27) of the National Centre for Hydro-meteorological Forecasting (NCHMF) were collected to assess the changes in weather in Vietnam over a long period. In the north of Vietnam exists four seasons per year, namely winter (from December to February), spring (from March to May), summer (from June to August), and autumn (from September to November). The lowest and highest values of temperature are found each year in January and July, respectively (MONRE, 2011; MONRE, 2016).

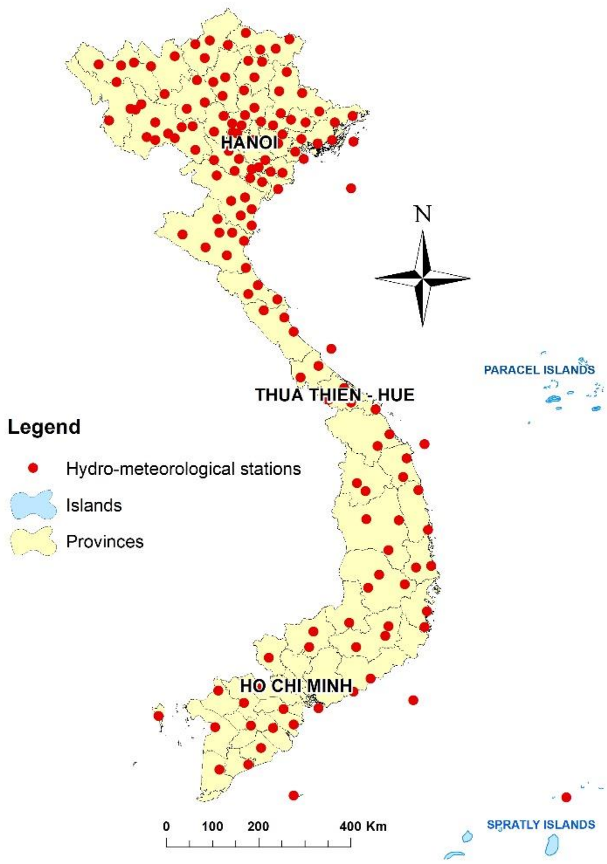


Figure 5.27: Positions of 60 hydro-meteorological stations in Vietnam

Many studies have indicated a positive relationship between the variety of plants and temperature as well as water resources (Lobo et al., 2001; Juli G Pausas et al., 2003). Temperature and precipitation are the key climatic conditions relating to forest production (Clark et al.,2003; Doughty & Goulden, 2009; Feeley et al.,2007) as well as the distribution of species (Austin et al., 1996; Currie & Paquin, 1987; Field et al., 2009; Hill, 2005; Knight et al., 1982; Miller, 1994; Morrison et al., 2006; Parmesan et al.,2000; Pausas & Carreras, 1994; Woodward & Williams, 1987). The ranges of temperature determine the limitations for plants and animals to survive (Moore, 2008). The tolerance of tropical trees to freezing temperatures is not so high, and many plants cannot survive in a temperature lower than 10^0C (Moore, 2008; Parmesan et al., 2000; Frank, 1987). The ability of photosynthesis of tropical plants decreases when the temperature is above the range of 26 to 34^0C (Graham et al., 2003; Ishida et al., 1999; Keller & Lerdau, 1999; Koch et al., 1994; Lerdau & Throop, 1999; Tribuzy, 2005). Protection was mentioned as an important function of the forest to cope with many different hazards (Führer, 2000). The forest helps to retain the climate balance as well as the atmosphere at the global level(Moore, 2008). Several studies have shown the potential responses of tropical forests to adjusting temperatures, drought, and other extreme factors (Deborah A. Clark, 2004).

The data from 13 hydro-meteorological stations in three provinces (Hoa Binh, Ninh Binh, Thanh Hoa), collected in 2015 were used to determine monthly average temperature, highest monthly average temperature, lowest monthly average temperature, highest absolute temperature in a month, lowest absolute temperature in a month, daily amplitude of monthly average temperature.

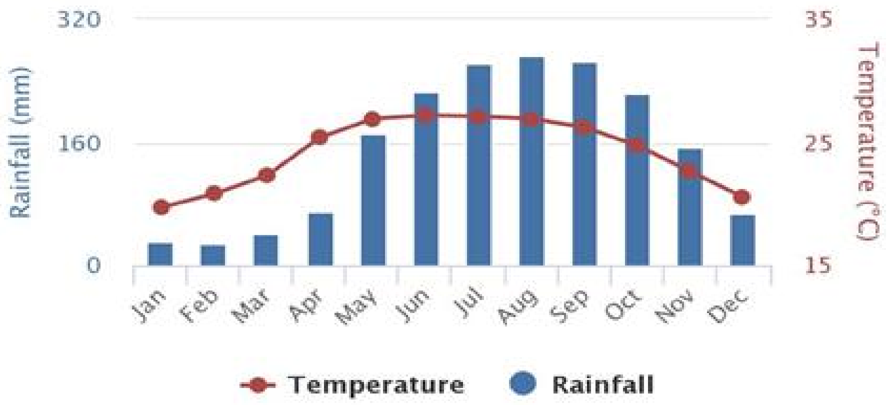
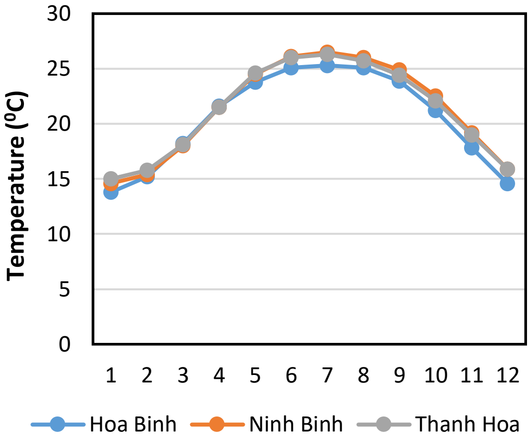
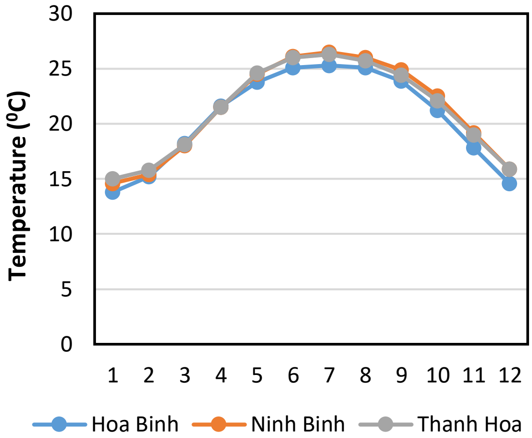


Figure 5.28: Average Monthly Temperature and Rainfall in Vietnam (Source: The World Bank Group)

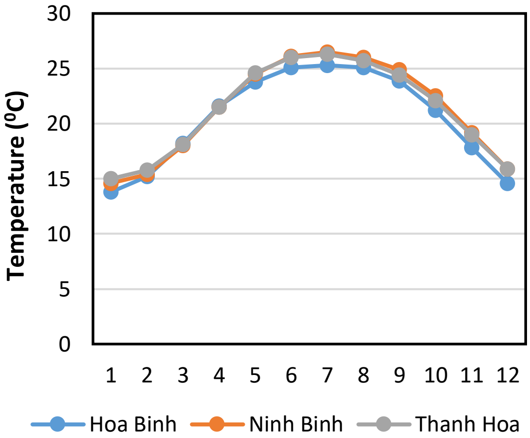
Figure 5.29 shows that changes in monthly temperature in the three provinces are similar. The lowest and highest temperature are in from December to January and from June to July, respectively. The same results were found from the statistic of the World Bank Group (Figure 5.28).



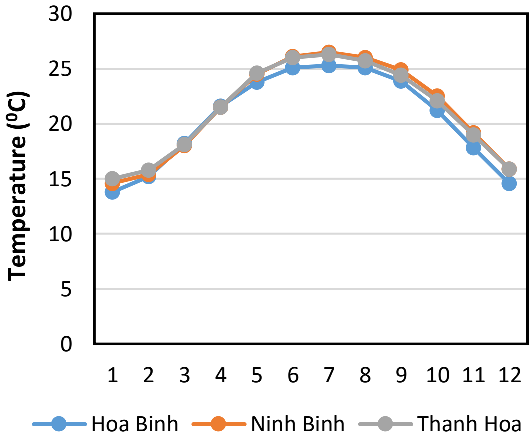
a. Lowest average monthly temperature



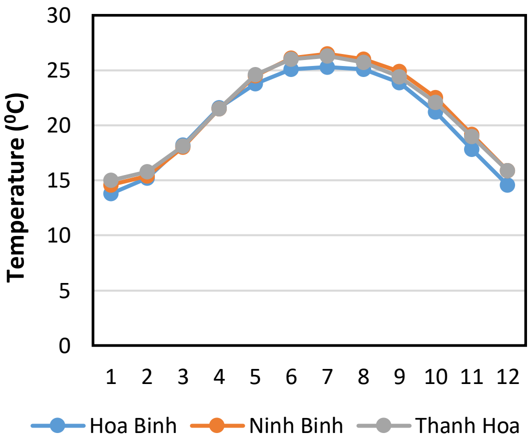
b. Highest average monthly temperature



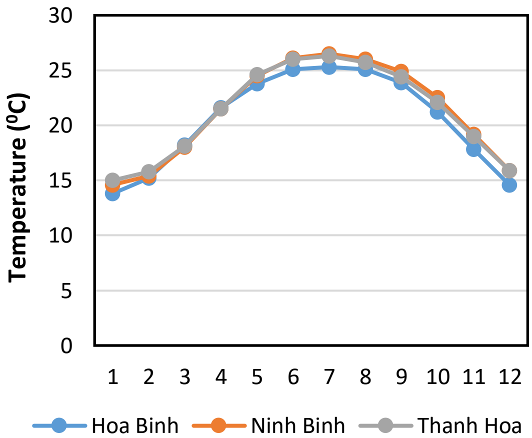
c. Lowest absolute temperature month



d. Highest absolute temperature month



e. Monthly average temperature



f. Daily amplitude of average monthly temperature

Figure 5.29: Monthly change of temperature in three provinces

Temperature and rainfall are two main aspects of climate that impact biodiversity conservation in Vietnam. The change of these elements can cause the decline of biodiversity and the disappearance of endangered species. In this study, we focused on the element of temperature since the change of temperature may largely influence the distribution of species. We did not have enough data to calculate the changes in rainfall.

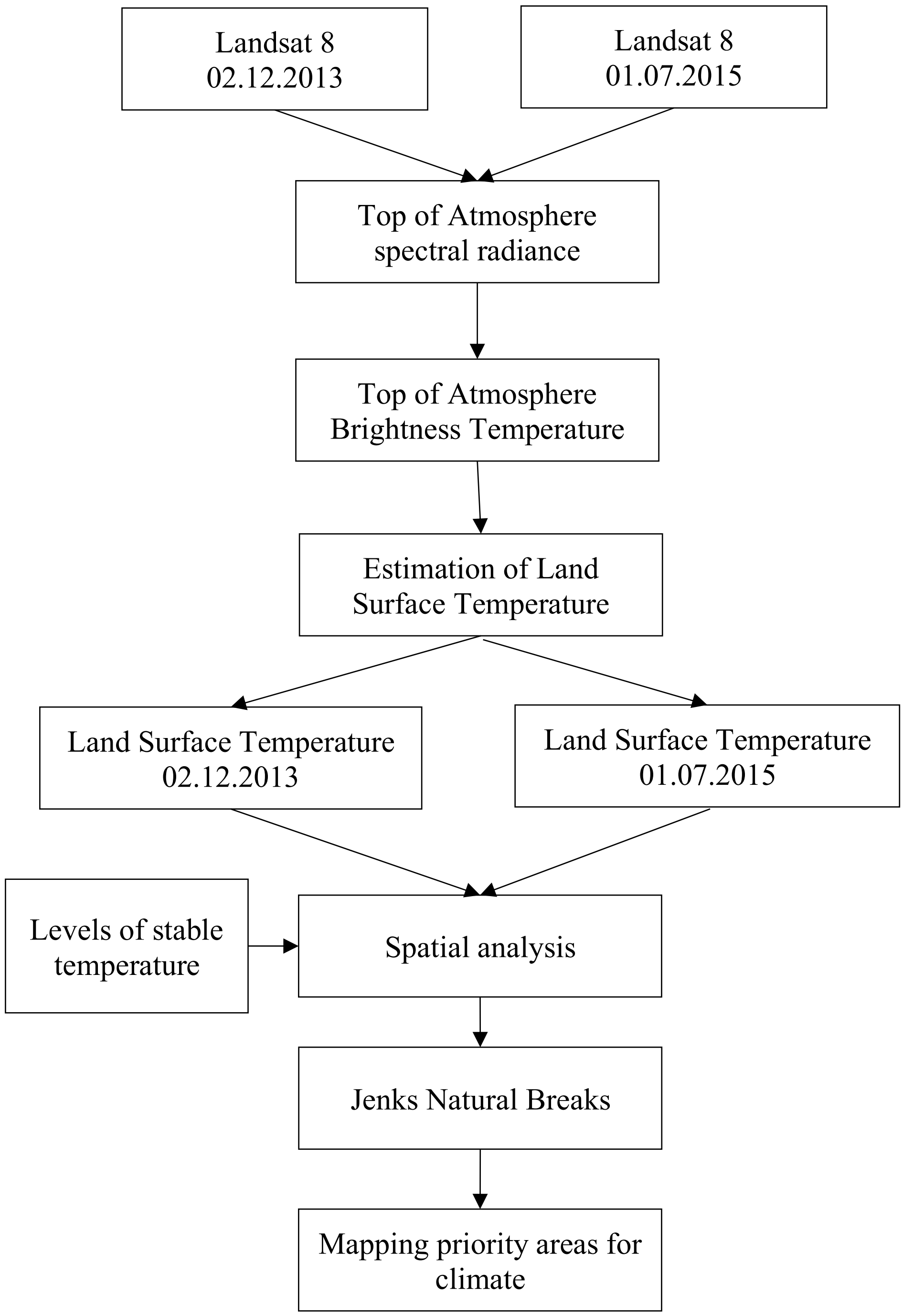


Figure 5.30: Framework for mapping priority areas of climate

Landsat 8 images acquired in December 2013 and July 2015 were collected to represent two specific periods of temperature in Vietnam as well as the study area. The land surface temperature of the study site in July and December was calculated through three steps, including top of atmosphere spectral radiance, top of atmosphere brightness temperature, and estimation of land surface temperature as described in Figure 5.30. The data of land surface temperature, including the lowest period and the highest period, were compared through spatial analysis method and classified by Jenks Natural Breaks to establish the map of priority areas for climate criterion in the study area.

Table 5.6: Satellite images used to define annual temperature change

No	Acquisition date	Path/ Row	Cloud cover (%)	Satellite image
1	02-12-2013	127/46	4.4	Landsat 8 OLI
2	01-07-2015	127/ 46	4.3	Landsat 8 OLI

Band 10 of Landsat 8 images was used to determine correctly and clearly the lowest and highest temperature of the study area. Two satellite images acquired in December 2013 and July 2015 were applied (Table 5.6).

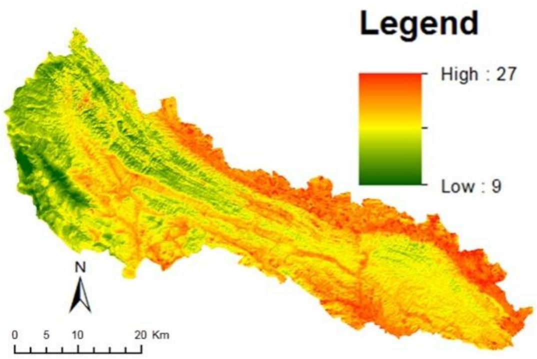


Figure 5.31: Land Surface Temperature in December 2013

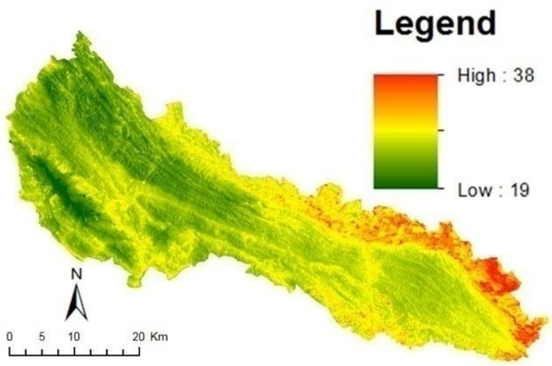
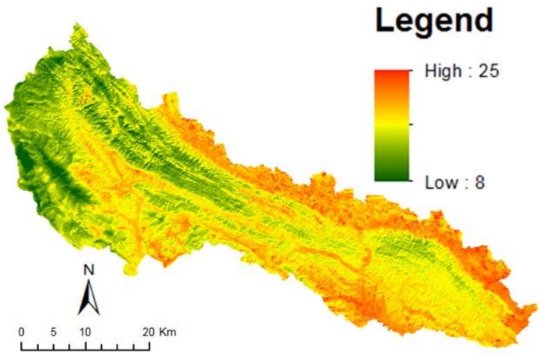


Figure 5.32: Land Surface Temperature in July 2015

Landsat 8 thermal bands were used to calculate the Land Surface Temperature in the study area. Land Surface Temperature was calculated through Landsat 8 images acquired in December 2013 and July 2015, which represent two seasons in a year with the lowest and highest temperature in the study area, as described in Figure 5.31, Figure 5.32 respectively. The temperature data of Landsat 8 images in December 2013 and July 2015 were re-calculated based on the acquired times and the daily temperature fluctuations of corresponding hydro-meteorological stations. The results are shown in Figure 5.33 and Figure 5.34.



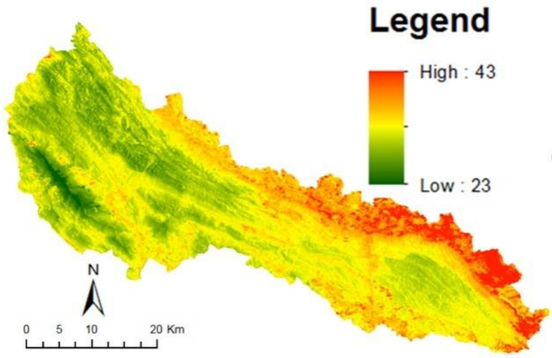


Figure 5.33: Land Surface Temperature recalculated in December 2013

Figure 5.34: Land Surface Temperature recalculated in July 2015

The results have shown that the lowest temperatures in the study area could be observed in December (Figure 5.33), and the highest temperatures could be found in July (Figure 5.34). Maps were created based on surface temperature in these two months and then overlaid them to show the fluctuation of temperature in the study area. Table 5.7 shows the five levels of temperature changes in the study area that range from 8^0C (very low) to approximately 26^0C (very high).

Table 5.7: Priority levels of annual temperature change

N_0	Categories of annual temperature fluctuation (^{0}C)	Priority levels	Weights
1	8.01 - 14.00	Very high	4
2	14.01 - 15.33	High	3
3	15.34 - 16.65	Medium	2
4	16.66 - 18.32	Low	1
5	18.33 - 25.78	Very low	0

The temperature has a relationship with biodiversity of a specific area since the stability of temperature provides suitable conditions for many species, and these areas often have high biodiversity. Based on maps on temperature changes, we applied Jenks Natural Breaks to categorize five levels of stability of annual temperature, including very high, high, medium, low, and very low (Table 5.7) and present these levels in the study area (Figure 5.35).

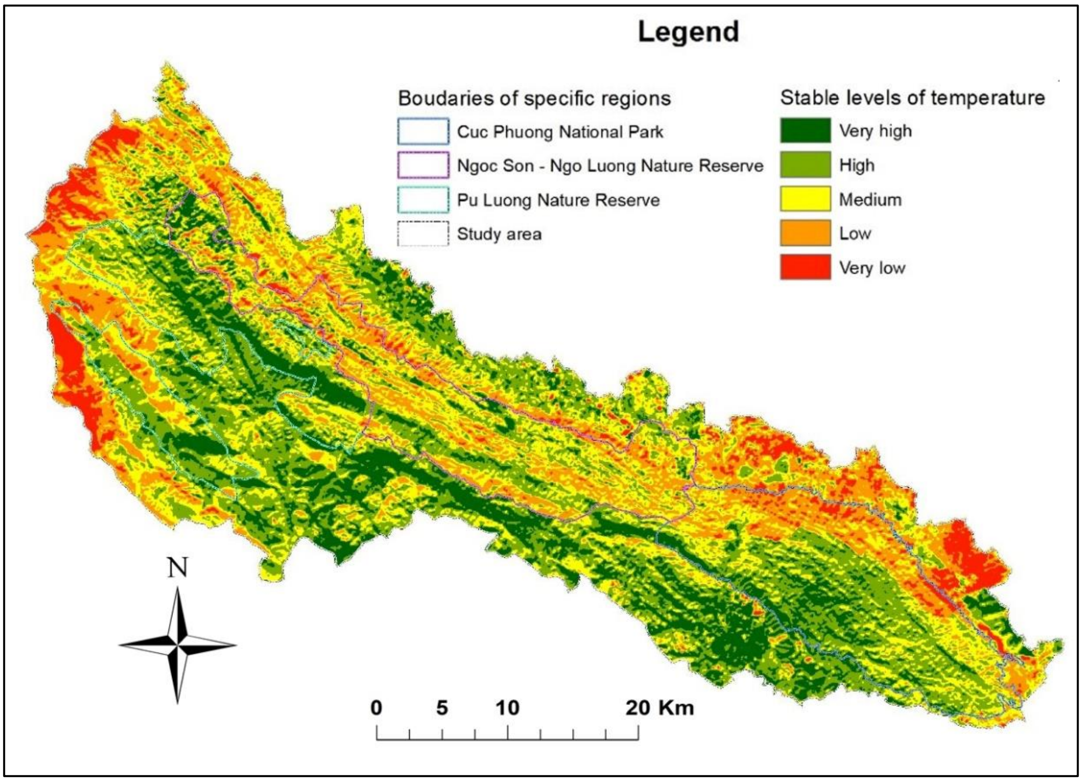


Figure 5.35: Stable levels of temperature in the study area

Appendix III - Table III. 10 shows the areas with the stability levels of temperature in the study area. 47.2% of the total area has very high or high stability level of temperature. The stability levels were also shown for each protected area. Of these, the proportion of area at very high or high stability level of temperature is 7.9%, 4.7%, and 7.4% for CPNP, NSNLNR, and PLNR, respectively (Figure 5.36).

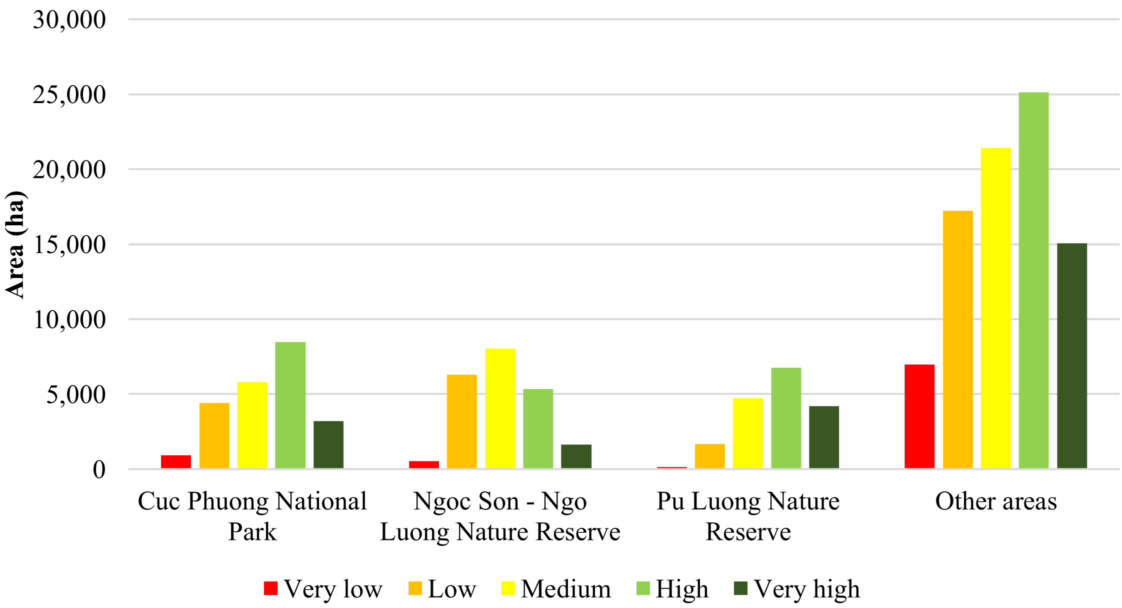
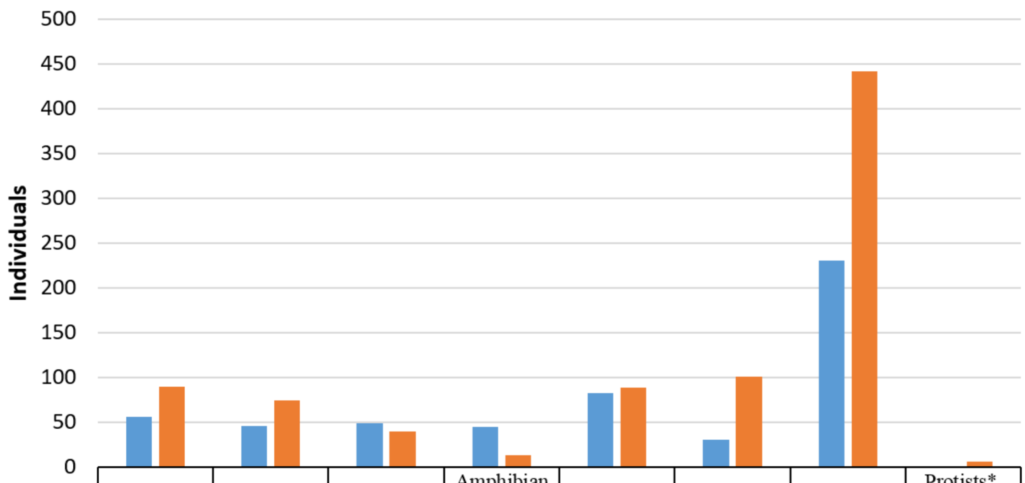


Figure 5.36: Assessment of priority levels of climate in the study area

5.1.2.4. Hydrology

Rivers and streams with their many tributaries are an indispensable component of most low land forests. They are considered as the habitat for numerous forest animals and fish (Moore, 2008; Williams et al., 2004). Streams and springs do not only provide habitats to a variety of species and supply food to neighboring ecosystems (Meyer et al., 2007). They are also an important source to disperse seeds, which help to enrich the number and distribution of plant species (Moore, 2008). The vital role of every river and wetland ecosystem is recognized broadly to conserve native biodiversity (Lytle & Poff, 2004; Poff et al., 1997; Postel & Richter, 2012).

According to the decree of the Vietnam Government on 23rd September 2003 on the conservation and sustainable development of submerged areas, the forest areas that help to maintain and protect the water resource, as well as the biological balance, are priority regions for conservation (VNG, 2003b). Forest in tropical regions plays a vital role in the water cycle by retaining water resources and intercepting rain and thus reducing the risk of erosion and floods (Moore, 2008). The relationships between hydrology and biodiversity of the plant-based on the water demand have been shown clearly from many studies over the past few decades (Feddes & Dam, 2004). Therefore, the loss of forest cover has threatened many fishes, which could lead to their extinction (Dudgeon, 2000).



	Mammals	Birds	Reptiles*	Amphibians	Fishes*	Molluscs*	Plants*	Protists* Fungi &
IUCN	56	46	49	45	82	30	231	0
Viet Nam	90	74	40	13	89	101	442	6

Figure 5.37: Taxonomic group of threatened species in Vietnam

Source: (Ban et al., 2007; IUCN, 2013; Thanh et al., 2007)

Additionally, hydrological areas play an essential role as the vital habitat of many endangered species, including fish and amphibians. Figure 5.37 shows the number of threatened species in Vietnam by IUCN and Vietnam Red Data Book 45 amphibian and 82 fish species, and 13 amphibian and 89 fish species, respectively. Vietnam Red Data Book in 2007 of animals has shown much freshwater fish (37 species), and amphibians (13 species) are critically endangered, endangered, or vulnerable species (Thanh et al., 2007).

A comparison of biodiversity in rivers, streams, ditches, and ponds in a region of Southern England showed the contrast with national protection strategies that merely concentrate on large waterbodies (Williams et al., 2004). The number of species recorded from the samples showed the decreasing trend of biodiversity at ponds, rivers, streams, and ditches, respectively (Figure 5.38). The hydrological areas do not only impact the diversity of fish and amphibians, but they also increase the number of terrestrial species.

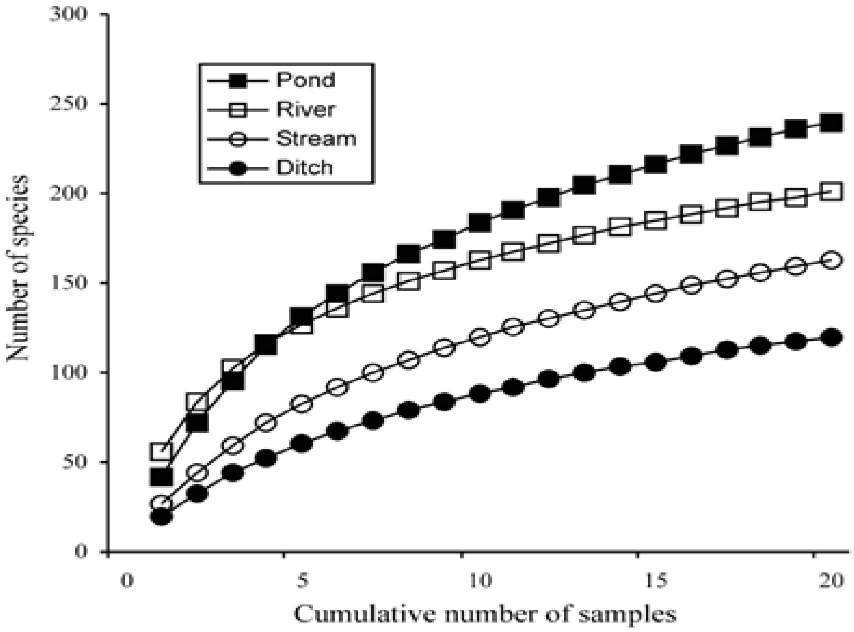


Figure 5.38: Accumulation curves of species from the four waterbody types

Source: (Williams et al., 2004)

The maps of Hoa Binh, Ninh Binh, and Thanh Hoa provinces have been established on two central meridians (105^0 and 106^0) (Vietnam projection). Thus, data conversion is the first step in transforming the hydrological map in the three provinces into the selected standard projection and format before they are combined and clipped by the boundary of the study area (Figure 5.39). Sentinel-2 image acquired on the 9th of April 2018 is used as the data source to interpolate visually and obtain the map of hydrology in 2018.

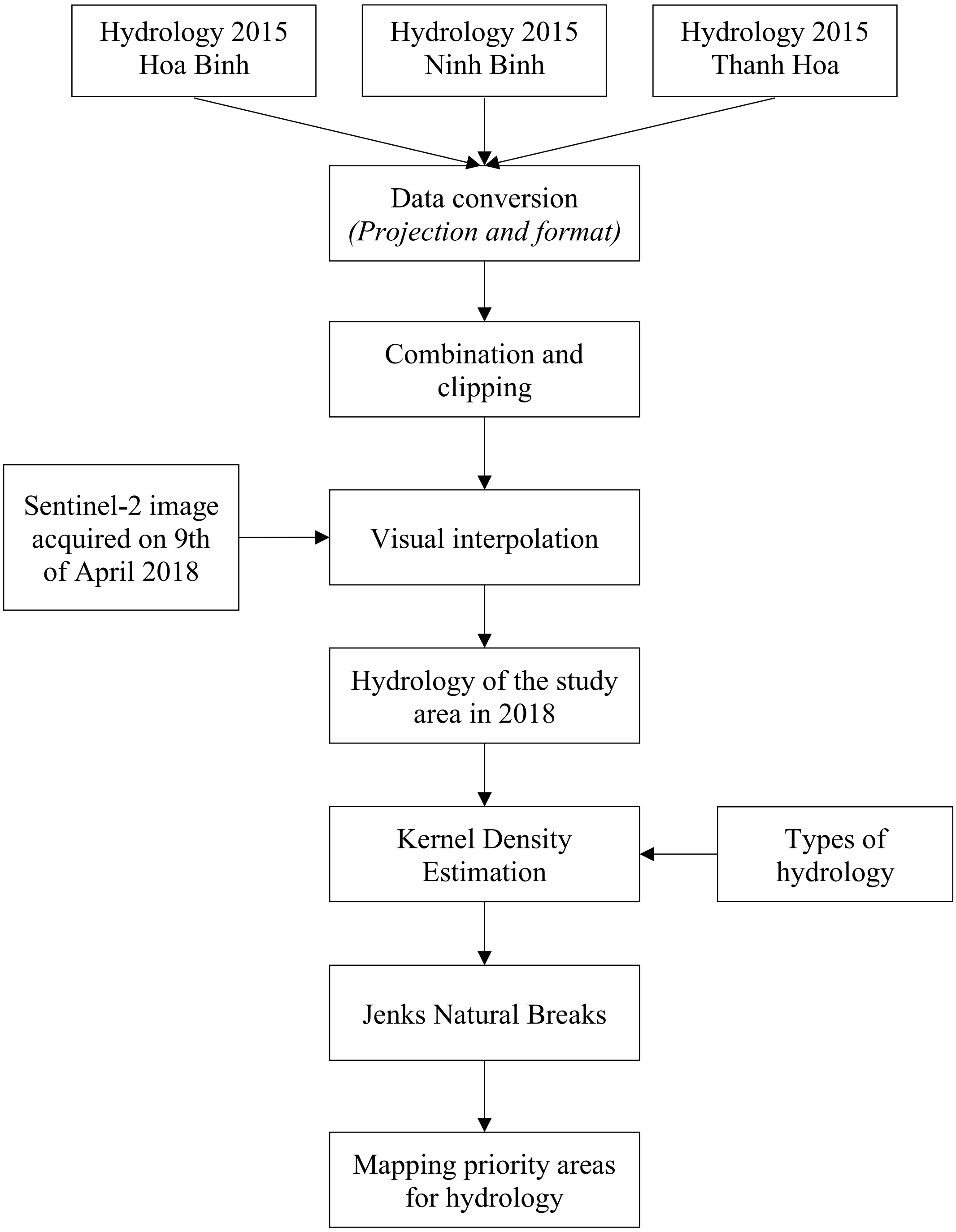
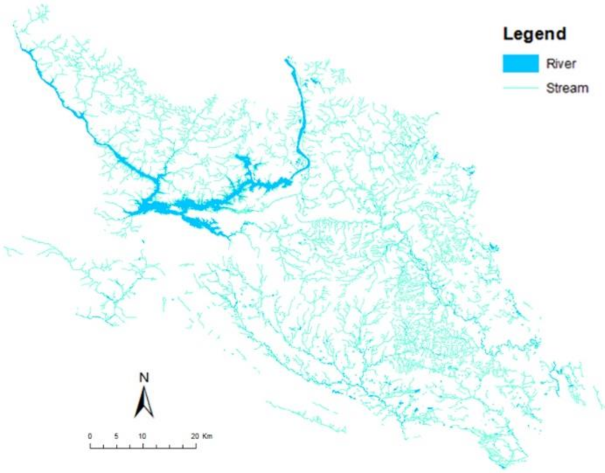
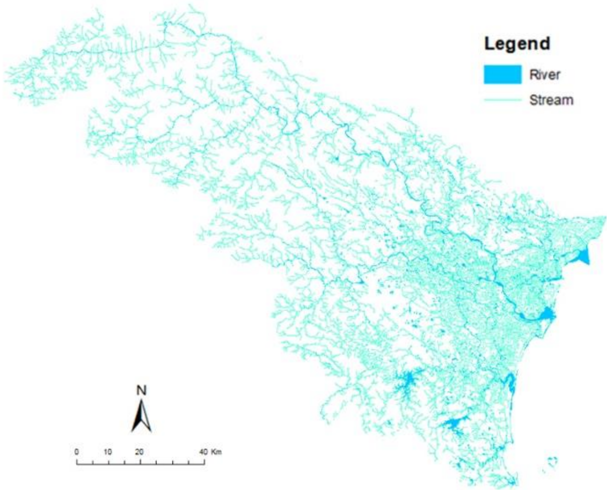


Figure 5.39. Framework for mapping priority areas of hydrology

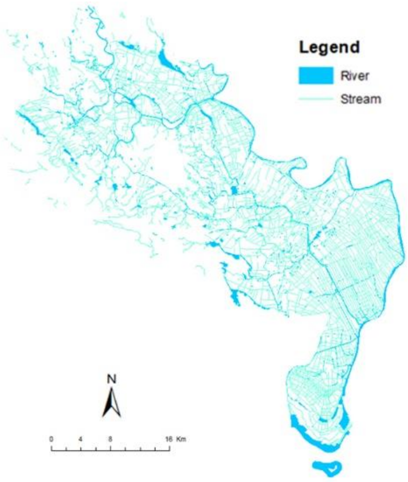
The hydrological map is digitized into two types of objects, including lines and polygons. However, to apply the Kernel Density Estimation method, features must be presented as points or lines. Thus, the polygon objects will be separated and converted into line format for calculating Kernel Density. The weights of hydrology are applied for the Kernel Density Estimation because of the difference in biodiversity between different types of hydrology in practice (Figure 5.39). Finally, the map of priority areas for hydrology criterion is divided into five groups with different levels ranging from very low to very high using Jenks Natural Breaks classification. The hydrological map of the study area is collected from the layers of rivers and streams on the published maps for Thanh Hoa, Ninh Binh, and Hoa Binh provinces (Figure 5.40).



a- HoaBinh province



b- Thanh Hoa province



c- Ninh Binh province

Figure 5.40. Hydrological system in Hoa Binh, Thanh Hoa, and Ninh Binh provinces

The maps of three provinces were established based on the Vietnam projection called VN2000. However, the VN2000 projections used in Thanh Hoa, Ninh Binh, Hoa Binh provinces are different and derived from divergence of positions and area. Therefore, there is a need to use different methods to convert the coordinate system from VN2000 to UTM (WGS84) for each province to combine and clip the hydrological map for the study area. A plugin for QGIS of converting coordinates system VN2000 developed by Green Field Consulting limited company was downloaded and applied in this case. The data of the hydrological system were synthesized and presented as in Figure 5.41.

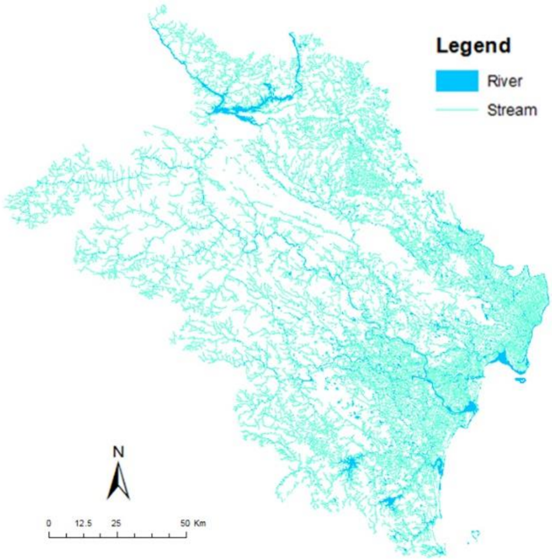


Figure 5.41: The hydrological system combined of three provinces

The layer of hydrology in the study area, combined and clipped from the published maps in Thanh Hoa, Ninh Binh, Hoa Binh provinces, was edited and updated by overlaying with the Sentinel-2 image acquired on the 9th of April 2018. According to Williams et al., 2004, the influence of waterbodies on biodiversity can be divided into two groups. The first group with rivers, lakes, and ponds are weighted higher than the second, including streams, springs, and ditches. The weights of the two groups were considered and illustrated, as shown in Table 5.8.

Table 5.8. Classification of hydrology in the study area

N0	Category	Weight
1	Rivers, lakes, and ponds	3
2	Streams, springs, and ditch	1

Many previous studies have shown the influences of hydrology (i.g. river, stream, lake, pond) on the level of biodiversity (Moore, 2008; Williams et al., 2004). The level of biodiversity is higher in the areas which have a high density of hydrological elements (Lytle & Poff, 2004; Poff et al., 1997; Postel & Richter, 2012).

It has shown that the areas with a high density of hydrological elements are classified as priority areas for biodiversity conservation. Based on the collected data, we identified and divided the hydrological system into two categories with priority levels, as shown in Table 5.8.

Table 5.9: Classification of priority levels for hydrology in the study area

N0	Thresholds for priority levels of hydrology	Priority levels	Weights
1	≥ 6.79	Very high	4
2	4.71 - 6.78	High	3
3	2.88 - 4.70	Medium	2
4	1.20 - 2.87	Low	1
5	≤ 1.19	Very low	0

We applied Kernel Density Estimation to estimate the influence levels of the hydrology system in the study area. According to the method of Jens Natural Breaks, there are five levels of priority based on the criterion for hydrology (Table 5.9). Then, we established maps on priority levels of hydrological density in the study area (Figure 5.42).

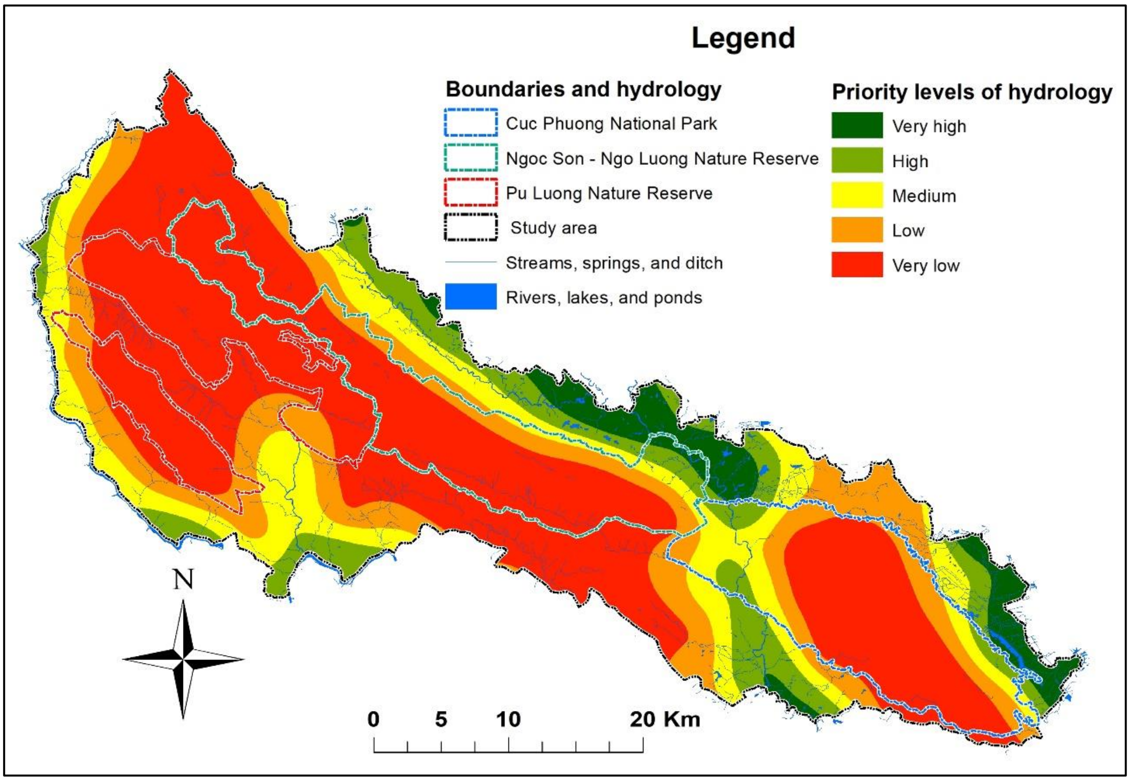


Figure 5.42: Priority areas for hydrology in the study area

The results calculated based on the priority areas of hydrology for biodiversity conservation in the study area show that most areas of high or very high priority levels of hydrology are outside of three protected areas (Figure 5.42). The area accounts for

16.3 % of the study area, with 14.3 % being outside of the protected areas. No priority areas regarding hydrology exist within the PLNR (Figure 5.43).

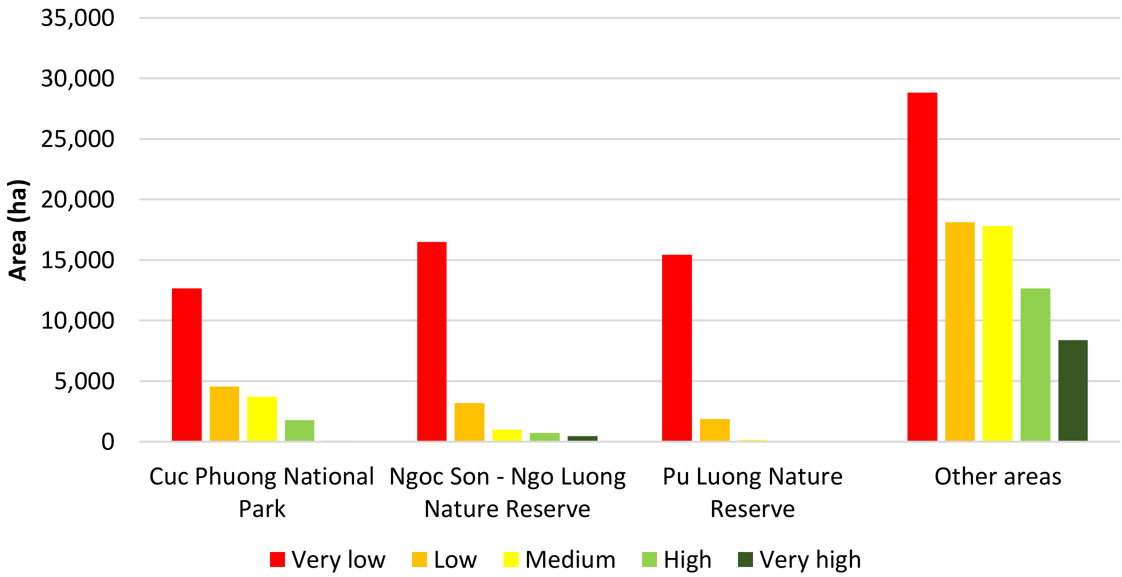


Figure 5.43: Assessment of priority levels for hydrology in the study area

The areas of high or very high priority belonging to the protected areas are only 2 % of the total area of the study area. It accounts for 8.1 % and 5.4 % of the areas of CPNP, and NSNLNR, respectively (Appendix III - Table III. 11).

5.1.2.5. Forest types

The ecosystem of tropical forests is known as a biodiversity hotspot due to its complex structure of valleys, mountains, wetlands, and rivers (Moore, 2008). Previous studies have shown that tropical forests contain many vegetation layers and various plant stratifications that provide food and appropriate habitats to many species (Coops et al., 2004; John et al., 2008; Luoto et al., 2004; Waring et al., 2006).

Besides, the Annamites, ***limestone formations***, and Hoang Lien mountains are significant ecoregions for many endemic species (Carew-Reid et al., 2011). Therefore, natural forests distributed on limestone mountains are considered as a high priority for biodiversity conservation since they support the diversity of species and endemism. The weights for priority level of forest types were calculated based on experts interview during fieldwork in Vietnam in 2017.

The forest statistic maps of Hoa Binh, Ninh Binh, and Thanh Hoa provinces in 2015 are primary input data of the framework (Figure 5.44). The data on forest types from the maps were separated before they were converted to preferred projection and format. Then the maps of forest types for the three provinces were combined into one layer, which was clipped using the boundary of the study area.

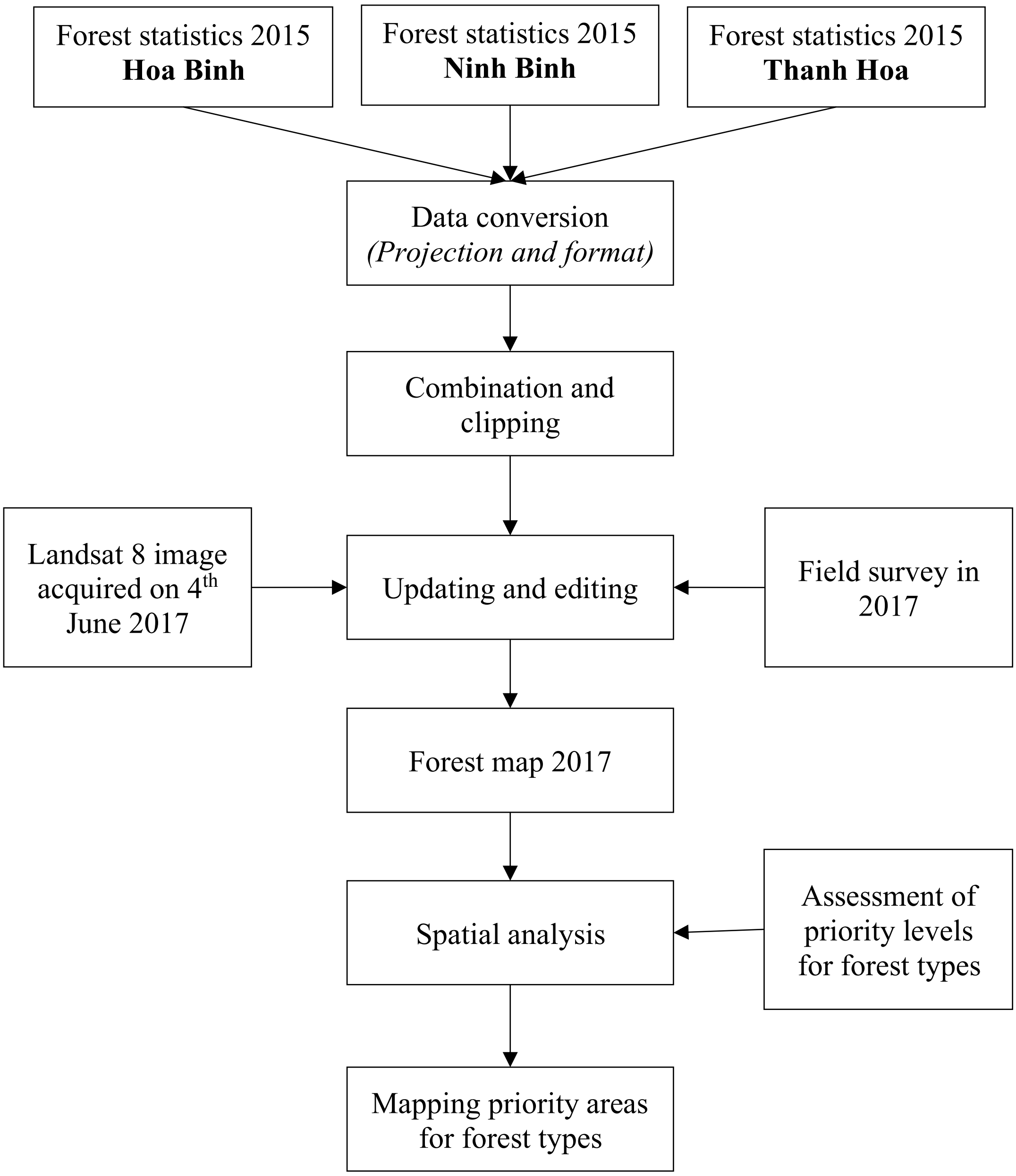
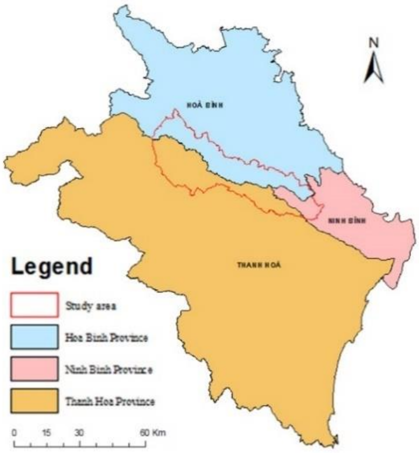
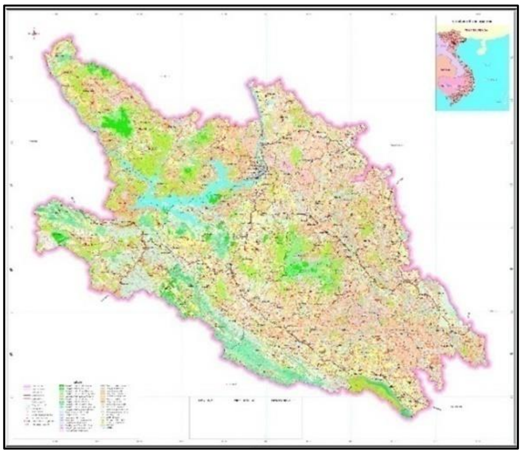


Figure 5.44. Framework for mapping priority areas regarding forest types

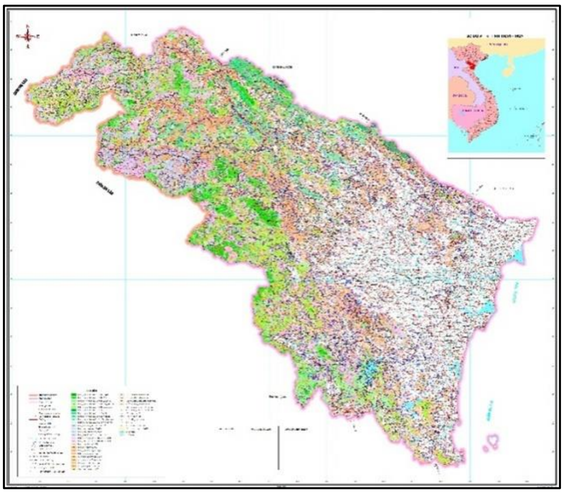
To understand the changes in forest types from 2015 to now, the forest map of the study area was updated using Landsat 8 image acquired on 4th June 2017 and the information from the field survey in 2017. An assessment of priority levels of forest types for biodiversity conservation was performed to determine the weight of each forest type. Finally, the spatial analysis was used as a tool to synthesize the data for establishing the map of priority areas regarding forest type criterion for biodiversity conservation (Figure 5.44).



a – Boundary of the study area



b - HoaBinh province



c – Thanh Hoa province

d – Ninh Binh province

Figure 5.45: Maps of forest statistics of Hoa Binh, Thanh Hoa and Ninh Binh in 2015

The primary data of forest types are based on the maps of forest statistics in 2015 of Hoa Binh, Thanh Hoa, and Ninh Binh provinces (Figure 5.45). Land use and land cover types were determined and zoned with 14 groups based on the maps on forest statistics in 2015 of Thanh Hoa, Ninh Binh, Hoa Binh provinces (Appendix III - table III. 12). It is crucial to assess the priority levels of forest types for biodiversity conservation in the study area.

Three maps were converted from VN2000 into UTM (WGS84), enabling overlay with other maps created in this research. Then the data of the three provinces were combined and clipped to the boundary of the study area (Figure 5.45). Finally, forest map of the study site was edited and updated by using the data from the field survey in 2017 and the Landsat 8 image acquired on 14th June 2017, as shown in Figure 5.46.

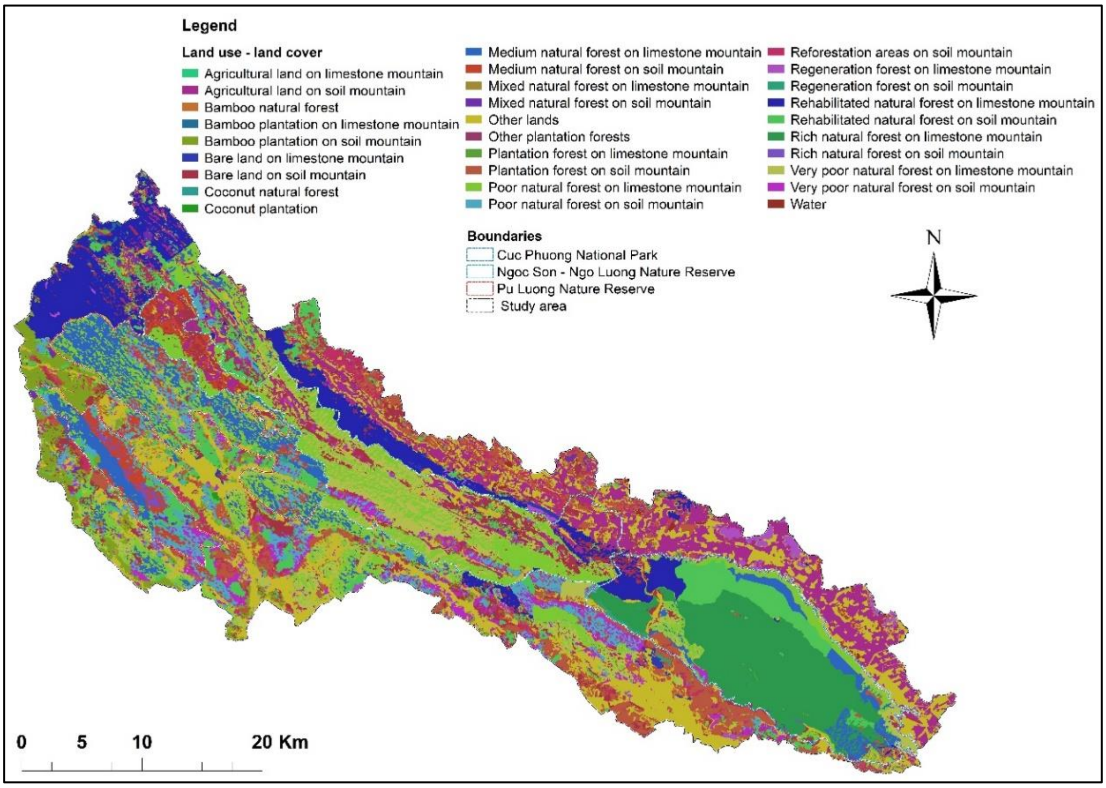


Figure 5.46: Forest map updated by Landsat 8 image in 2017

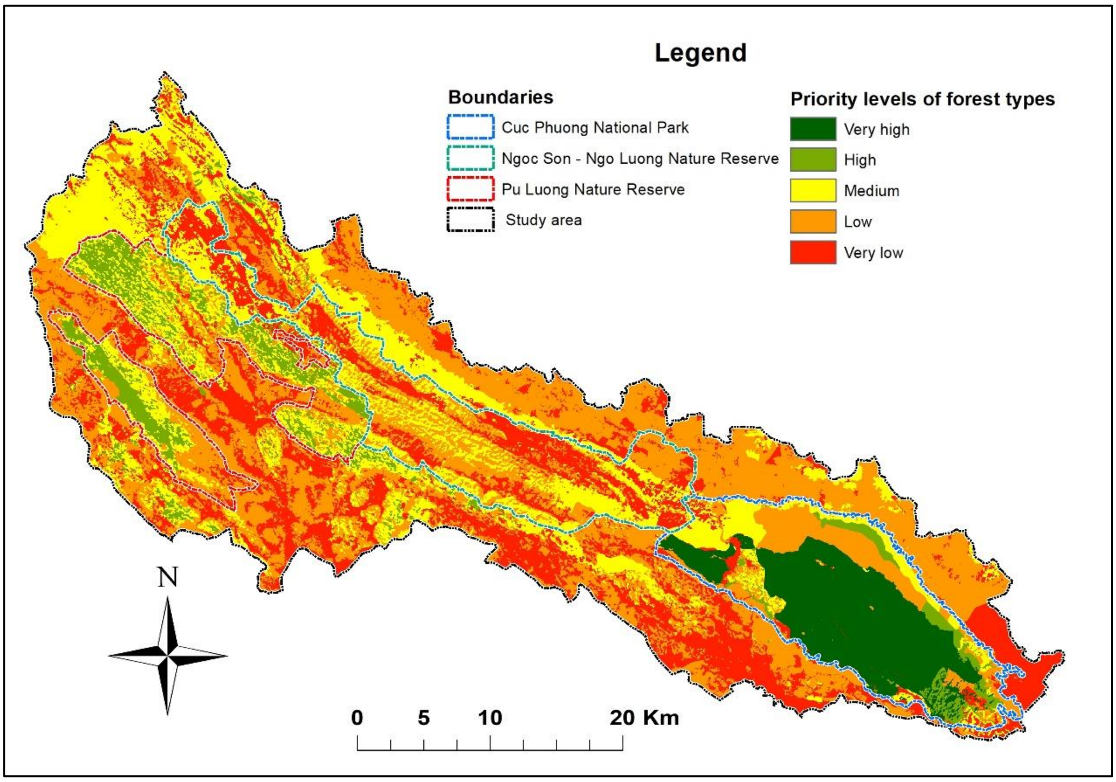


Figure 5.47: Priority areas regarding forest types in the study area

Forest statistic maps of three provinces have been collected to establish maps on forest types in the study area. In forest statistic maps, forest types are classified based on the

Circular 34/2009/TT-BNNPTNT released by the Vietnamese Ministry of Agriculture and Rural Development. The maps of forest types were updated using Landsat 8 images in 2017 to increase the accuracy and reliability of these maps. There are 32 types of different land use – land cover listed, of which 10 are types of forest (Appendix III - Table III. 12).

Based on the maps of forest types, we classified and evaluated priority areas for biodiversity, as presented in table 27. There are five priority levels in forest types, including very low, low, medium, high, and very high. A map was then created to show priority areas for biodiversity conservation based on forest type criterion (Figure 5.47).

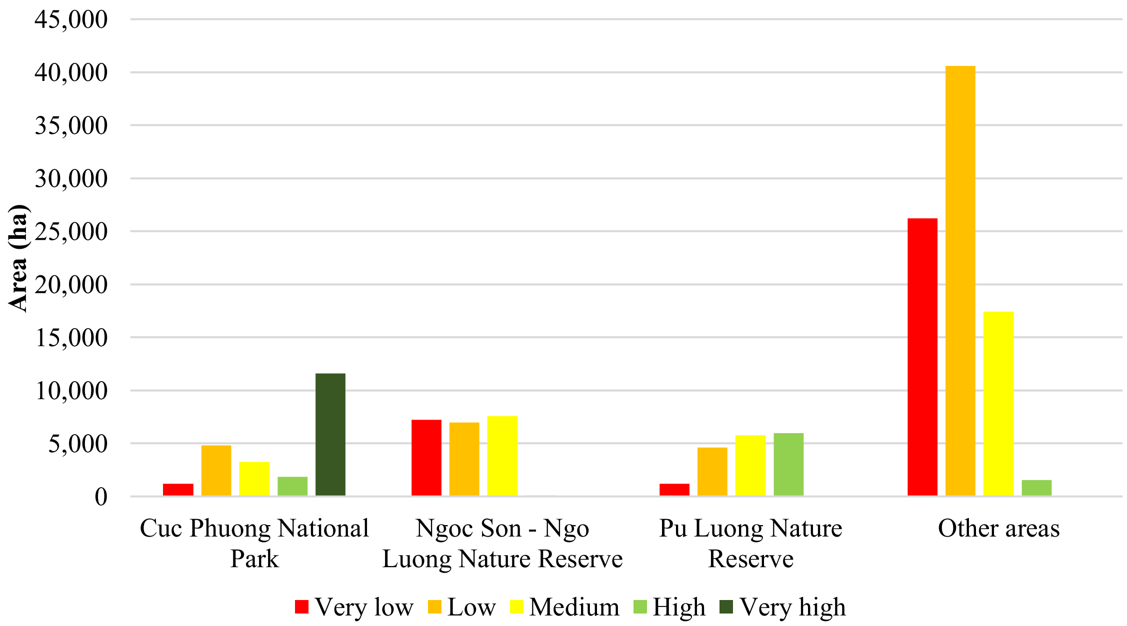


Figure 5.48. Assessment of priority levels for forest types in the study area

The areas of different priority levels have been calculated based on forest type criterion (Appendix III - Table III. 13). Our results show that 14.3% of the total area is classified as very high or high priority areas with the proportion of CPNP, NSNLNR, and PLNR, accounting for 9%, 0.1%, and 4% respectively. The rest (1%) is found outside the three protected areas. We also calculated the areas at very high or high priority levels for each protected area. It showed that very high or high priority areas accounted for 59%, 0.4%, and 34% in CPNP, NSNLNR, PLNR, respectively (Figure 5.48).

5.1.3. Nature

Over the last decades, the earth has experienced many considerable changes in the global climate. These changes have caused a variety of negative impacts such as the sea level rising, extreme changes in temperature, unpredictable fluctuations of precipitation and its distribution, and many other natural disasters (Moore, 2008). The human being has been facing the most complex challenges named climate change (Nguyen & Tenhunen, 2013). Several studies calculated and predicted the global modelling scenarios after 2050, which show the principal threats to biodiversity from climate change (IPCC et al., 2007; Strengers et al., 2004; Watson et al., 2005).

Global warming is the leading cause of climate change, which in turn influences the entire ecosystem (Kudo, 2016). Modelling analyses of climate change showed that a small change in temperature (2°C) and precipitation (20%) could have a profound influence on forest ecosystems (C. Miller & Urban, 1999). The changes in temperature or lack of vital resources can cause a significant decline in species (Moore, 2008). The World Bank considers that climate change will bring higher temperatures, extreme changes in rainfall patterns, sea levels rising, and more frequent natural disasters (MONRE, 2016).

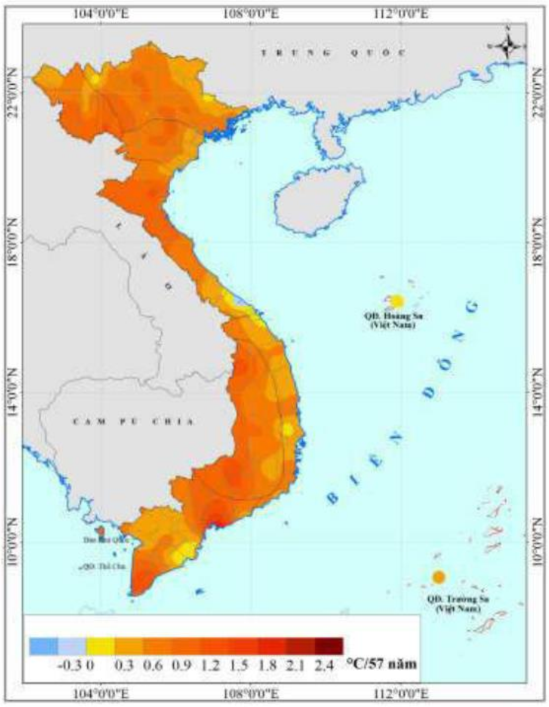


Figure 5.49: The changes in annual temperature (^{0}C) from 1958 to 2014

Source: (MONRE, 2016)

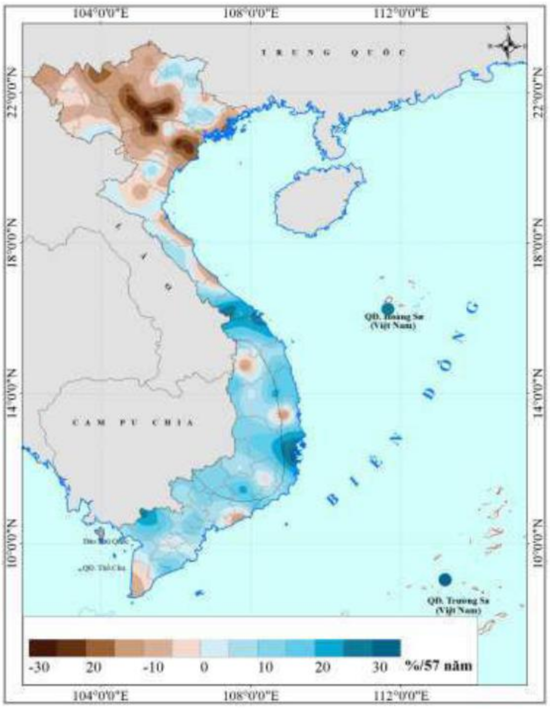


Figure 5.50: The changes in annual rainfall (%) from 1958 to 2014

Source: (MNRE, 2016)

Vietnam is considered as a country that has suffered significantly from the negative impacts of climate change (MONRE, 2016). To mitigate the impacts of climate change, five climate models were used to calculate and establish the climate change scenarios for

Vietnam including AGCM/MRI model of Japan, PRECIS model from the UK Met Office, CCAM model from Australia, RegCM model from Italy, and clWRF model from the United States (MONRE, 2016). To create the 2016 scenario of climate change (Figure 5.49, and Figure 5.50), data from 150 meteorological stations throughout Vietnam from 1986 to 2018 were collected.

The trend of climate change in Vietnam can be summarized as follows (MONRE, 2016)***:***

- The temperature at the number of meteorological stations has increased quickly in recent decades.
- The average amount of annual rainfall has fallen in the north and risen in the south of Vietnam.
- The minimum and maximum temperatures recorded at the meteorological stations have climbed.
- Drought appears more frequently in the dry season.
- The number of large storms has increased.

Vietnam, with a long 3200-kilometres coastline, frequently suffers from many storms (up to 10 storms per year) from the East Sea. According to the Japan International Cooperation Agency (2015), storms accounted for 52% of disasters in Vietnam, followed by floods with 42% (Rylko et al., 2015).

Table 5.10. The risk levels of Natural disasters in Vietnam

High Risk	**Medium Risk**	**Low Risk**
Flood	Hail rain/ tornado	Earthquake
Typhoon	Drought	Accident (Technology)
Inundation	Landslide	Frost
	Flash flood	Damaging cold
	Deforestation	

Source: The World Bank

The classification of natural disasters in Vietnam was divided into three groups, including high risk, medium risk, and low risk (Table 5.10). Flood, Typhoon, and Inundation are considered the highest risks.

5.1.3.1. Climate change

The workflow to identify pressure levels of climate change includes three key steps (Figure 5.51). The steps of data conversion were conducted to transform the data into the preferred projection and format used in the study. Then, maps that show changes in temperature and rainfall were clipped to obtain relevant data for the study area. Then, an assessment was conducted to identify the weights through the change levels of temperature and rainfall. The weights were used to classify the different regions that depend on the change levels of temperature and rainfall. Lastly, the maps that show changes in temperature and rainfall were overlaid to analyze and edit to present the criterion of climate change for defining priority areas in the study area.

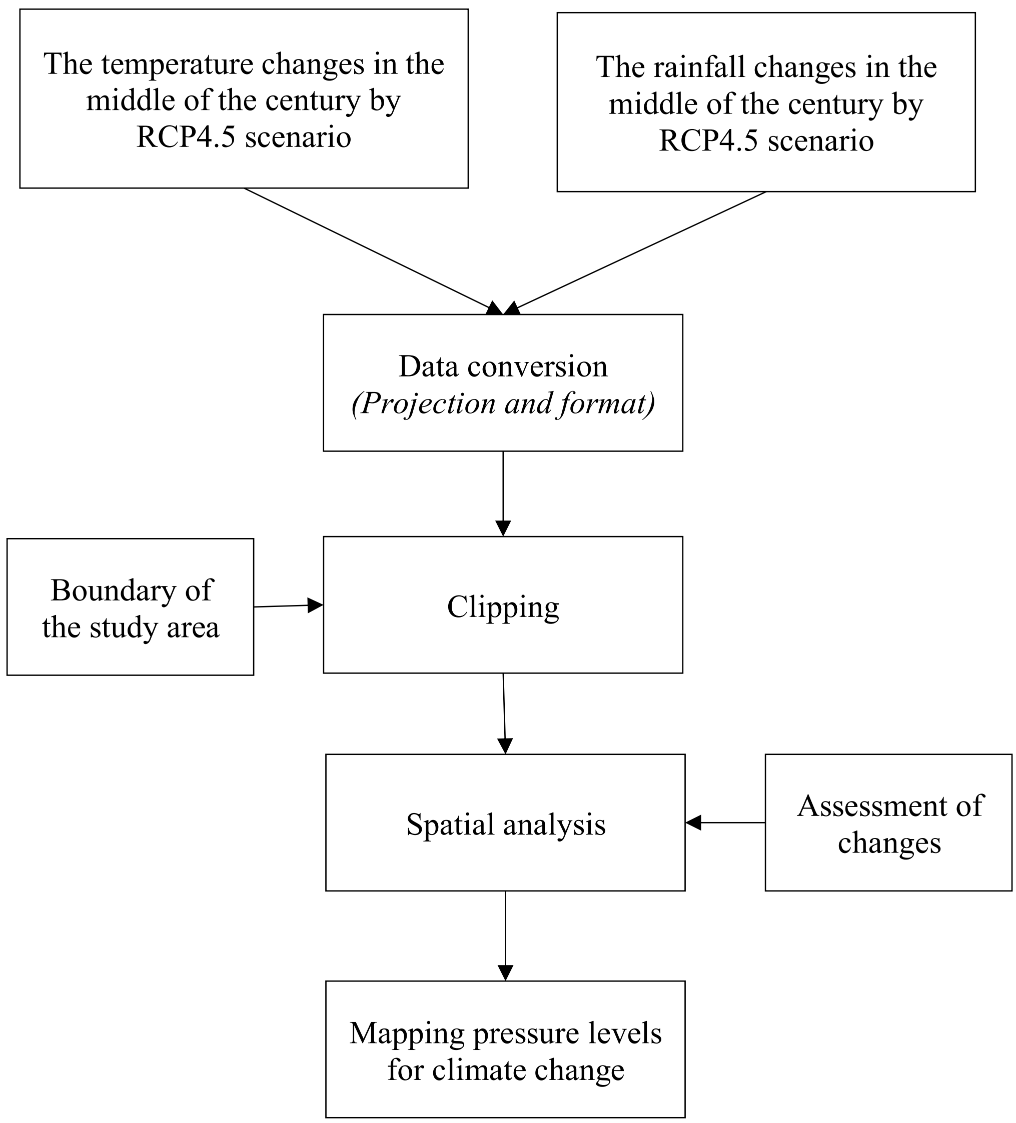
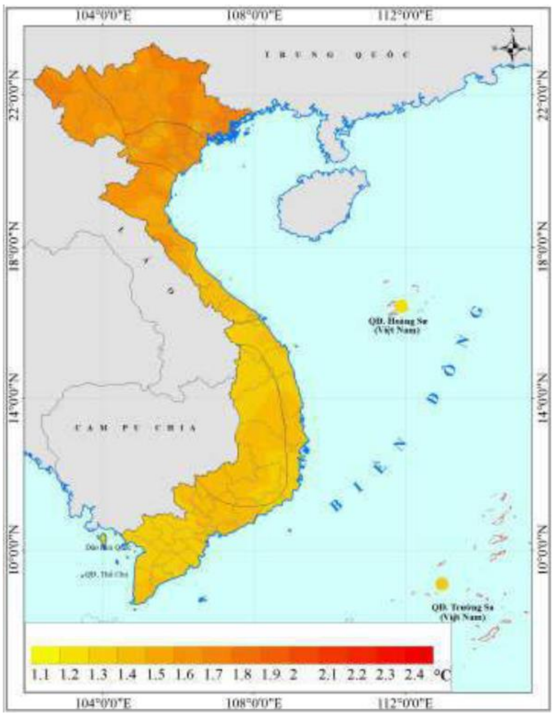
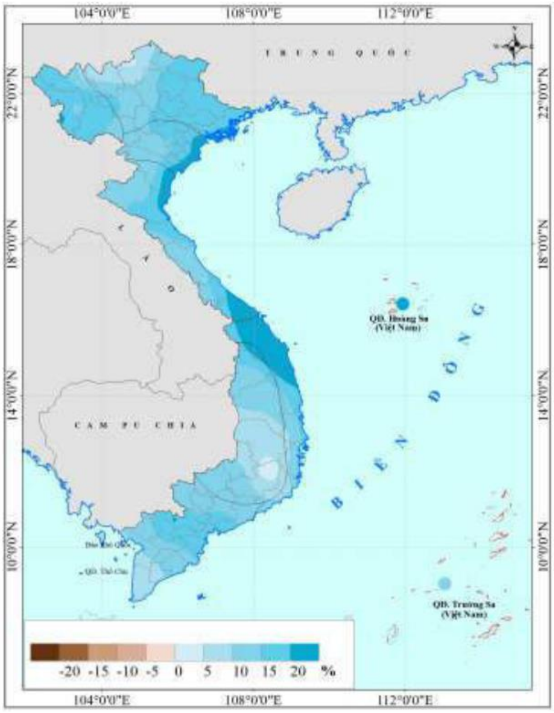


Figure 5.51. Framework for mapping pressure levels for climate change



a. The changes in annual temperature (^0C) created by RCP4.5 scenario



b. The changes in annual rainfall (%) created by RCP4.5 scenario

Figure 5.52. Estimation of annual temperature and rainfall changes from 2045 to 2065

Source: (MONRE, 2016)

The data on the changes of temperature and rainfall in the middle of this century (2046 - 2065) by the medium-low of Representative Concentration Pathways (RCP 4.5 scenarios) in 2016 were collected from the Ministry of Natural Resources and Environment (MONRE) (Figure 5.52).

Table 5.11. Change levels of temperature and rainfall in the study area (2046 –2065)

Temperature (^0C)	**Change levels of temperature**	**Rainfall (mm)**	**Change levels of rainfall**
1.96	Low	110.12	Low
2.23	Medium	118.28	Medium
2.44	High	122.58	High

Based on the climate change scenarios by MONRE, the data of Pu Luong – Cuc Phuong was clipped to the maps that represent the estimated changes in temperature and rainfall in the study area. Then the method of Jenks Natural Breaks was used to identify three thresholds for both temperature and rainfall changes, which represent three levels, including low, medium, and high (Table 5.11). Based on change levels, maps in estimating the temperature and rainfall changes were created for the period between 2046 and 2065 (Figure 5.53, and Figure 5.54).

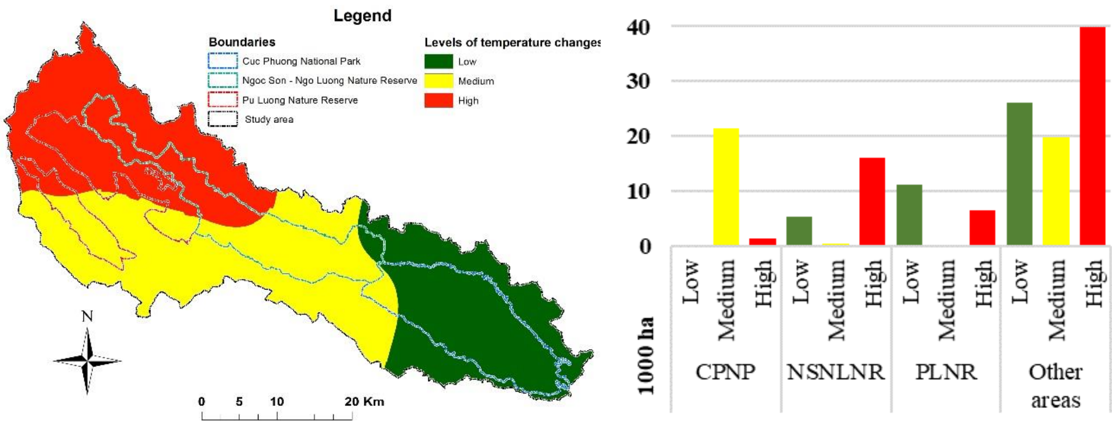


Figure 5.53. Pressure from temperature changes estimated from 2046 to 2065

We calculated the area at different change levels of temperature in the study area. Our results have shown that the areas of high, medium and low-temperature changes account for 32%, 39.4%, and 28.6% respectively. The most significant change of temperature was found in the Northwestern part of the study area, which covers NSNLNR and PLNR, making up 6% and 7.5% of the total area (Figure 5.53).

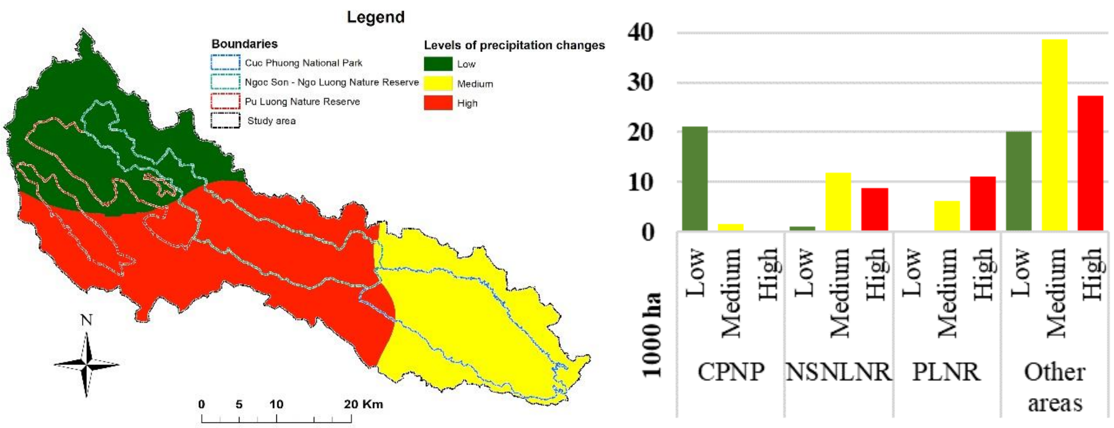


Figure 5.54. Pressure from precipitation changes estimated from 2046 to 2065

The rainfall changes in the study area also presented at high, medium, and low levels, making up 43.1%, 28.1% and 28.8% of the total area. It has predicted that the most considerable change in rainfall would affect NSNLNR (10.9%) and a small proportion in PLNR (4.3%) and CPNP (0.9%) (Figure 5.54).

Table 5.12. Classification of climate change through temperature and rainfall changes

Temperature	Rainfall	Climate change
High	High	Very high
High	Medium	High
Medium	High	
High	Low	Medium
Low	High	
Medium	Medium	
Medium	Low	Low
Low	Medium	
Low	Low	

In this study, the effects of climate change were predicted based on changes in temperature and rainfall. Therefore, we overlaid the maps on temperature and rainfall changes to show different levels of climate change in the study area (Table 5.12). There are four levels of climate change, which include very high, high, medium, and low.

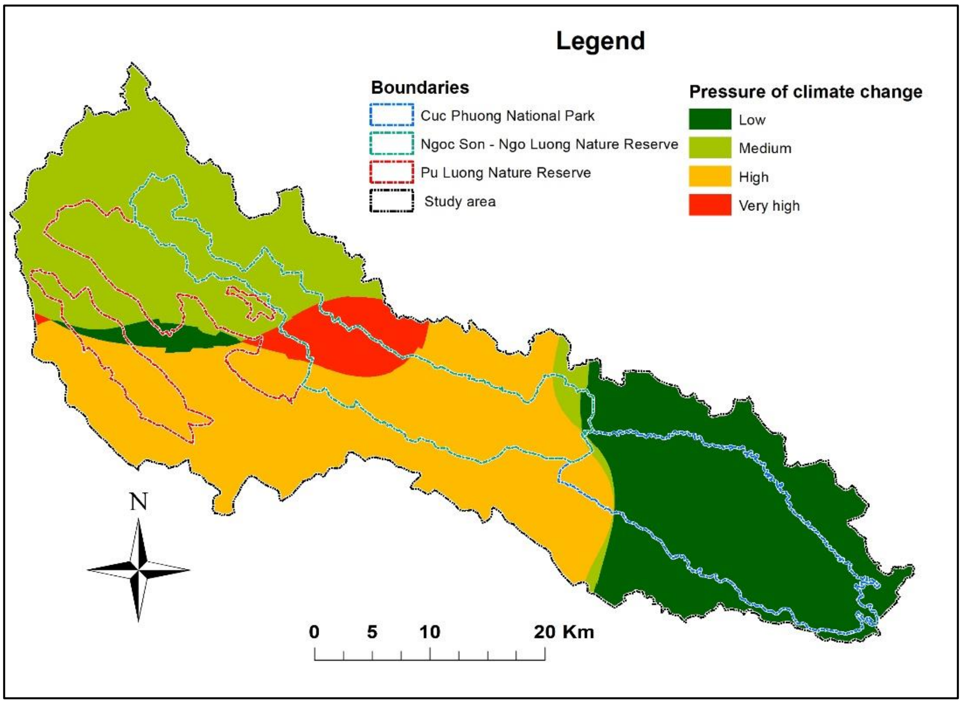


Figure 5.55. Predicted priority areas of climate changes in the study area (2046 - 2065)

Our results have predicted that climate change at high or very high levels would occur mainly in NSNLNR (10.5%), and a small percentage in PLNR (4.3%) and CPNP (0.9%) (Figure 5.55).

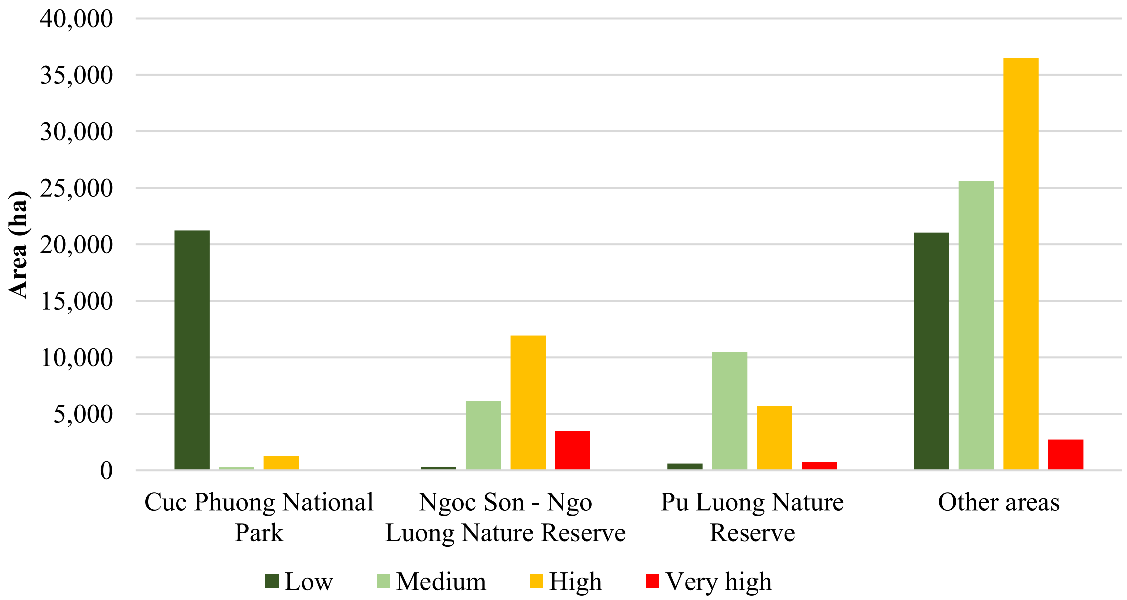


Figure 5.56. Assessment of pressure of climate change in the study area

We estimated the area at different levels regarding climate change in the study area, as shown in appendix III - Table III. 14. Our results have indicated that the areas at very high, high, medium, low levels of climate change account for 4.7%, 37.4%, 28.7%, and 29.2%, respectively. Of these, NSNLNR is predicted to hold a high proportion of area at the very high or high-level impact of climate change (10.5%). PLNR and CPNP make up 4.3% and 0.9% of the total area (Figure 5.56).

5.1.3.2. Natural disasters

To assess the risks of natural disaster in the study area, disaster information was collected across Vietnam. The locations of disasters were presented using points and their relative attributes on the map. The points were grouped into risk levels before they were used to calculate Kernel Density Estimation. Then the estimated maps were classified by the Jenks Natural Breaks method to determine the five pressure levels on biodiversity conservation arising from natural disasters (Figure 5.57).

Information on the natural disasters collected from the website of GLIDE (http://www.glidenumber.net/) which lists the disaster types, and particular characteristics such as date of occurrence, name of location, position (latitude, longitude), as well as the source cited (Appendix III - Table III. 15). The website shows that 119 natural disasters in Vietnam have been recorded during the period 1997 and 2018. The types of natural disasters include tropical cyclones, floods, drought, landslide, technology-related disaster, and local storms.

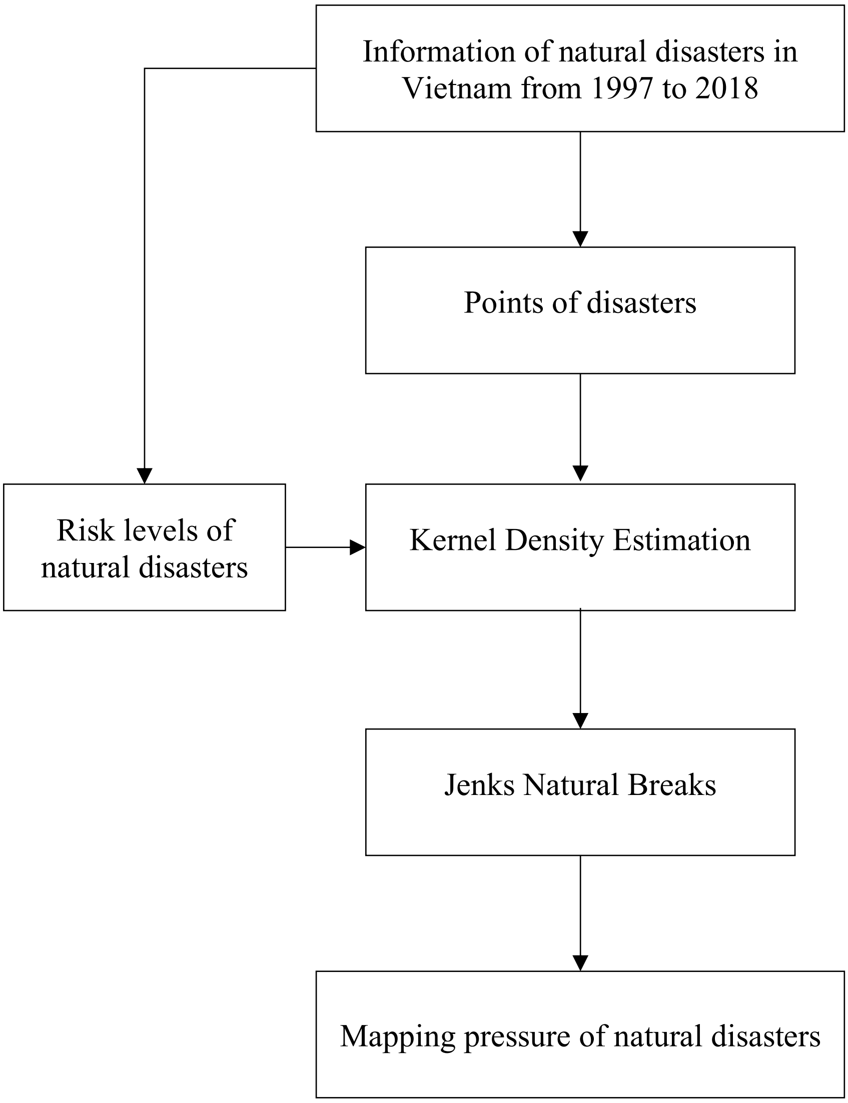


Figure 5.57. Framework for mapping pressure of natural disasters

The disasters were classified into three levels of risk based on categories of the World Bank (Table 5.10) and were used as the weights in the Kernel Density Estimation. The positions of the natural disasters were displayed as points on the map shown in Figure 5.58. To evaluate the pressure of natural disasters in the study area, we applied Kernel Density Estimation to the positions of natural disasters from 1997 to 2018 in Vietnam (Figure 5.59).

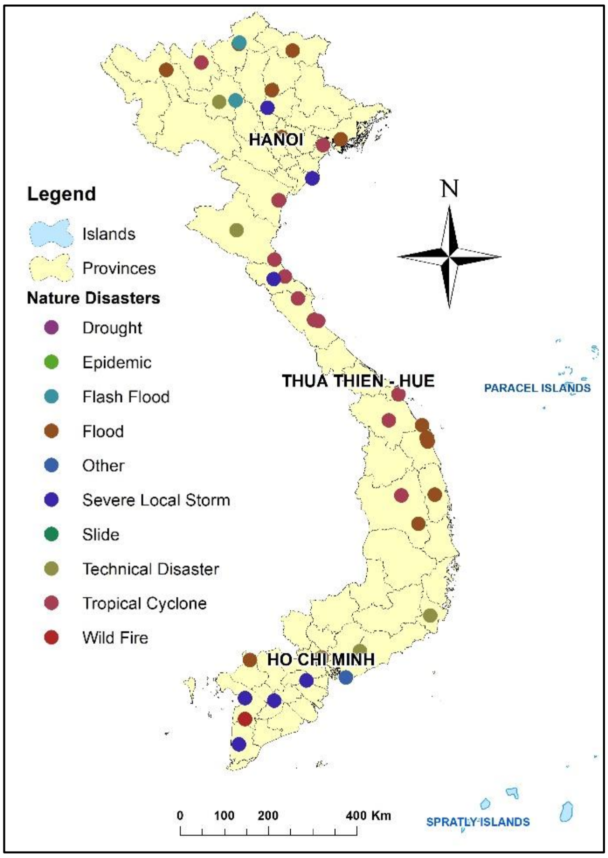


Figure 5.58. Locations of Natural Disasters in Vietnam from 1997 to 2018

The results have shown that natural disasters have little influence in the Pu Luong - Cuc Phuong region. Since there was not much difference in pressure of the natural disasters in the study area, and the influences of natural disasters were not used to define priority areas for biodiversity conservation in this research.

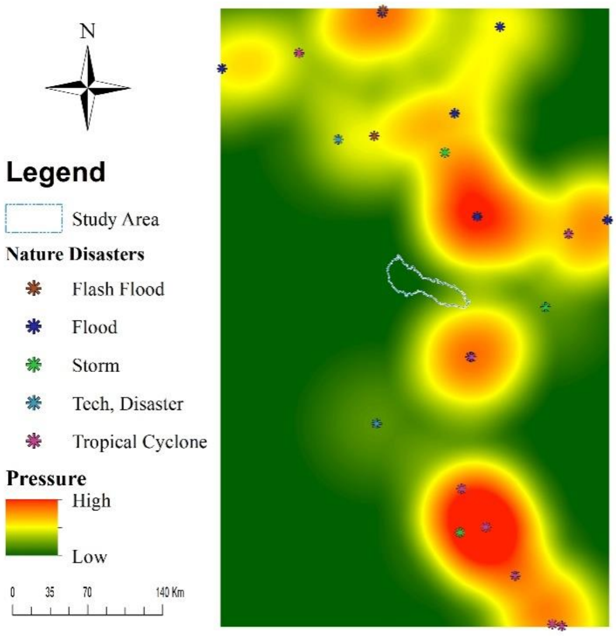


Figure 5.59. The pressure of natural disasters in the study area (1997 - 2018)

5.1.4. Human

Human beings have been widely accepted as a significant element, indirectly influencing biodiversity (B. Y. N. Dudley et al., 2006; Gordon et al., 2005; L. Joppa, 2012; L. N. Joppa et al., 2009; J. Liu et al., 1999; Luck, 2007; Naughton-Treves et al., 2005; Nguyen et al., 2013; Saunders et al., 1998; Sterling & Hurley, 2005). Among the many activities of humans, urbanization is considered as an urgent issue that impacts directly on global biodiversity due to its predicted expansion in the future (Seto et al., 2012). According to the Vietnam Academy of Forest Sciences, human settlement is an important criterion to assess and estimate the degradation of headwater-protected forests. The levels of impact depending on the distance between human settlements and protected forest. Three levels of influence (high, medium, and low) were identified based on three levels of distance between human settlement and protected areas, including under 2 km, from 2 to 5 km, and more than 5 km, respectively (http://vafs.gov.vn).

5.1.4.1. Distribution

The Land Use – Land Cover (LULC) maps in 2015 of Hoa Binh, Ninh Binh, and Thanh Hoa provinces were used to create the LULC data in 2018 of the study area. The maps were converted, combined, and clipped to the boundary of the study area before the data were updated and edited through the Sentinel-2 image acquired on the 9th of April 2018 and the information collected in the field survey in 2017 (Figure 5.60).

To establish the maps on the pressure of population distribution to biodiversity conservation, the information on settlements in the study area were separated by applying Kernel Density Estimation with the weight for each settlement class. Then, five levels of the pressure of the population distribution were identified by the Jenks Natural Breaks classification (Figure 5.60).

The study area is located on the boundaries of nine districts of three provinces (Hoa Binh, Ninh Binh, and Thanh Hoa). However, three communes of Trung Xuan, Trung Ha, and Trung Thuong that are located in Quan Son district were added to analyze the impacts of population distribution on biodiversity conservation. To acquire the maps on population distribution, land use-land cover maps released in 2015 of the ten districts and the Sentinel-2 image acquired on the 9th of April 2018 were used to update and edit the data on settlement distribution within and around the study area (Figure 5.61).

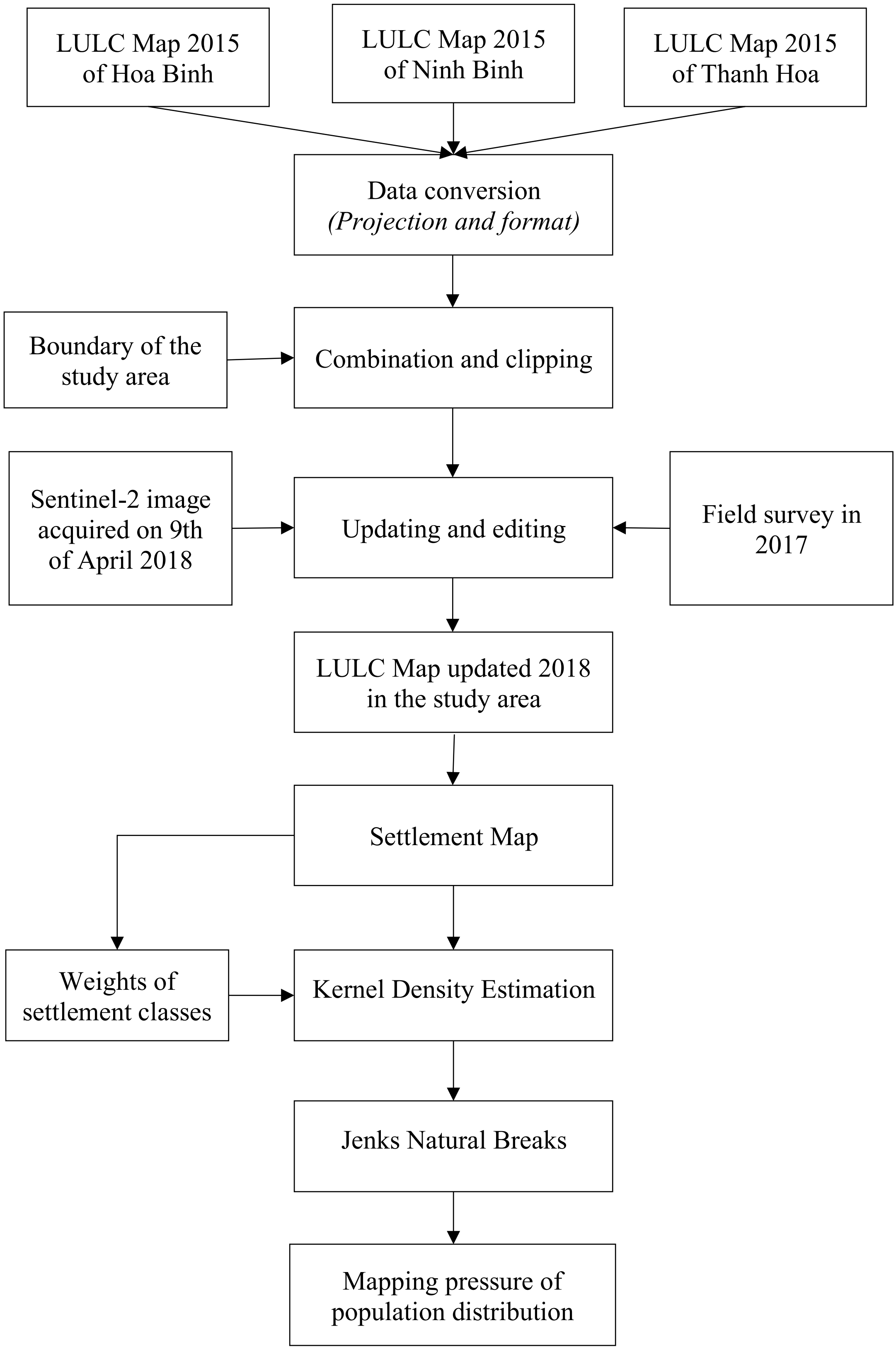


Figure 5.60. Framework for mapping pressure of population distribution

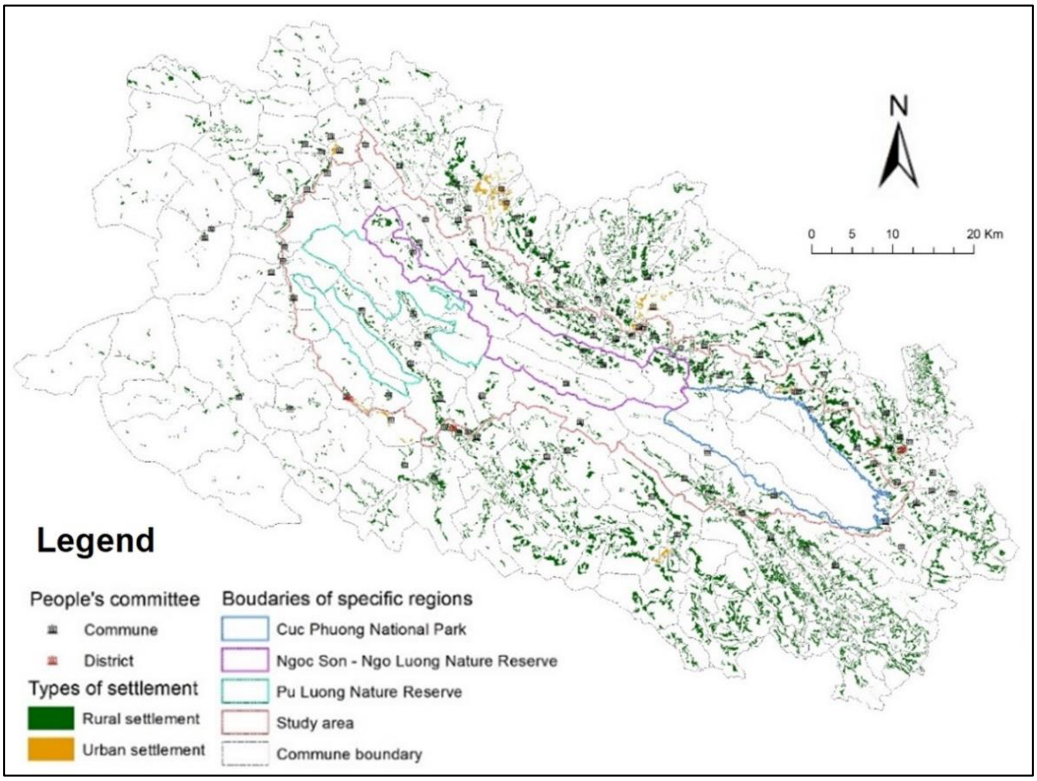


Figure 5.61. Settlement distribution of districts within and around the study area

To better understand population distribution in the study area, an assessment of settlements in urban and rural areas was performed and shown in Figure 5.62. Appendix III - Table III. 16 shows only 5.6% of the total area is settled with 5.5% and 0.1% split between rural and urban areas, respectively. The largest area of settled land exists inside the protected areas with 1,128 ha (0.8%) in NSNLNR. It is shown that the pressure of population distribution on the protected areas is small.

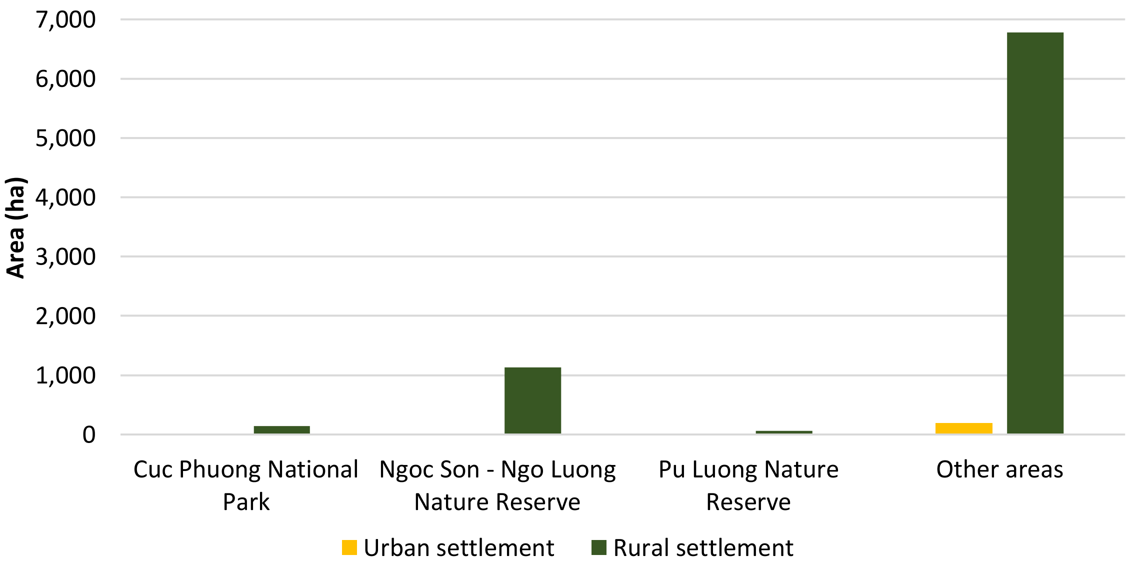


Figure 5.62. Comparison of settlement area among specific regions in the study area

To assess the impacts of population distribution in the study area, the data on settlements in the study area were used. It is complicated to apply the polygon format of the data by the Kernel Density Estimation method because only line and point formats can be used in this method. The polygons were converted into a raster file at a resolution of 10 meters before it was converted into point format with which it was able to apply the Kernel Density to define the areas influenced by population distribution (Figure 5.63).

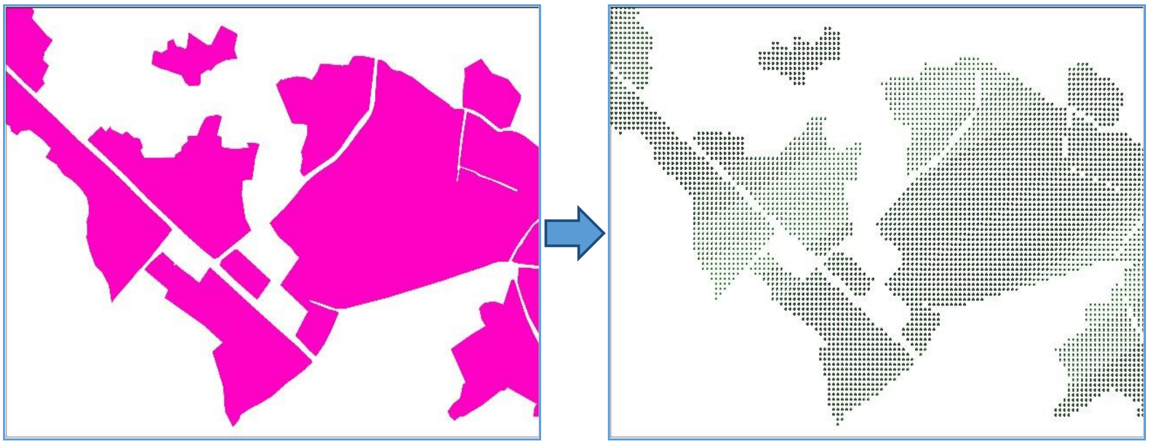


Figure 5.63. Converting Polygons to Points for using Kernel Density Estimation

The impacts of population distribution were assessed with the difference between rural settlements and urban settlements. The population of the urban regions is often higher than in the rural region. It means that the demand for wild products, as well as land resources, is significantly different among the settlement types. Therefore, different weights were applied to quantify the impacts of rural and urban settlements (Table 5.13).

Table 5.13. Impact levels of settlement types on biodiversity conservation

ID	Categories	Weight
1	Urban settlement	2
2	Rural settlement	1

Map data have been collected (e.g., land use map 2015, forest statistic map 2015, topography map, administration map) to gather data on population distribution and settlement area. Then we used the Sentinel-2 image in April 2018 to update information on settlement areas, which were then put into two categories: Urban settlement (town, city) and Rural settlement (commune, village). Two settlement areas were presented on maps to evaluate their influence on biodiversity conservation (Figure 5.61). It has shown that the influences of urban settlement and rural settlement on biodiversity conservation are different due to the differences in demand for forest products between the two settlement areas (Table 5.13).

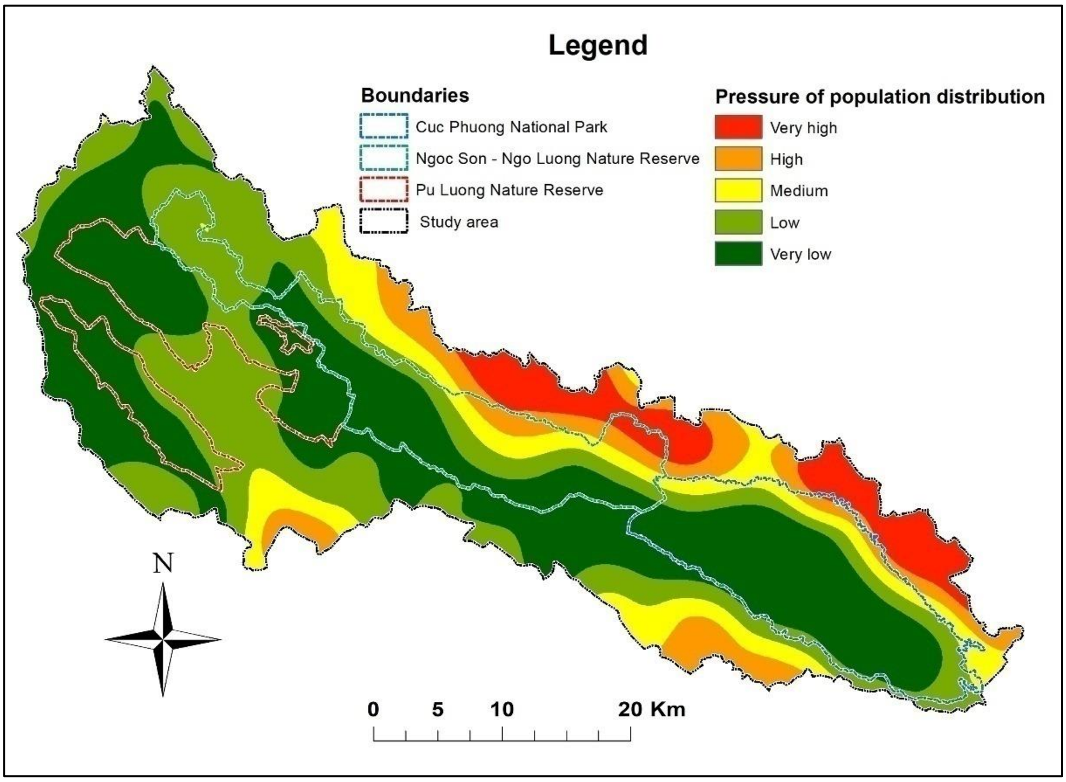


Figure 5.64. Levels of pressure of population distribution in the study area

In this study, Kernel Density Estimation was applied to identify the influence of population distribution on biodiversity conservation. Since Kernel Density Estimation can only be applied to objects which are presented by points or lines, the settlement areas were coded as points on the map. Based on the Jenks Natural Break method, the influence of population distribution on biodiversity conservation could be categorized into five levels, including very high, high, medium, low, and very low. Then a map was established to show five influence levels of settlement distribution on biodiversity conservation (Figure 5.64).

The results have shown that the influence of settlement distribution on biodiversity conservation in CPNP is shallow. It is because the population inside CPNP was moved out of the national park during its establishment. Settlements exist inside NSNLNR and PLNR, which led to the influences of population distribution on biodiversity at low or medium levels in PLNR and at a high level in NSNLNR. The influences of settlement distribution on biodiversity conservation at very low or low levels were found in 40.72%

of the total area. 16.8% of the total area was under the powerful influence of settlement distribution on biodiversity conservation (Appendix III - Table III. 17).

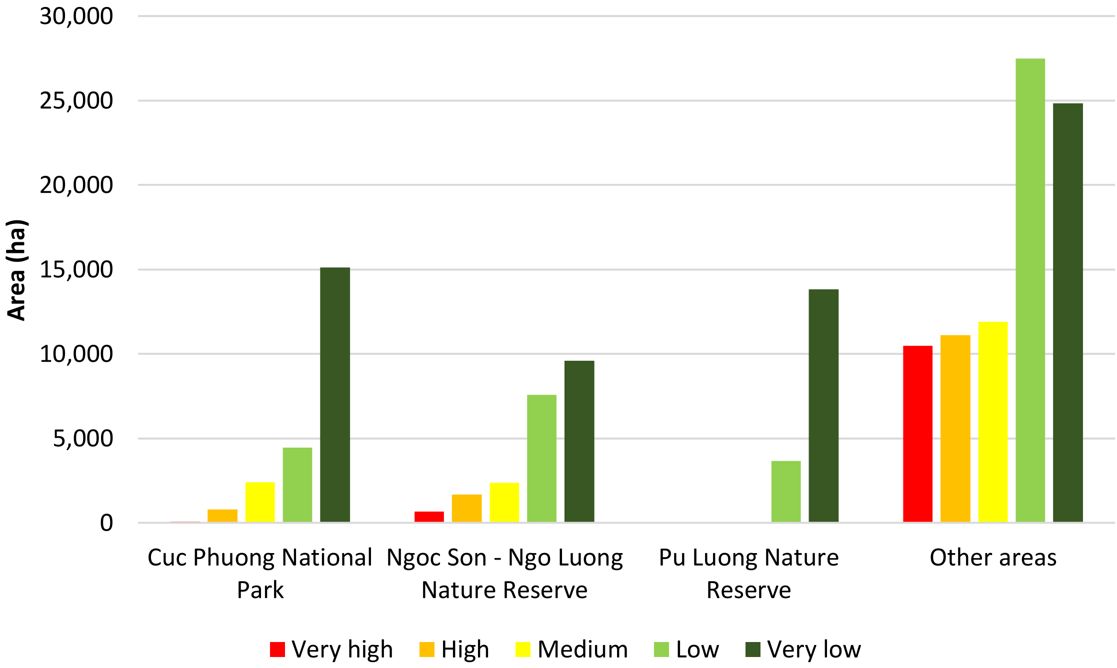


Figure 5.65. Assessment of pressure of settlement distribution in the study area

The influence levels of settlement distribution on biodiversity conservation were estimated for each protected area. In the CPNP, 3.8% of the national park's area was influenced by settlement distribution at very high or high levels. 85.8% of CPNP was under a low or very low influence from settlement distribution. In NSNLNR, the very high or high influence of settlement distribution could be found in 10.8% of the NSNLNR area, while 78.4% of the protected area was affected at the very low or low levels of settlement distribution. PLNR has only two influence levels: low and very low, accounting for 21% and 79%, respectively (Figure 5.65).

5.1.4.2. Density

In this study, the influences of population density on defining priority areas for biodiversity conservation were estimated based on data on the population, settlement areas, and the boundaries. The information on the population of the communes in the study area was gathered through the data on the Vietnam population statistic released in 2011 (Appendix III - Table III. 18).

The data were combined with the distribution of local people in each commune by overlay analysis. The human density was calculated based on the number of population and the area of settlement in each commune. The values were then used as the weights in the Kernel Density Estimation method to define the impact levels of population density. The map of human density pressure on biodiversity conservation was established with five influence levels ranging from very high to very low and was created by the Jenks Natural Breaks classification method (Figure 5.66).

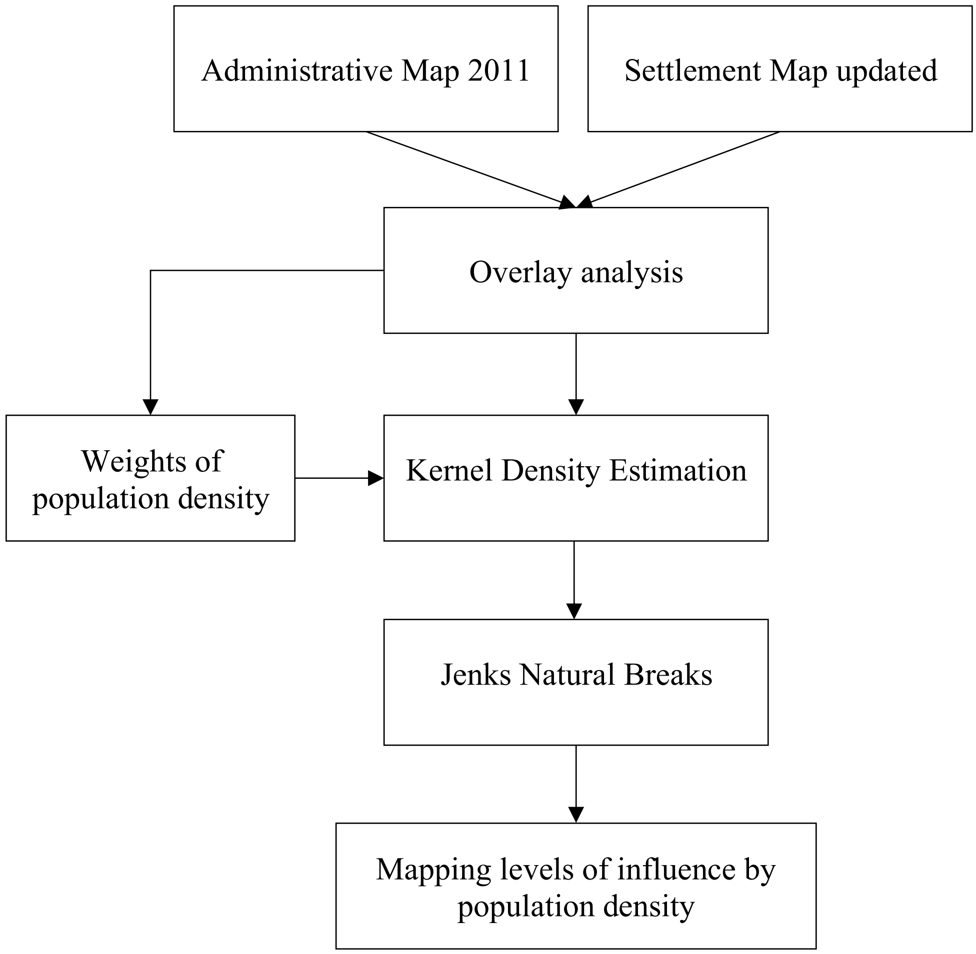


Figure 5.66. Framework for mapping pressure of population density

In this study, population density is defined as the number of people living within an area unit in each commune. We calculated the area of the settled regions based on the data of collected maps in each commune. The population was collected from statistics data in 2011 in each commune. Then we employed the Kernel Density Estimation method to analyze the influence of population density on biodiversity conservation. The used weight is population density, which is calculated by the number of people within the total area of the settlement in all communes. The influence of population density was categorized into five levels ranging from very low to very high that was presented in the map (Figure 5.67).

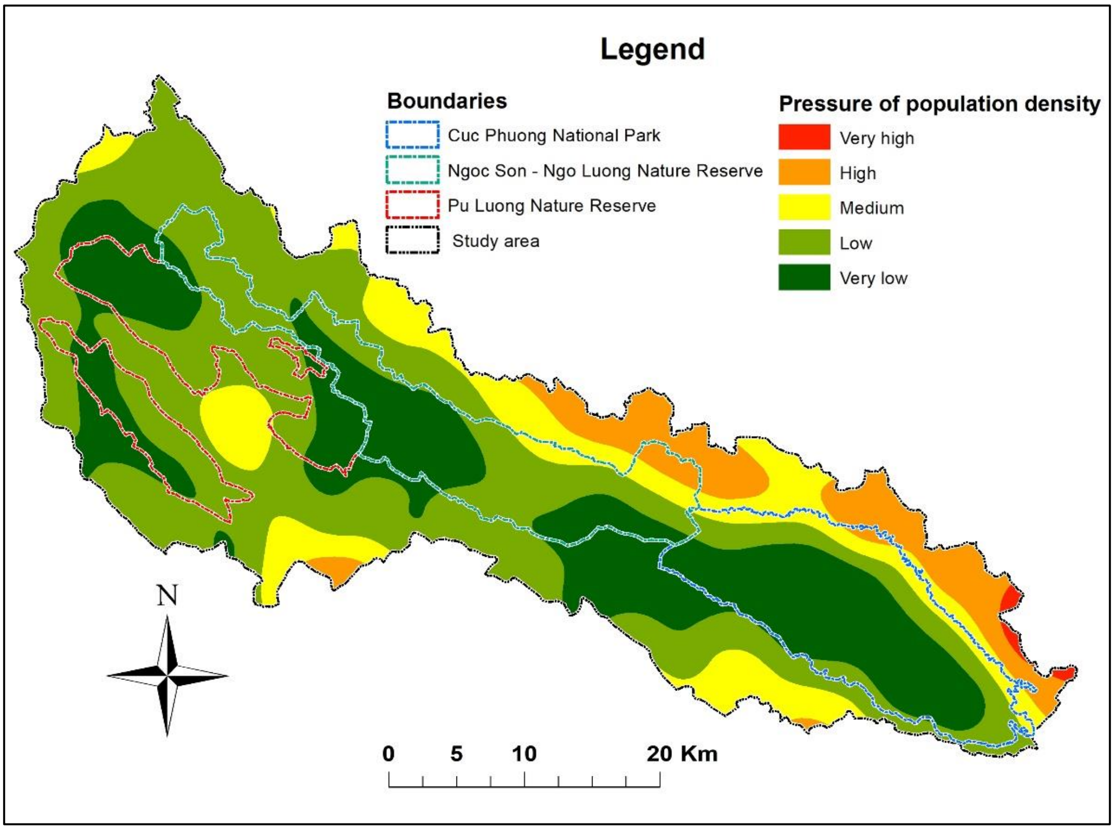


Figure 5.67. Levels of pressure of population density in the study area

Figure 5.67 shows that significant influences of population density on biodiversity conservation could be mainly found outside the three protected areas, which are settled in cities or towns with a high population density (e.g., Nho Quan, Ninh Binh). In the three protected areas, population density generally has little influence on biodiversity conservation. Only a small area of Ngoc Son – Ngo Luong NR was influenced by population density at the high and medium levels.

The results show that 75.3% of the total area was influenced by population density at very low or low levels while population density which has the high or very high influence on biodiversity conservation is 9.3% and 0.4% of the total area, respectively (Appendix III - Table III. 19). We also estimated the influence of population density on biodiversity conservation in each protected area. It has shown that there are not strong influences of population density on biodiversity conservation in the three protected areas. Only a small proportion of CPNP and NSNLNR was highly influenced by population density, accounting for 0.4% and 3.8%, respectively. Three protected areas (PLNR, NSNLNR, and CPNP) have mainly low or very low impacts by population density, making up 99.8%, 89.3%, and 86.9%, respectively (Figure 5.68).

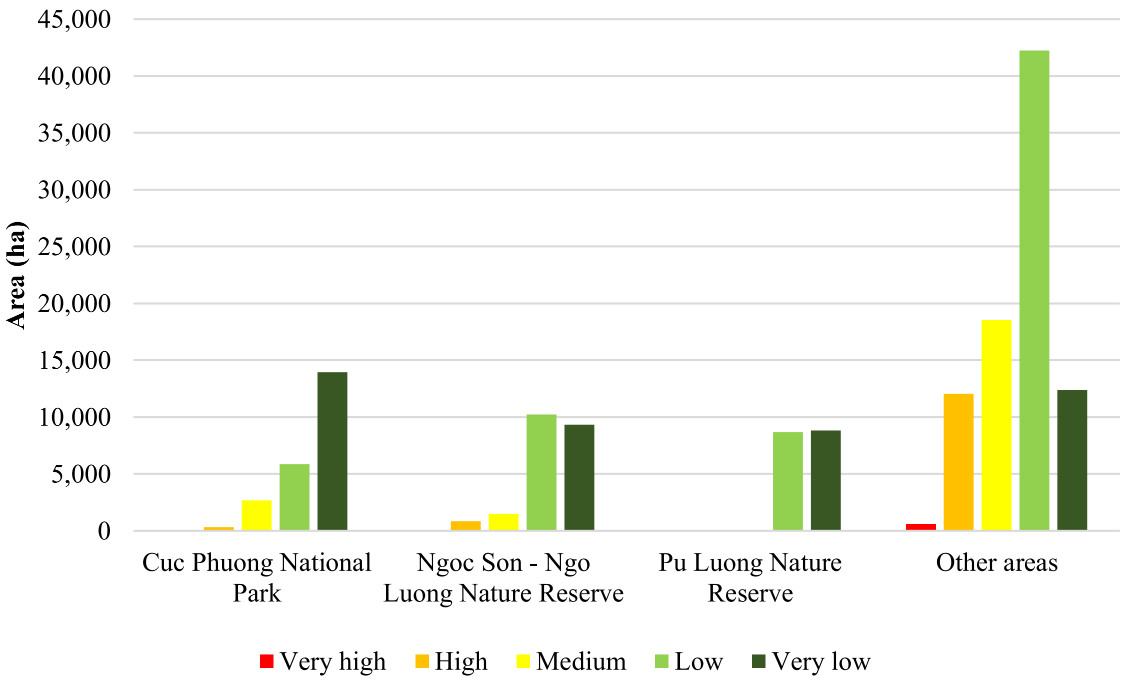


Figure 5.68. Assessment of pressure of population density in the study area

Although there are no residents inside CPNP, population density in the surrounding areas of CPNP is higher than the other two protected areas. It is because CPNP is a popular tourist site in Vietnam, which leads to the establishment of many services for tourism and high concentration of population in the areas surrounding CPNP.

5.1.4.3. Population

The process to identify the influences of population quantity is the same as the one used for population density. The only difference lies in the weights used in the Kernel Density Estimation method. The weight assigned for each commune is the number of local people who are living inside the communes. The value was synthesized by using overlay analysis for both two layers, including the administrative maps and the settlement map. The procedure for mapping influence levels of population on biodiversity conservation is illustrated in Figure 5.69. The data were used for input sources in this study, including the administrative map in 2011 with the information on the population in each commune (Appendix III - Table III. 18) and the settlement maps updated (Figure 5.61).

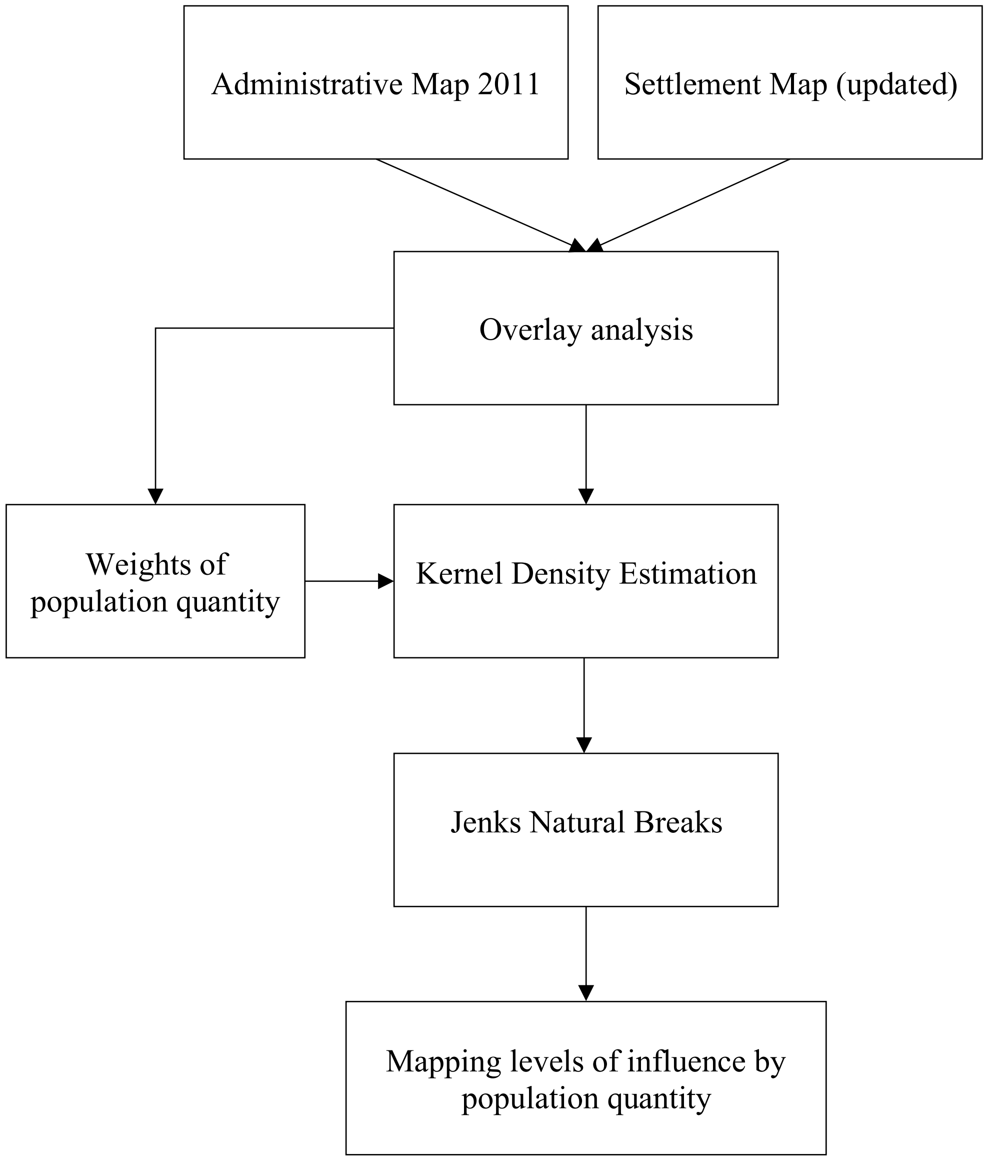


Figure 5.69. Framework for mapping pressure of population quantity

Based on population statistics from 2011, the influences of population on biodiversity conservation in the study area were estimated by applying the Kernel Density Estimation method. The weighting is based on the population size in all communes. The influences of population number on biodiversity conservation could be categorized into five levels ranging from very low to very high. Then we established a map to illustrate the influence levels of population number on biodiversity conservation in the study area (Figure 5.70).

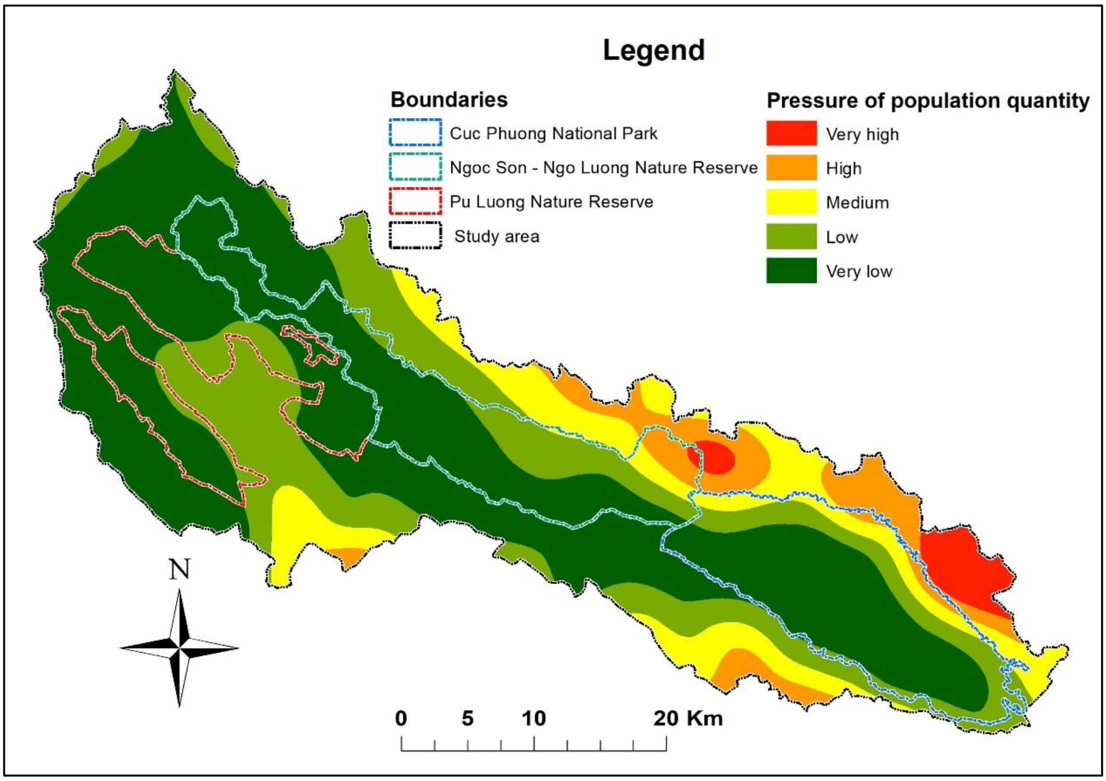


Figure 5.70: Levels of pressure of population quantity in the study area

Appendix III - Table III. 20 shows that the number of the population influences 9.4 % of the total area at high or very high levels, but 8.2% out of 9.4% was found outside the three protected areas, and the rest belongs to NSNLNR (0.8%).

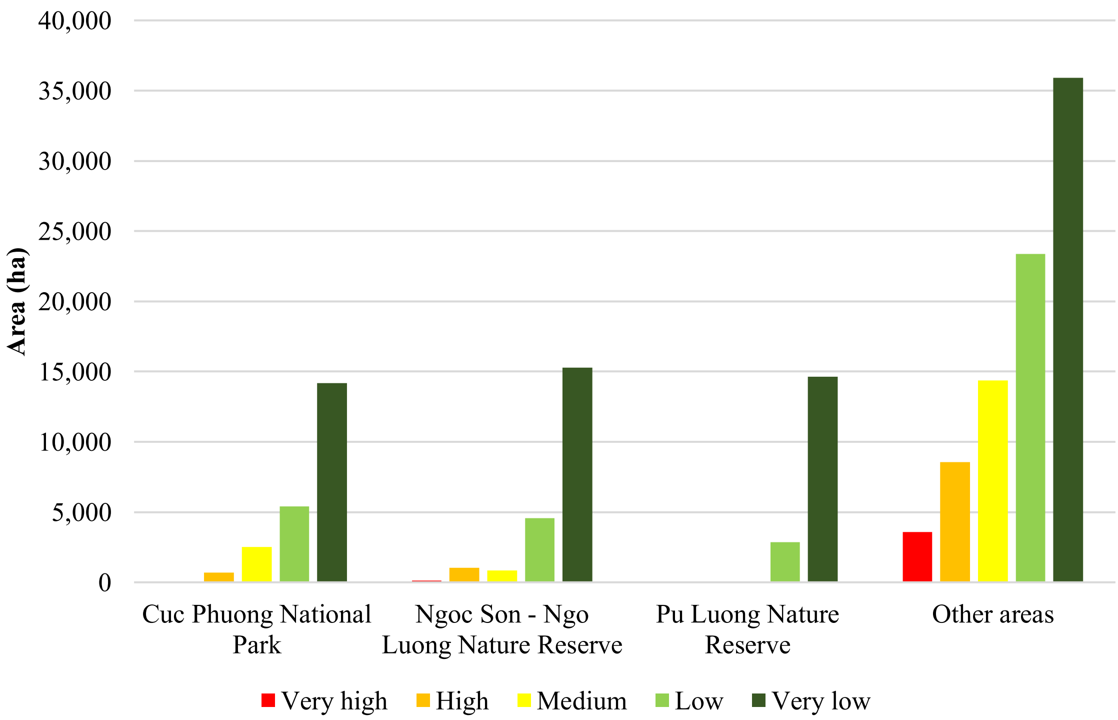


Figure 5.71. Assessment of pressure of population numbers in the study area

The influence of population numbers on biodiversity conservation was also estimated for each protected area in the study area. The results have shown that the influence of population number on biodiversity conservation is mainly at very low or low levels, accounting for 100%, 90.7%, and 85.9% in PLNR, NSNLNR, and CPNP, respectively (Figure 5.71).

5.1.4.4. Livelihood

Livelihood is defined as the basic demands of people, such as food, water, medicine, settlement, and clothes (Baumgartner et al., 2004). The sources of livelihood could be diverse, depending on material sources available for people. Livelihood has been considered as a vital indicator that increasingly promotes the forest cover as well as biodiversity conservation in Vietnam (Lambini & Nguyen, 2014; Nguyen et al., 2010, 2014; Nguyen & Nghiem, 2016). In the study area, most of the activities serving as the livelihood of local people have been performed using many types of land use – land cover areas such as agricultural lands, settlements, transport lands, water bodies, and industrial areas, as well as on the forest areas.

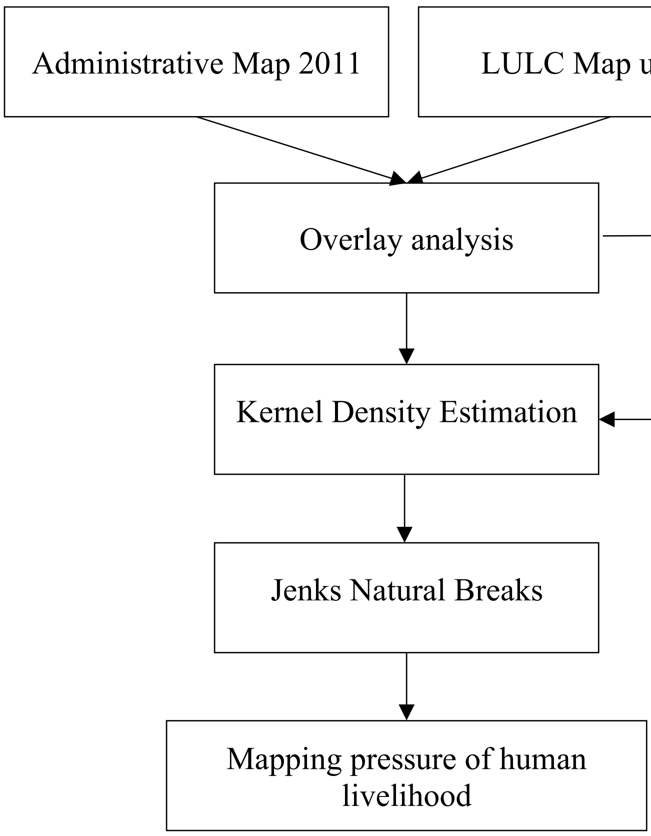


Figure 5.72. Framework for mapping pressure of human livelihood

The pressure of livelihood on biodiversity conservation was shown as the stress to the forest areas. The limitation of livelihood areas excluding forest areas became the primary cause of creating pressure on the forest as well as biodiversity conservation. Therefore, the population density on the land, providing the livelihood for local people, was considered as a solution to determine the pressure of livelihood on the forest area and thus biodiversity conservation. The pressure of livelihood was estimated through the population density in the areas where local people can secure their necessary demands such as water, food, animal fodder, medicine, shelter, and clothing, etc. In this case, the areas of forest cover were excluded for biodiversity conservation purposes. The classification and assessment of land use – land cover types for livelihood were important steps that supported developing the weights of the pressure of livelihood for each commune (Figure 5.72).

The weight is the population density calculated based on the area of livelihood for each commune. The Kernel Density Estimation method was applied to identify the weights for the regions of the settlement in each commune. The map of the pressure of human livelihood on biodiversity conservation was established with five levels of the pressure after the data were classified by the Jenks Natural Breaks method.

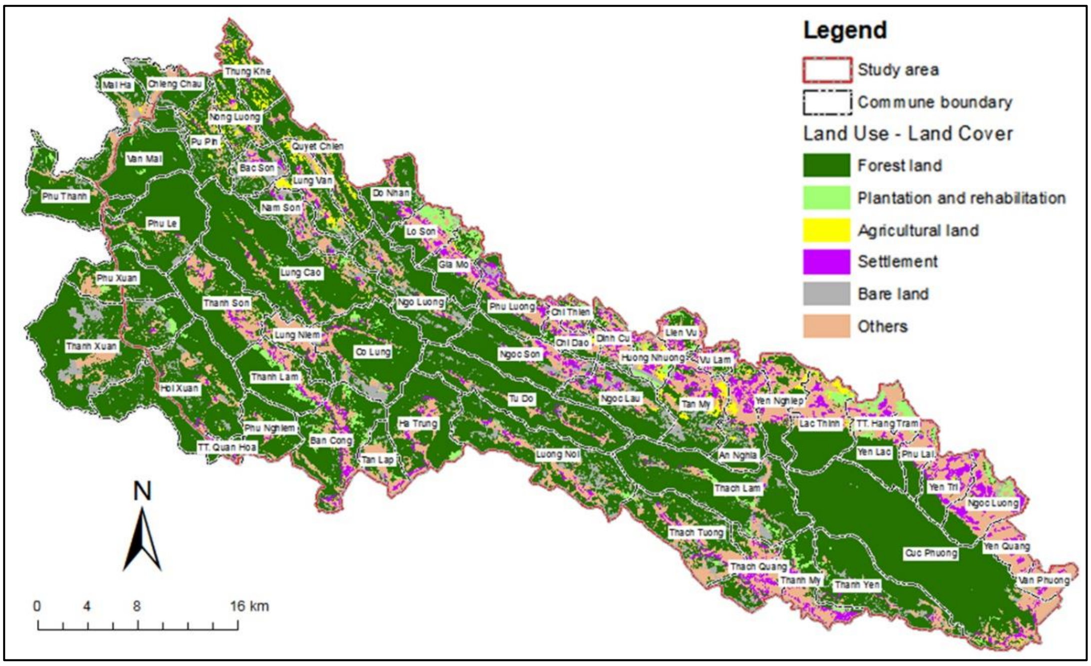


Figure 5.73. Land Use - Land Cover Map of communes around the study area

It was very challenging to synthesize and assess the data of the livelihood of the whole study area directly. Previous studies demonstrated the relationship between land use - land cover types and livelihood (Baumgartner et al., 2004; Tschirley, 1998; Turner et al., 1995). Therefore, to define the impacts of livelihood on the biodiversity conservation, the land use - land cover map of 57 communes within eight districts and three provinces in the study area was established. The map was acquired by synthesizing the maps of land use – land cover (LULC) in 2015 in three provinces (Hoa Binh, Ninh Binh, and Thanh Hoa), updating and editing through the Sentinel-2 image acquired on the 9th of April 2018. Then, 32 types of LULC which were shown in appendix III - Table III. 12 were grouped into six classes, including forest land, plantation and rehabilitation, agricultural land, settlements, bare land, and others (Figure 5.73). The summary of population and land use – land cover areas of communes in and around the study area, as illustrated in appendix III - Table III. 18.

Bare land is a unique area that is not the livelihood area. In order to assess the pressures of humans to the forest, three elements, including forest (forest land, and plantation and rehabilitation), livelihood (agriculture land, settlement, and others), and bare land were identified for analyzing and calculating the pressure levels of livelihood in the study area. The area statistics of the three classes for eight districts within three provinces were synthesized and compared with the number of population of each district and is shown in Figure 5.74.

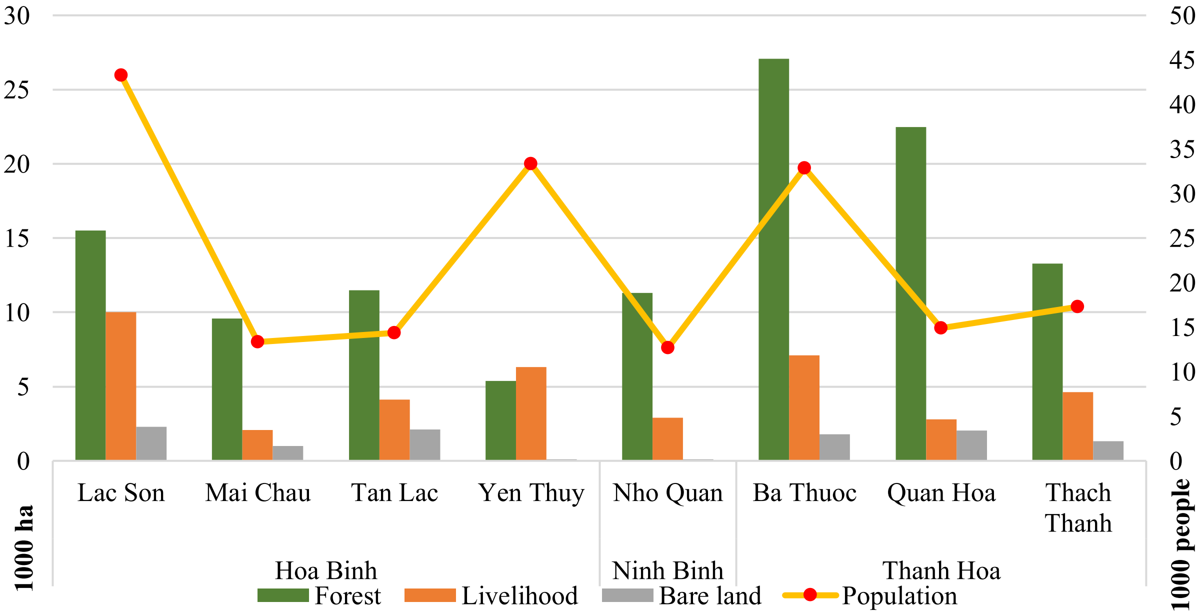


Figure 5.74. Comparison between population and areas of livelihood, forest, and bare land on the districts in the study area

The results show that Mai Chau and Tan Lac districts have a nearly equal number of populations with 13,000 and 14,000 people. However, the areas of livelihood have displayed a significant difference. The area of Tan Lac (4,107 ha) is nearly twice that of Mai Chau (2,077 ha). It means that the pressure of local people to livelihood in Mai Chau is much higher than in Tan Lac, where there is a larger forest area.

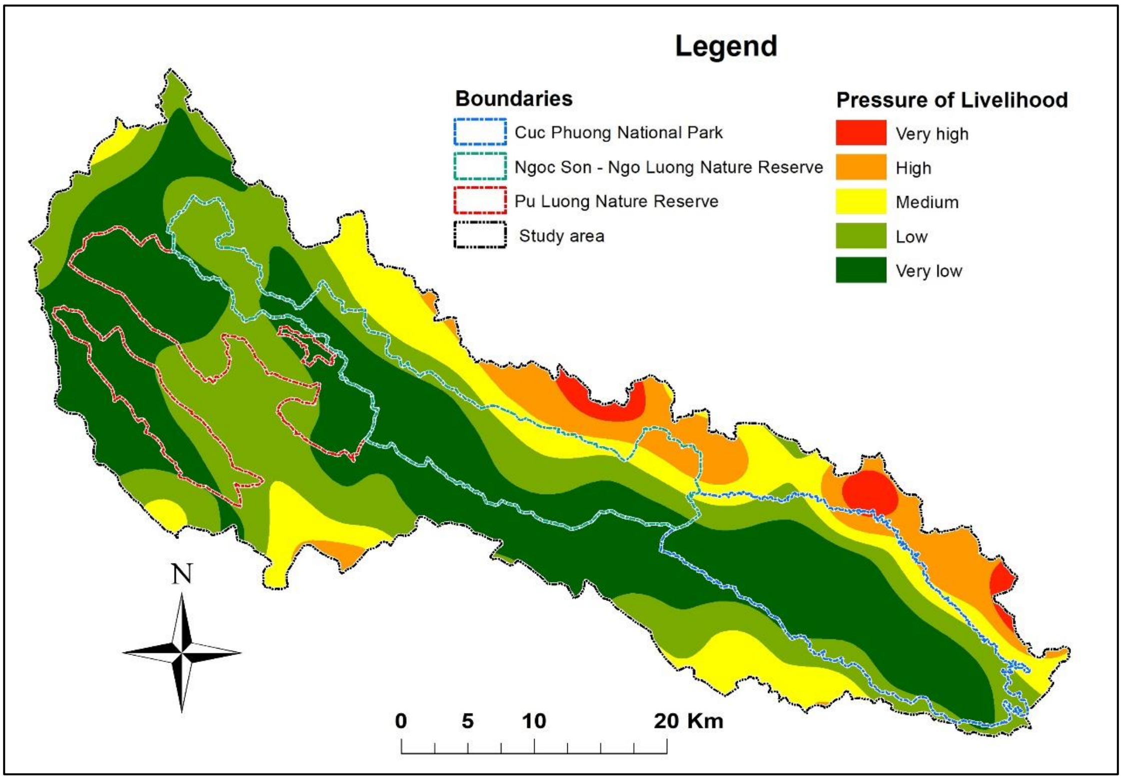


Figure 5.75. The pressure of livelihood in the study area

Based on the 2015 land use – land cover map of three provinces, data on land use status of 201 communes were gathered with 59 communes in the study area. Then we created a map to indicate land use-land cover of 59 communes in the study area (Figure 5.73). This map was then updated by using a Sentinel-2 image in April 2018. We also identified types of land use in the study area. Then all types of land use were classified into selected land types, which provide the main livelihood for local people. There are 34 types of land use in the study area, which are divided into six main groups: forest land, restoration, and plantation forest land, agriculture land, settlement land, bare land, and others (Figure 5.73). The results have shown that the livelihood of local people relies on forest land, agriculture land, settlement land, and other lands. However, the statistics indicated that the areas of agricultural land, settlement land, and other lands (herein "livelihood land") are quite limited in the study area (Appendix III - Table III. 21). Thus, the livelihood sources of local people mainly come from forest land and other sources. Based on this fact, pressure on local people to forest land was evaluated by analyzing the area of forest land and "livelihood land" that provides a livelihood to local people. It means that the less livelihood land local people have, the more pressure they put on forest land.

We calculated the area of "livelihood land" for each commune. The influence of livelihood on forest land depends on population numbers and the area of "livelihood area." To identify the influence level of livelihood on forest and biodiversity conservation, we used weighting, which is calculated by population density on "livelihood land" for each commune. The method of Kernel Density Estimation was applied to create a map that shows the influence of livelihood on forest land as well as biodiversity in the study area. By using the method of Jenks Natural Break, five levels of influence were identified, ranging from very low to very high (Figure 5.75).

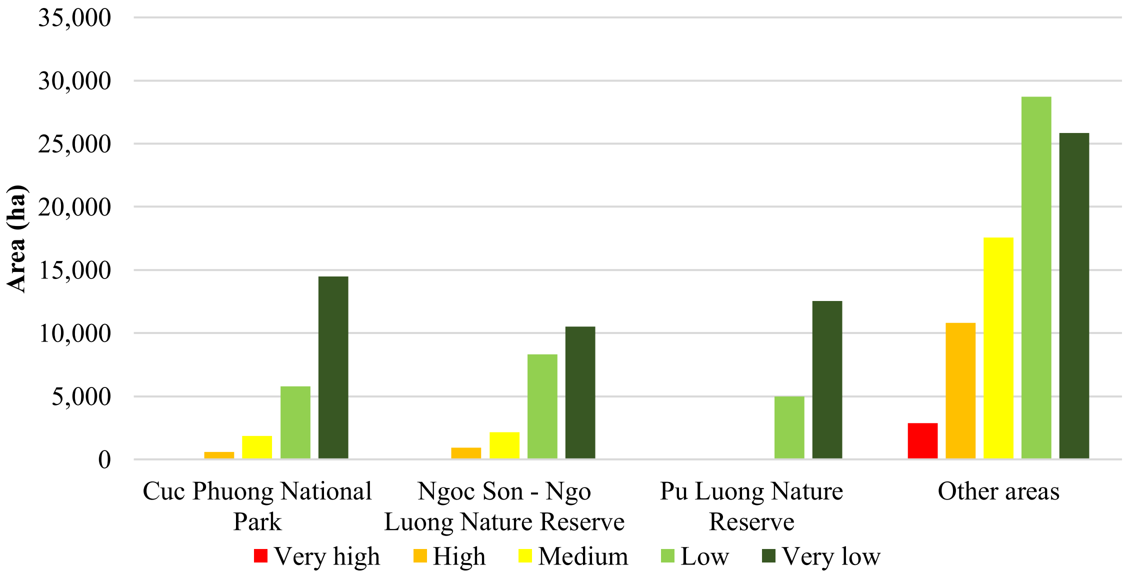


Figure 5.76. Assessment of pressure of livelihood in the study area

Our results have shown that 10.3% of the total area is influenced by livelihood at very high or high levels (Appendix III - Table III. 22). This area is found outside three protected areas. In the three protected areas, the influence of livelihood on biodiversity is low or very low, accounting for 100%, 86%, and 89% in PLNR, NSNLNR, and CPNP, respectively (Figure 5.76).

5.1.5. Conservation

More and more attention of scientists and conservationists has been focused on how to conserve and maintain the biodiversity conservation (Johnson, 1995; Saunders et al., 1998) since the loss of biodiversity has become a serious environmental issue that can lead to a mass extinction of species (Myers, 1979; Wilson, 1988). A suitable method of biodiversity conservation could help to protect and manage biological resources such as genes, species, habitats, and ecosystems (Gordon et al., 2005; Johnson, 1995).

In Vietnam, forests have been classified into three main categories based on their principal use purposes, namely special-use forest, protection forest, and plantation forest. The levels of protection, as well as contributing to conservation, are implemented based on their importance (MARD, 2009). The highest priority levels for protection are reserved for national parks followed by nature reserves, watershed protection forests to the least priority level of protection by plantation forests.

The fragmentation, including isolated and small patches, is considered a negative index to identify important places for biodiversity conservation (Groom et al., 2006). The large areas free from human activities have provided important ecosystems for containing a higher and more stable number of species through large home ranges (Gordon et al., 2005). It means that a strong relationship between species richness and size have existed. Larger forest areas usually contain a higher number of plants and animals (Gordon et al., 2005; Moore, 2008).

5.1.5.1. Forest management types

The maps of the forest statistics and land use-land cover in Thanh Hoa, Hoa Binh, and Ninh Binh provinces were collected as an input data to identify priority areas regarding management types of forest (Figure 5.77). Administrative management types were defined based on the purposes of land use types presented on the maps.

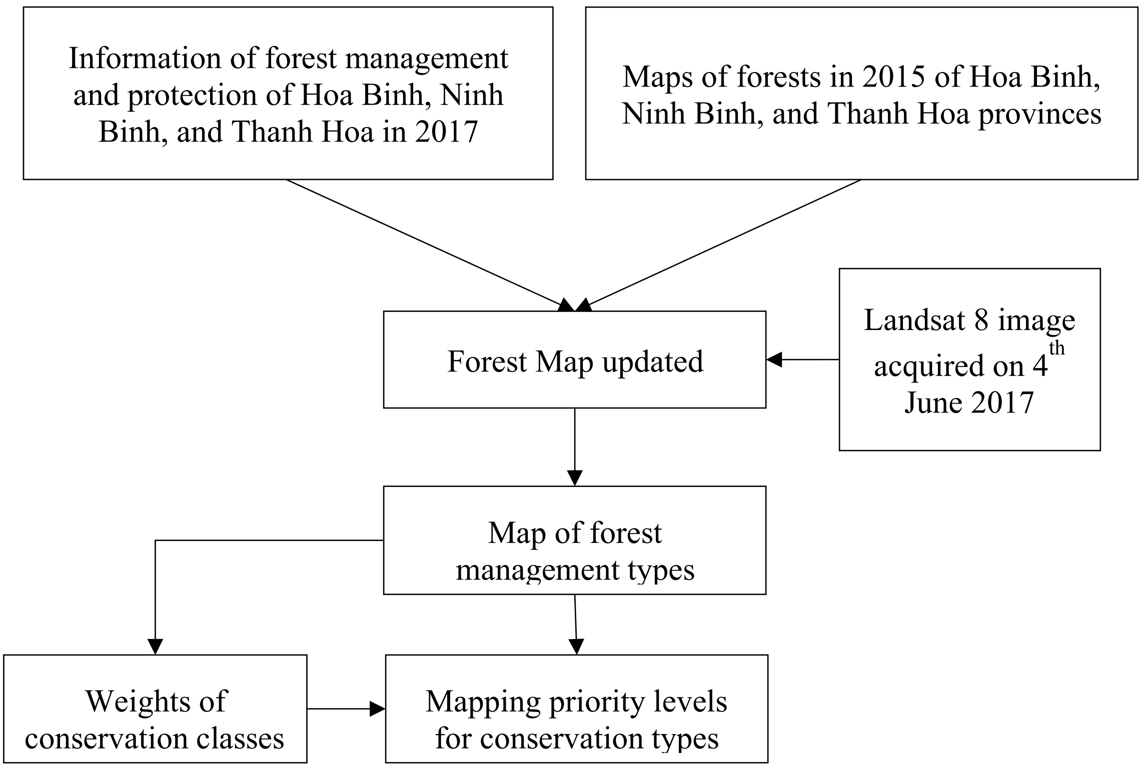


Figure 5.77. Framework for mapping priority areas of forest management types

Seven classes of management forest types were gathered, such as National Park, Nature Reserve, Watershed Protection Forest, Plantation of Bamboo, Big and Small timber trees, and other uses (Table 5.14). The weight of each class was assessed and considered to fit with the levels of protection for the regions. The map of priority levels for management types was established through the weights selected (Table 5.14).

Table 5.14. Categories of forest management types in the study area

ID	Categories of uses	Codes of uses	Levels of conservation	Codes of conservation
1	National Park	VQG	Very high	4
2	Nature Reserve	BTTN	High	3
3	Watershed Protection Forest	PHDN	Medium	2
4	Plantation of Bamboo	SXTN	Low	1
5	Plantation of Big timber trees	SXGL	Low	1
6	Plantation of Small timber trees	SXGN	Low	1
7	Other Uses	MDK	None	0

The map of forest management types in the study was synthesized from the maps of forest statistics from 2015, and information on forest management and protection in 2017 in the Hoa Binh, Ninh Binh, and Thanh Hoa provinces. Then, the map was updated through Landsat 8 image acquired on 4th June 2017. The map on management types was classified and edited with seven classes in Table 5.14 and is shown in Figure 5.79.

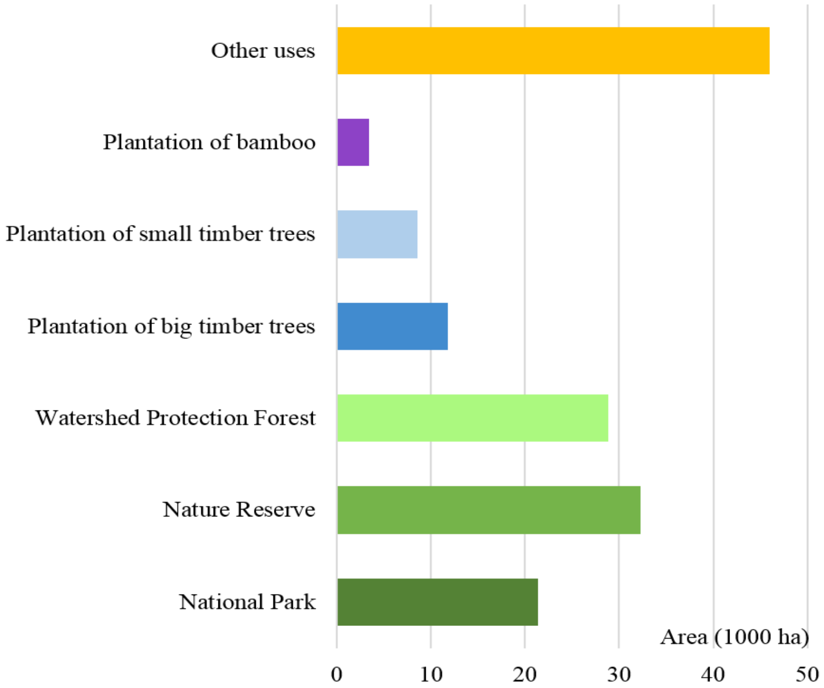


Figure 5.78. Area comparison of forest management types in the study area

The administrative management types of forest were displayed inside the protected areas as well as outside of PAs in the study area (Figure 5.79). The forest area accounts for near 70 % of the study area. Four categories that include national park, nature reserve, watershed protection forest, and plantation account for 14.1 %, 21.2%, 18.9%, and 15.7 % in Figure 5.78.

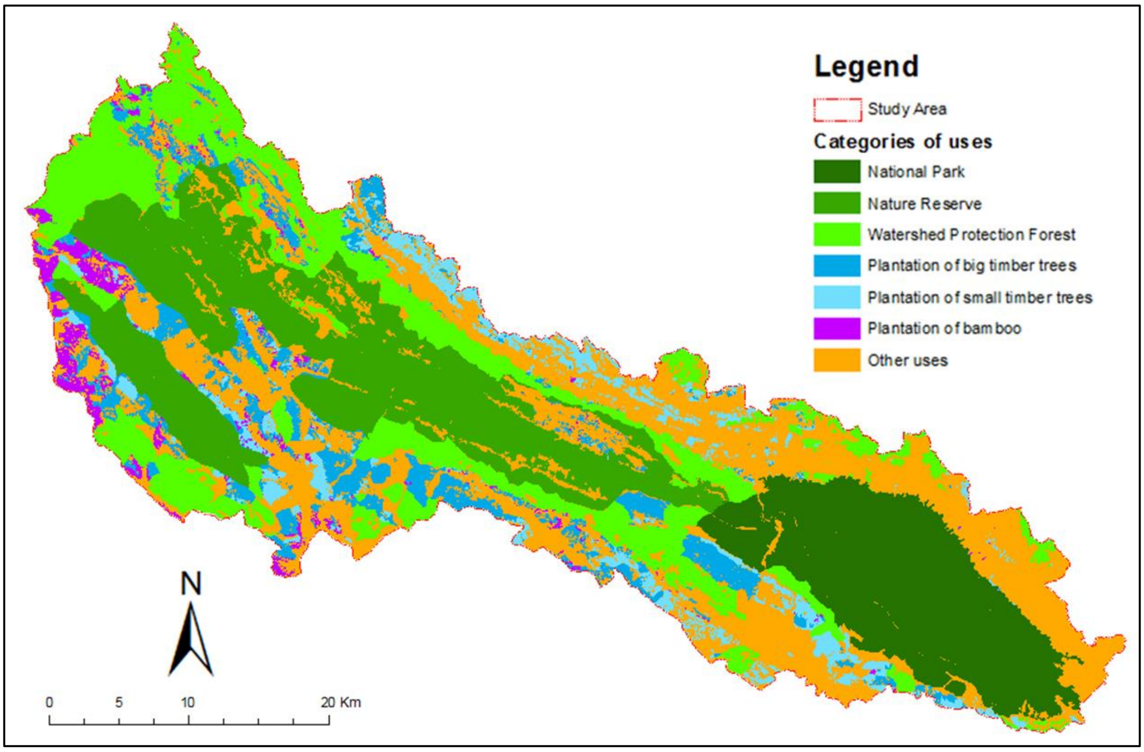


Figure 5.79. Map of forest management types in the study area

Forest management types were identified and classified into seven types, including National Park, Nature Reserve, Watershed Protection Forest, Plantation Forest of Bamboo, Plantation Forest of big timber trees, Plantation Forest of small timber trees, and others. Based on the characteristic of these forest types, their priority levels were evaluated regarding important levels to forest and biodiversity (Table 5.14) and presented forest management types on the map (Figure 5.79). Then a map of forest management types with priority levels regarding biodiversity conservation status was created (Figure 5.80).

The results show that in CPNP, 14.5% of the total area and 92.1% of the CPNP area are at a very high priority level for biodiversity conservation in forest management type. The high priority level could be found in both PLNR and NSNLNR, making up 10.4% and 11.3%, respectively (Figure 5.81).

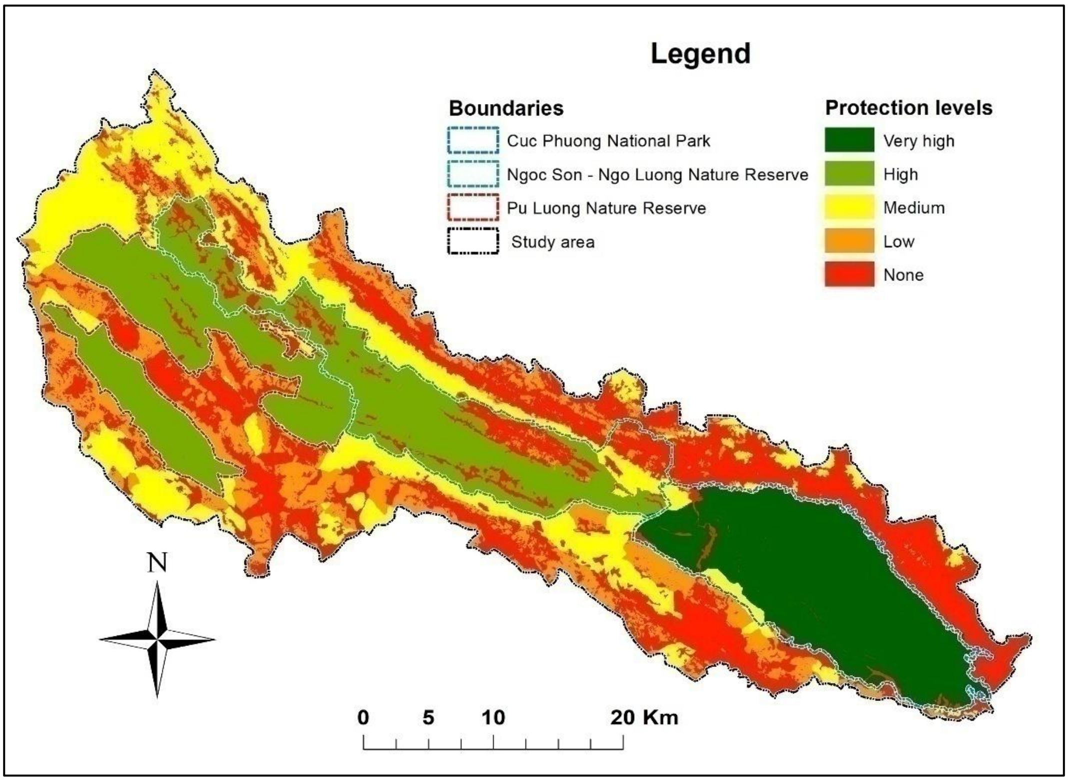


Figure 5.80. Priority areas of forest management types in the study area

The area of medium priority level is fragmented and located outside the three protected areas, which is a watershed protection area, accounting for 18.9% of the total area. 17.6% out of 18.9% could be found outside the three existing protected areas (i.e., the remaining 1.3% is found inside the three protected areas). This trend is similar to the area at a low priority level, making up 15.5% of the total area, with 15% lying outside three existing protected areas (Appendix III - Table III. 23).

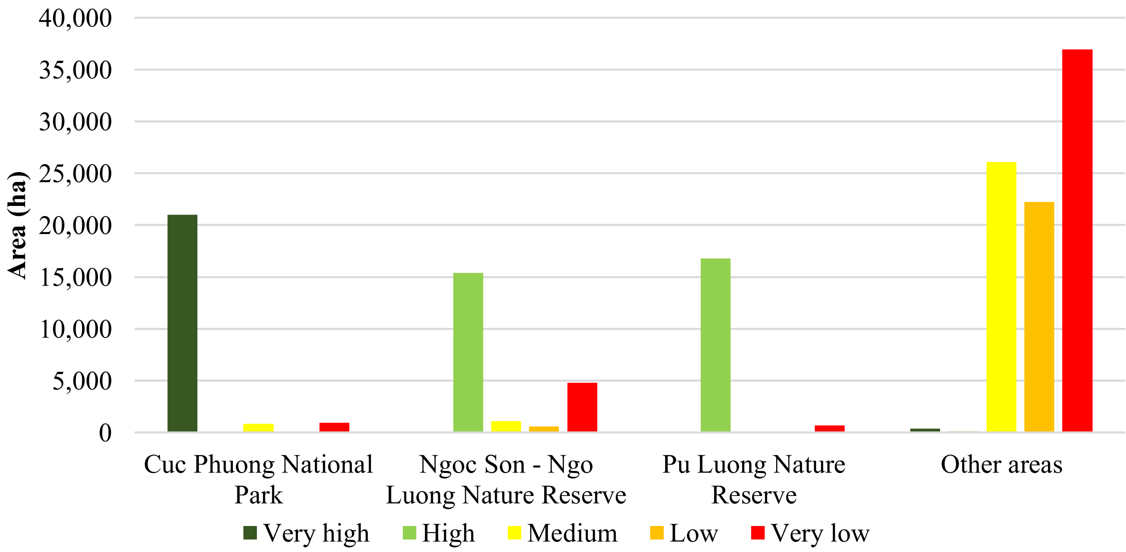


Figure 5.81. Assessment of priority areas of forest management types in the study area

5.1.5.2. Size of forest area

The forest map that was updated and edited in 2017 for the study area (Figure 5.46) was used as input data for this criterion. The forest areas were selected and aggregated based on the geometrical link among them. The combined regions of forest cover were calculated in the area before they were classified by the Jenks Natural Breaks method to estimate five levels concerning the size of the forest areas. The process of establishing the map on priority areas by the size of the forest area is shown in Figure 5.82.

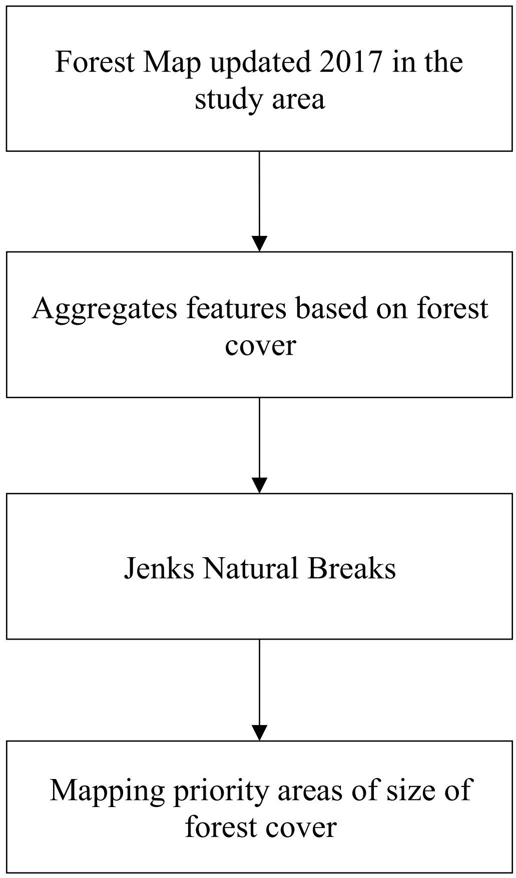


Figure 5.82. Framework for mapping priority areas of size of forest area

The region's forest (National Park, Nature Reserve, Watershed Protection Forest, and Plantation) were selected to classify the levels of the size of forest areas. The small polygons were combined to define the size of forest areas. Thresholds of area size were identified by the Natural Breaks (Jenks) method.

The forest status map of the study area was updated by satellite images from 2017 to identify the forest areas and their sizes. Forest areas are classified based on their sizes by applying the method of Jenks Natural Break. There are five levels regarding the size of forest area in the study area ranging from very small to very large (Table 5.15).

Table 5.15. Categories of priority levels of size of forest area

ID	Area Size (ha)	Levels of size	Code
1	≥ 14,290.0	Very large	4
2	5,446.2 – 14,289.9	Large	3
3	2,257.9 – 5,446.1	Medium	2
4	598.2– 2,257.8	Small	1
5	≤ 598.1	Very small and none	0

The results have shown that 32.4% of the total area is covered by a vast forest area, which was found mainly in the three protected areas (CPNP, NSNLNR, and PLNR), split 14.1%, 10.3%, and 7.6%, respectively (Figure 5.84).

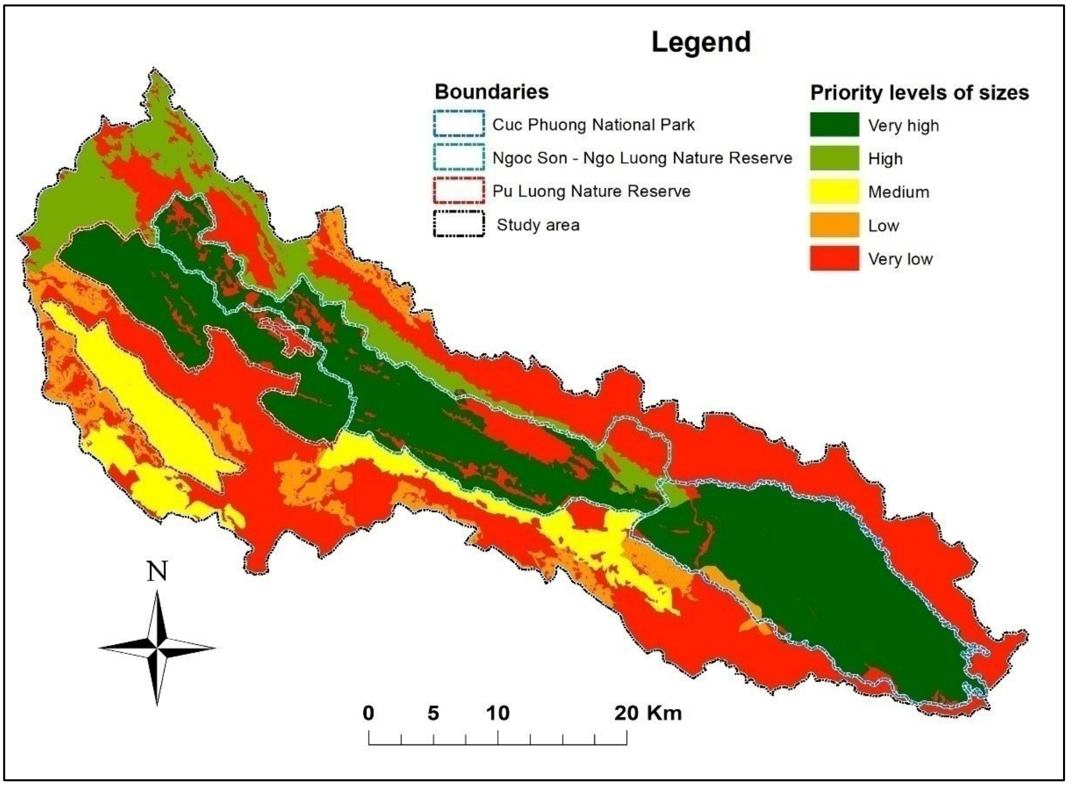


Figure 5.83. Priority areas based on forest area size in the study area

Large forest areas cover about 9.4% of the total area, with 8.6% lying outside the three existing protected areas. 49% of the total area includes small forest areas, and 43.7% out of 49% is distributed outside the three existing protected areas (Appendix III - Table III.

24). It means that the majority of small and fragmented forest areas are found outside the three existing protected areas.

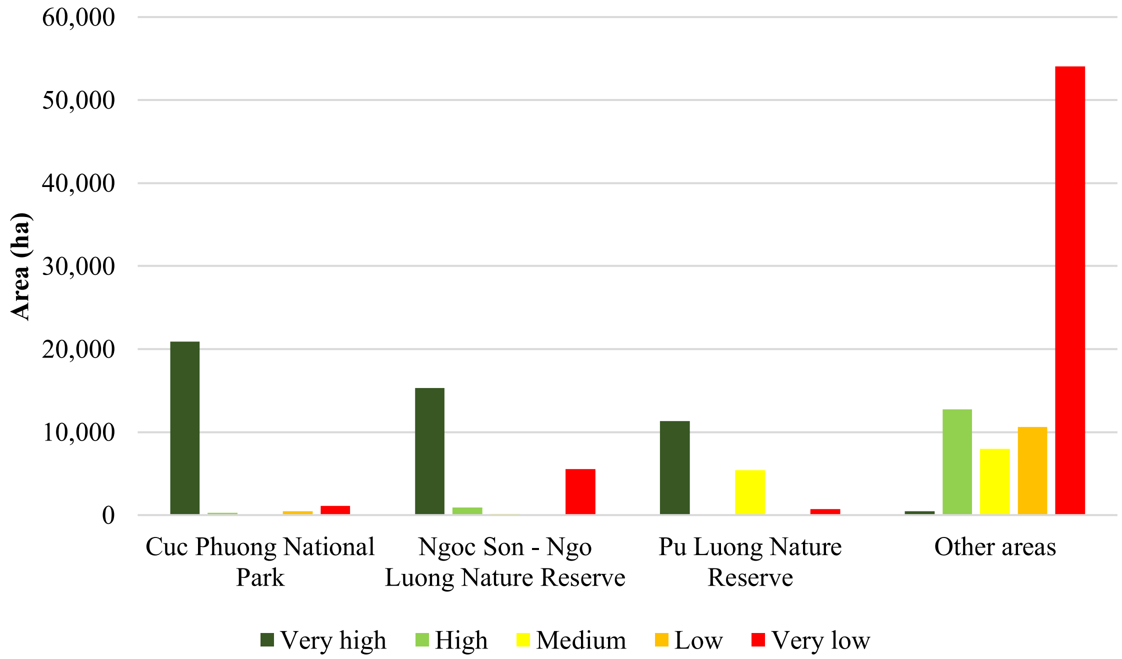


Figure 5.84. Assessment of priority areas regarding forest size in the study area

5.1.6. Education

Many efforts have been made to reduce biodiversity loss in developing countries (Poffenberger, 1998; Quy & Can, 1994; Sterling & Hurley, 2005). Among these, education on issues of biodiversity conservation and environmental protection is considered as an essential tool in changing people's habits and conceptions towards more sustainable development goals. UNESCO (2005) has shown that conservation, education, and sustainable development are keys to preserving the biosphere. However, the implementation should focus on helping local people to understand and appreciate positive activities arising from biodiversity conservation rather than just isolating them away from protected areas (Reid, 2012). Local people can be aware of the values of natural resources through the knowledge gained from education and training (Mcneely et al., 1990; Nguyen et al., 2014). The weak awareness of local communities about the need to protect the environment is considered as the leading cause of biodiversity decline in the developing countries (Pauchard et al., 2006). Therefore, education and information are essential to analyze and assess biodiversity conservation projects.

Figure 5.85 illustrates the process of defining the impact levels of education for biodiversity conservation. The information on schools in and around the study area was collected and updated from the land use – land cover maps in 2015 of Hoa Binh, Ninh Binh, and Thanh Hoa provinces. Locations were checked and updated through the visual inspection with the Sentinel-2 image acquired on the 9th of April 2018 as well as the additional information from the field survey in 2017. Locations of all schools in 9 districts of the three provinces were determined and overlaid on the settlement map (Figure 5.86). The comparison between two layers helped to visualize the areas of local communities that are hardly reached by the schools.

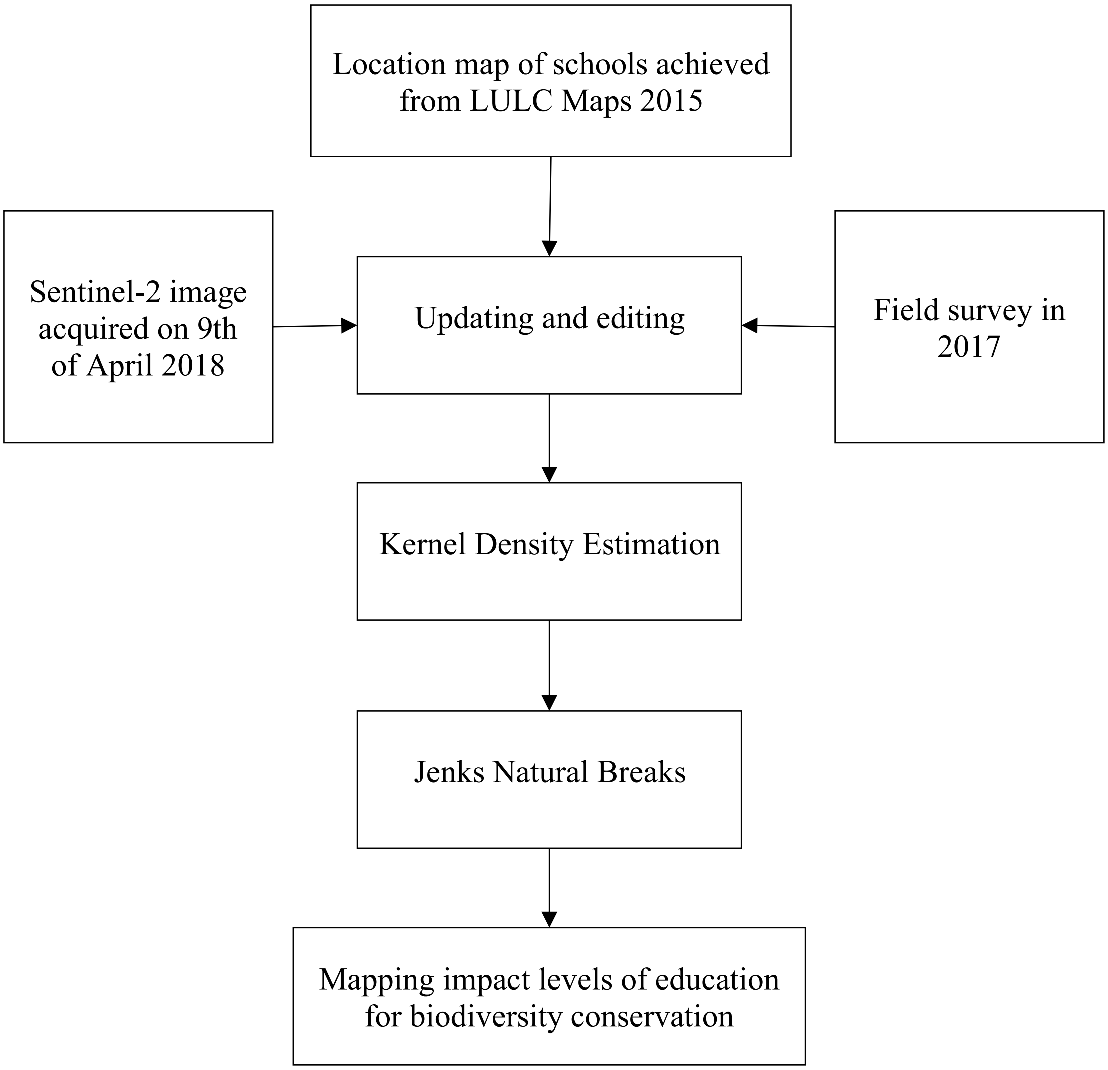


Figure 5.85. Mapping impact levels of education for biodiversity conservation

To assess the impact levels of education for biodiversity conservation, the Kernel Density Estimation method was applied for the updated locations of schools. Lastly, five degrees of influence of education were classified by Jenks Natural Breaks method for establishing the map that shows priority areas regarding the education criterion.

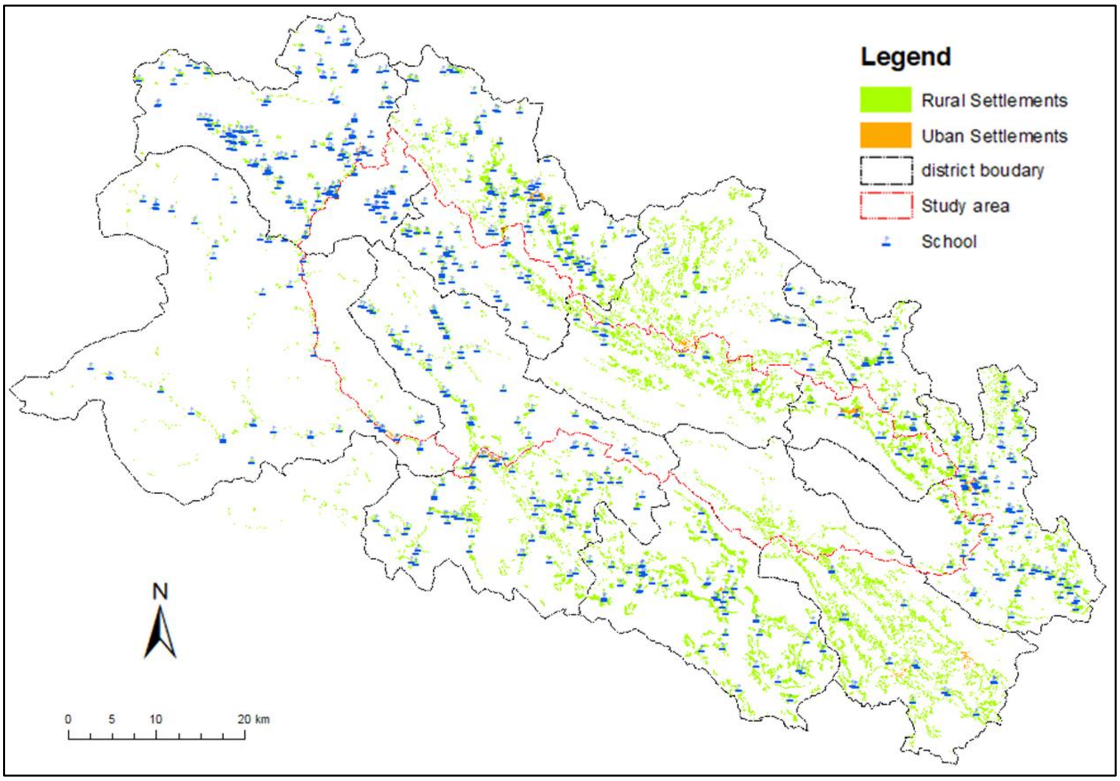


Figure 5.86. Distribution of schools in districts around the study area

To evaluate the influence of education on biodiversity conservation, the distribution of schools in the study area is considered as an essential indicator. We argue that the deficit of schools reduces the opportunities to teach and introduce the concept of protecting the environment as well as biodiversity conservation. Thus, there is an increasing priority for biodiversity conservation in the regions that lack schools or educational centers. Based on the land use status map in 2015, we identified the distribution of schools in the study area and presented it on the map. The map of the distribution of schools was updated by using the Sentinel-2 image in April 2018 and the fieldwork in 2017.

The influence of education on biodiversity conservation was identified by applying the method of Kernel Density Estimation for the positions of the schools in the study area. There are five influence levels of education that impact on biodiversity conservation based on the method of Jenks Natural Breaks, ranging from very low to very high. Then we presented five influence levels of education on biodiversity conservation on the map, as shown in Figure 5.87. It has shown that a shallow influence of education was found mainly in CPNP and PLNR. There are high or very high influence areas of education for biodiversity conservation in Nho Quan city of Ninh Binh province and a part of NSNLNR.

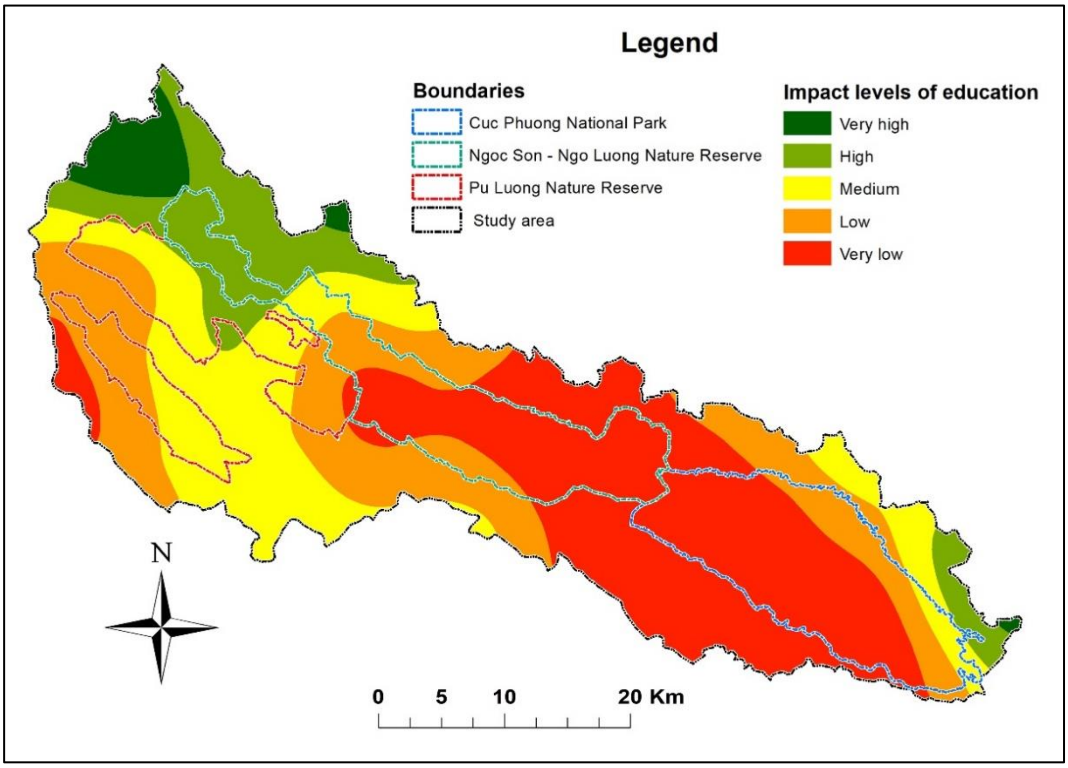


Figure 5.87. Impact levels of education for biodiversity conservation in the study area

The results have shown that 61.7% of the total area has low accessibility to education with the distribution of CPNP, NSNLNR, and PLNR, being 14.6%, 11.6%, and 4.7%, respectively (Figure 5.88) (Appendix III - Table III. 25). It shows that there is still a lack of education system in remote areas around CPNP and NSNLNR. There is an increasing need to improve the education system and transfer of knowledge on forest and environmental protection in these areas. Thus, defining priority areas for biodiversity conservation needs to take into account the influence of education in the criteria system.

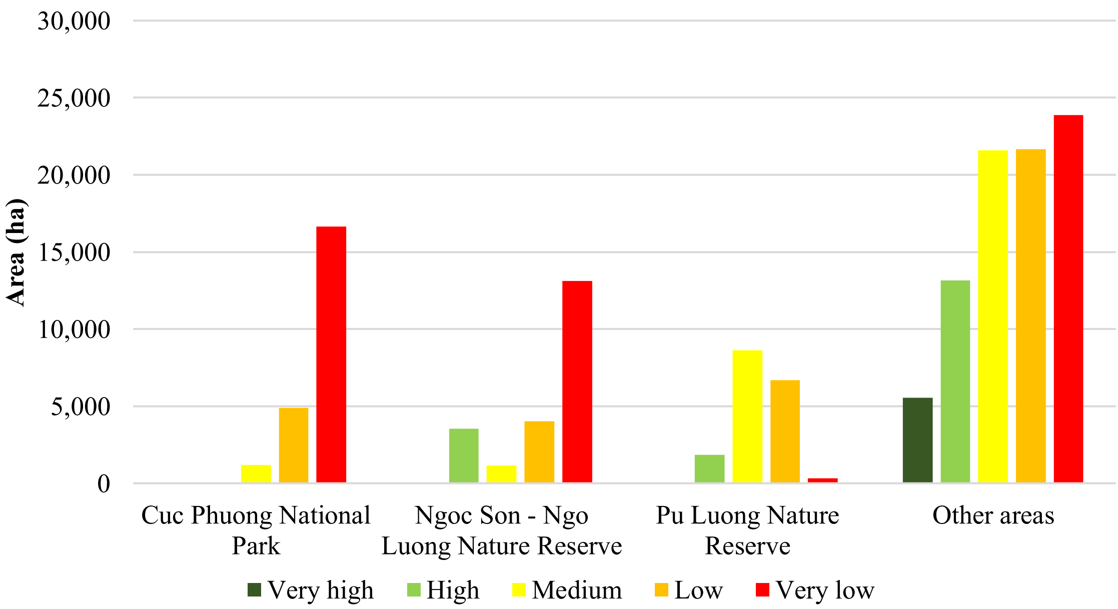


Figure 5.88. Assessment of priority areas of education in the study area

5.1.7. Law

The implementation of biodiversity conservation has faced various threats and challenges. Using legally binding laws are considered as a traditional tool to halt the loss of biodiversity in many countries (Reid, 2012). The laws are integrated with existing national policy and legislative frameworks to enable the different levels of administration that can adapt to the complex and dynamic nature of ecosystems.

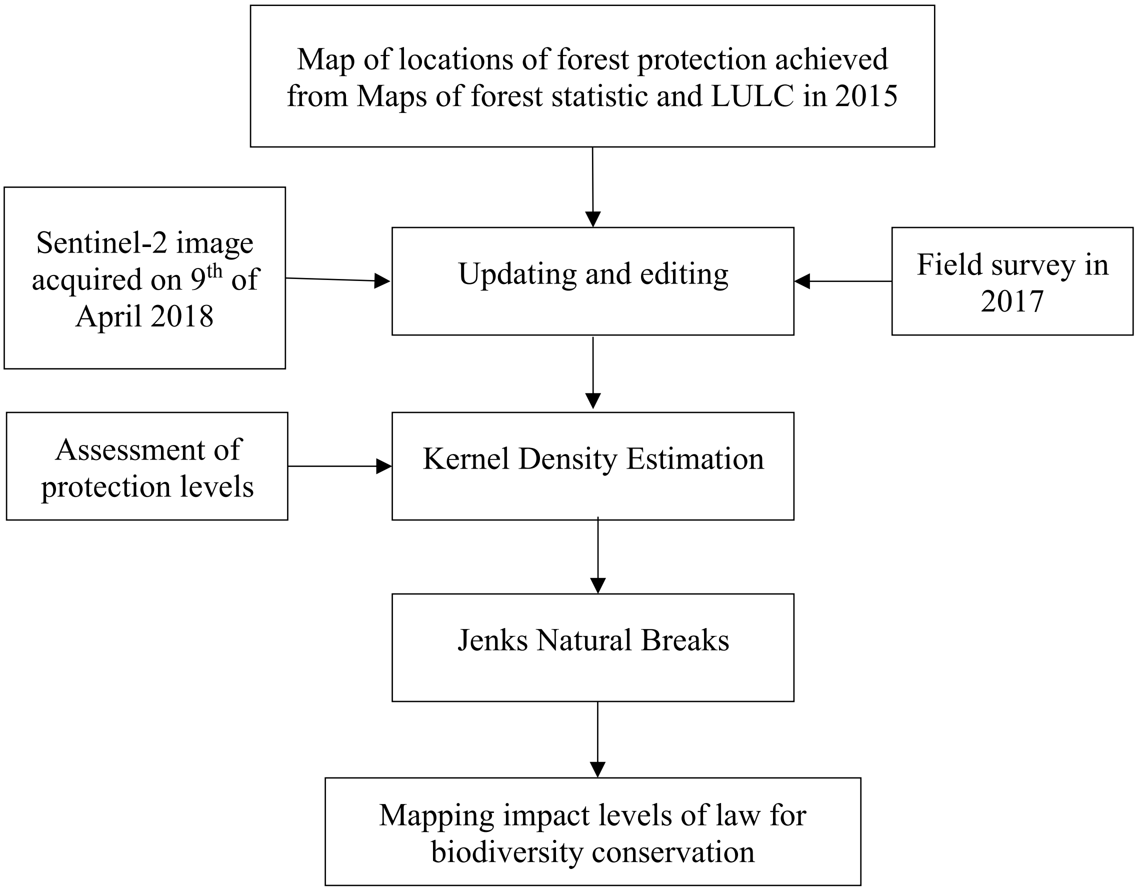


Figure 5.89. Framework for mapping impact levels of law for biodiversity conservation

Generally, the fundamental basis of environmental laws and regulations in Vietnam is well-established (Brunner, 2012). In Vietnam, the laws have been used as a fundamental tool for the management and implementation of conservation and sustainable development of biodiversity (VNG, 2008a). Many stakeholders are participating in biodiversity conservation. Among these, governmental agencies that are responsible for forest protection and management, including forest stations, forest protection departments, people's committees of communes, districts, and provinces. These organizations directly uphold the governmental laws for protecting and conserving forests and biodiversity. Thus, positions of these organizations are significant in assessing the capacity for protecting biodiversity conservation. We assume that the presence of governmental agencies could influence the competence for protecting forests and biodiversity in general.

The locations of the official governmental organizations of forest protection were determined through the maps on forest statistics and LULC in 2015. Then the data were inspected and updated through the Sentinel-2 image acquired on 9th April 2018 and associated with the information from the field survey in 2017 (Figure 5.89). The locations of forest protection administrations were classified and assessed as importance levels for identifying the weights, which were then used in the Kernel Density Estimation method for the determined points. The map for law criterion was built up with five levels ranging from very low to very high impact for biodiversity conservation through the Jenks Natural Breaks method.

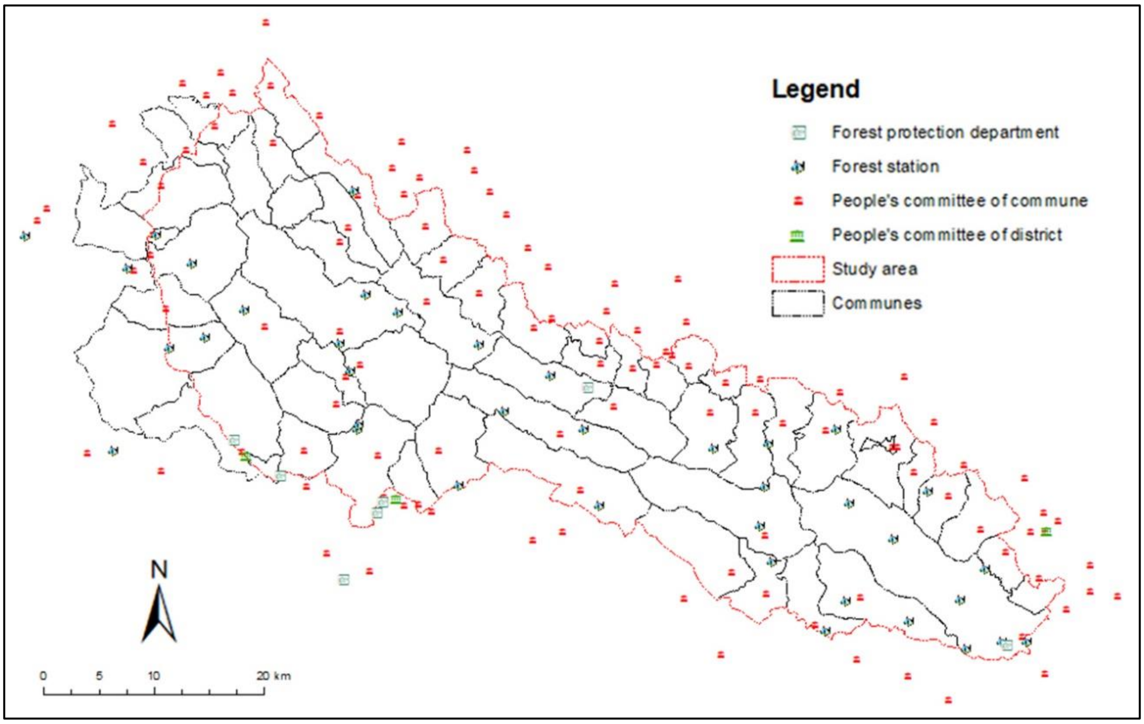


Figure 5.90. Positions of governmental offices responsible for protecting biodiversity

One layer of forest stations, forest protection departments, and people's committees were established based on the maps collected and information acquired from the field survey in 2017. The layer was also checked and edited by overlaying on the 10-meter Sentinel-2 image. Figure 5.90 shows the positions of governmental organizations inside and outside 5 km-buffering of communes for protecting forest and biodiversity in the study area. Kernel Density method for features of points in ArcGIS 10.1 was used to calculate the degrees of influence associated with the distribution of governmental organizations for protecting the forest area and biodiversity. The impacts of organizations are different for each group. Thus, the weights were created to show the differences. The weights are presented in Table 5.16. The maximum range for impact ability of the organizations considered is around 10 kilometers from their locations.

Table 5.16. Assessing the ability of offices in protecting forest and biodiversity

ID	Groups	Weight
1	People's committee of commune	1
2	People's committee of district	2
3	Forest station	4
4	Forest protection department	5

To evaluate the possibility of forest and biodiversity management by using law and regulations, we based on the position of agencies related to forest protection and biodiversity conservation in the study area. Four central agencies are responsible for forest protection and biodiversity conservation, including forest protection department, forest station, people's committee of commune, and people's committee of district. Based on collected map data, the locations of these agencies were identified and then updated by Sentinel-2 in April 2018 and the fieldwork in 2017.

Table 5.17. Categories of protection levels based on the law in the study area

ID	Levels of influence	Old values	New values
1.	Very high	≥ 0.308	4
2.	High	0.209 - 0.307	3
3.	Medium	0.135 - 0.208	2
4.	Low	0.066 - 0.134	1
5.	Very low	≤ 0.065	0

The positions of these agencies were classified based on their capacities and responsibilities for forest protection and biodiversity conservation to identify the priority level of these criteria in the assessment process (Table 5.16). Then, by applying the method of Kernel Density Estimation, we estimated the influence levels of the positions of these agencies on forest and biodiversity protection in the study area. We argue that the distribution of forest protection agencies influences forest management. It means that forest management is considered better in the regions that are closer to forest protection agencies. Then we established a map on the distribution of forest protection agencies to identify their influence on biodiversity conservation in all positions within the study area. Based on the method of Jenks Natural Breaks, there are five influence levels of the positions of forest protection agencies, ranging from very low to very high (Table 5.17).

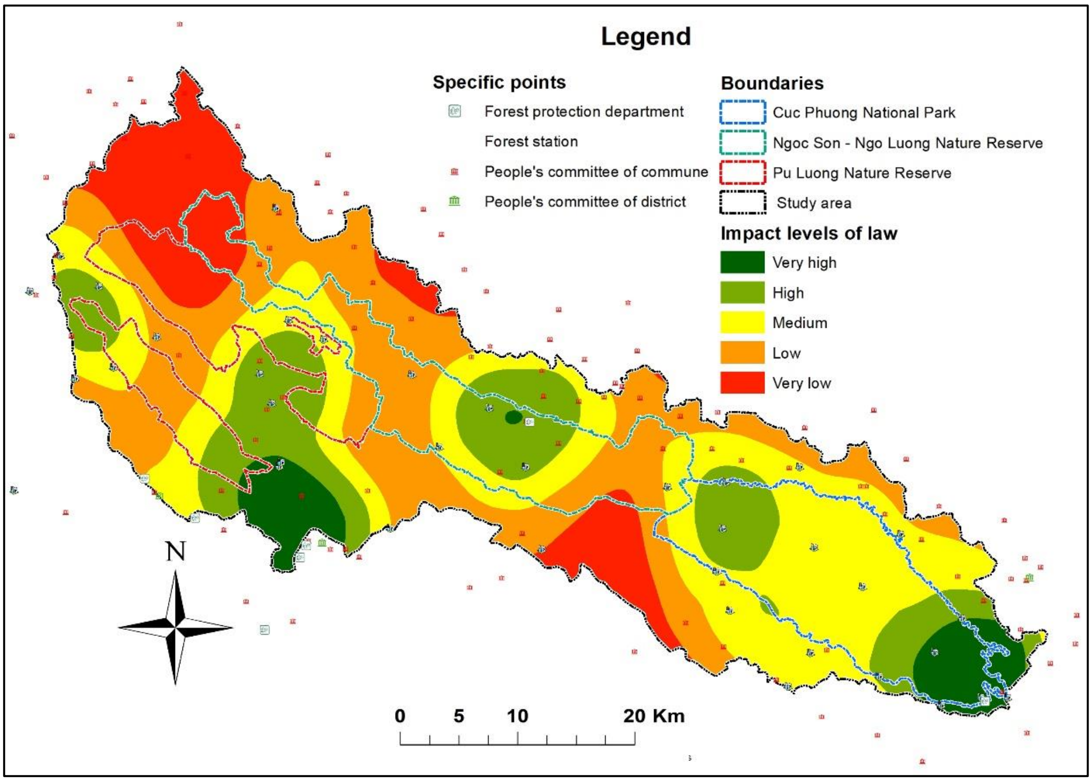


Figure 5.91. Levels of protection ability of forest offices in the study area

The results have shown that in NSNLNR and PLNR have a low distribution of forest protection agencies, while the distribution of these agencies is medium or high in CPNP (Figure 5.91). It has shown that 43.2% of the total area has a low distribution of forest protection agencies, which lead to weak management of forest by law (Appendix III - Table III. 26). 29.4% out of 43.2% could be found outside three existing protected areas while the rest of the area belongs to NSNLNR and PLNR, making up 7.9% and 5.9%, respectively. High distribution of forest protection agencies is found in CPNP, accounting for 42,5% of the national park area. 56.8% of CPNP has a medium distribution of forest protection agencies (Figure 5.92).

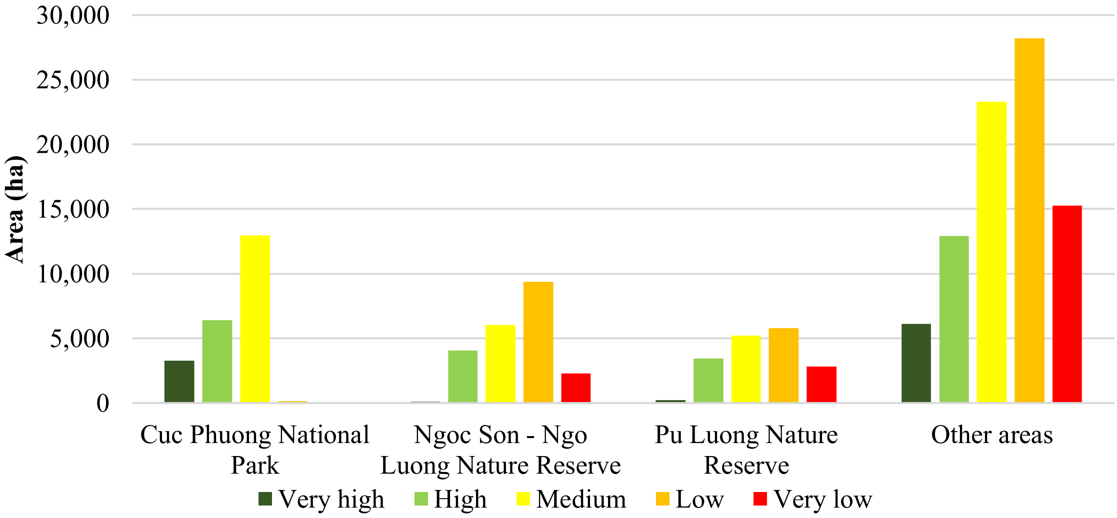


Figure 5.92: Assessment of priority areas of law in the study area

5.2. Synthesis of multiple criteria

According to Gordon et al. (2005), the main target of conservation often focuses on species, especially on the variety of species and threatened species. It is assumed that the protection of the species' habitat is one of the most effective methods for biodiversity conservation. The priority areas usually tend to be either primitive area where the human activities are at a minimum, or highly vulnerable and irreplaceable area with less protection in the future or critical loss of species and their habitat as happened in the past.

In this thesis, we developed criteria and their weights to identify priority areas for biodiversity conservation in Vietnam. The criteria system includes three factors: pressure, state, response. Then seven criteria, 15 sub-criteria, and their weights were determined through the results acquired from the field survey in 2017 (Figure 4.1).

The priority area for biodiversity conservation in the study area was synthesized from 17 layers including two criteria (Education and Law) and 15 sub-criteria (Richness, Rarity, Location, Topography, Climate, Hydrology, Forest type, Climate change, Natural disaster, Population Distribution, Population Density, Population Number, Livelihood, Forest Management Types, and Size of Forest Area). The values of each layer were multiplied with their weights. Then the layers were overlaid to define the priority areas for biodiversity conservation in the study area.

The factor of "state" consists of two main criteria, namely species and habitat, and five sub-criteria. The criteria of species rely on the richness of species and the number of endemic species in the study area. It means that an area is identified as a priority for biodiversity conservation regarding the factor of species if it covers a richness of species and suitable habitat of many endemic species. There are five sub-criteria to evaluate the priority level of ecosystems, including location, topography, hydrology, climate, forest types. Concerning the factor of the ecosystem, the priority areas are defined based on the location of the ecosystem, change of topography, the density of hydrology, levels of stable temperature every year, and different forest types.

The factor of "pressure" comprises human and natural pressures on biodiversity. This study has shown that there is an increasing need to protect biodiversity in the area that has a high pressure from human or nature. In this thesis, we used climate change and natural disasters as two sub-criteria for nature pressure. It is shown that priority should be put into areas that are sensitive to climate change and natural disasters. In addition, human pressure on biodiversity is an inescapable factor in Vietnam. We estimated human pressure by using four elements: population distribution, population density, population number, and livelihood. The requirement for protecting biodiversity will increase in the region where there is more substantial pressure from populations.

Another factor of the environmental model to define priority area is "response." This factor is derived from the solution to conserve biodiversity, such as education, law, size of forest area, and protect management types. This study has indicated that the limitation of education and law enforcement could lead to weaknesses of forest protection and biodiversity conservation, and thus, priority should be put into the areas that have a deficit in education and law enforcement. Education and law enforcement are also critical criteria to define priority areas for biodiversity conservation. Besides, the level of priority also depends on the size of the forest area and forest management types.

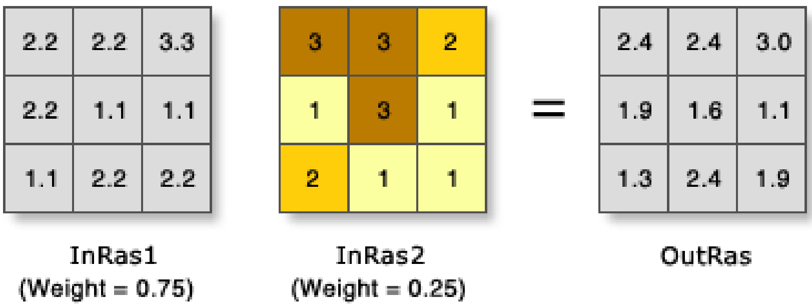


Figure 5.93. Example of application of the weighted sum method
(Source: https://pro.arcgis.com)

To combine multiple criteria in defining priority areas for biodiversity conservation, the weighted sum method was applied to create an integrated analysis. The output layer is a combination between the criteria and their given weights or relative importance. Figure 5.93 illustrates the combination of two factors with their given weight (75% and 25%) to create the output raster. For example, 2.2 and 3 are the values of the upper-left cell of each input. The calculated value of output cell becomes (2.2 x 0.75) + (3 x 0.25) = 2.4.

5.2.1. All respondents

The opinions of 185 respondents in the field survey in 2017 were synthesized to define the importance level of the criteria system, including three factors, seven criteria, and 15 sub-criteria. Appendix II - Table II. 4 presents the structure of a criteria system with three levels (factors, criteria, and sub-criteria). The importance levels of criteria are shown through their corresponding weights. According to the assessment of the importance levels of criteria, the “pressure” factor was considered as the most important element with 41.1 %. “Human” criterion of this factor accounts for the highest weight (30.8 %) in the next level, in which 13.1 % is the impact level of the “livelihood” sub-criterion to biodiversity conservation.

Table 5.18. Categories of priority levels for biodiversity conservation by all respondents

ID	Priority levels	Thresholds	New values
1	Very high	244.153 - 317.790	5
2	High	206.283 - 244.152	4
3	Medium	164.204 - 206.282	3
4	Low	114.762 - 164.203	2
5	Very low	49.540 -114.761	1

The values of synthesized layers were classified by Natural Breaks (Jenks) method into five groups in ArcGIS 10.1. The groups represented five levels of priority areas for biodiversity conservation, such as very high, high, medium, low, and very low. The divided thresholds for different levels are described in Table 5.18. The thresholds were applied to define priority areas for biodiversity conservation of the three groups, including Protected Areas, Universities and Research Institutes, and Government Organizations. It helps to gain the precise comparison of results of priority areas for biodiversity conservation in the study area among three groups as well as from all respondents.

The reclassified layer was converted to vector format for calculating and synthesizing the data on priority areas for biodiversity conservation in the study area. The maps on priority areas for biodiversity conservation in the study area, synthesized following the opinions of all respondents, were illustrated with five levels represented by five respective colors, as shown in Figure 5.94. It is easy to see the most important areas for conserving biodiversity represented on the map with the most areas located in three protected areas.

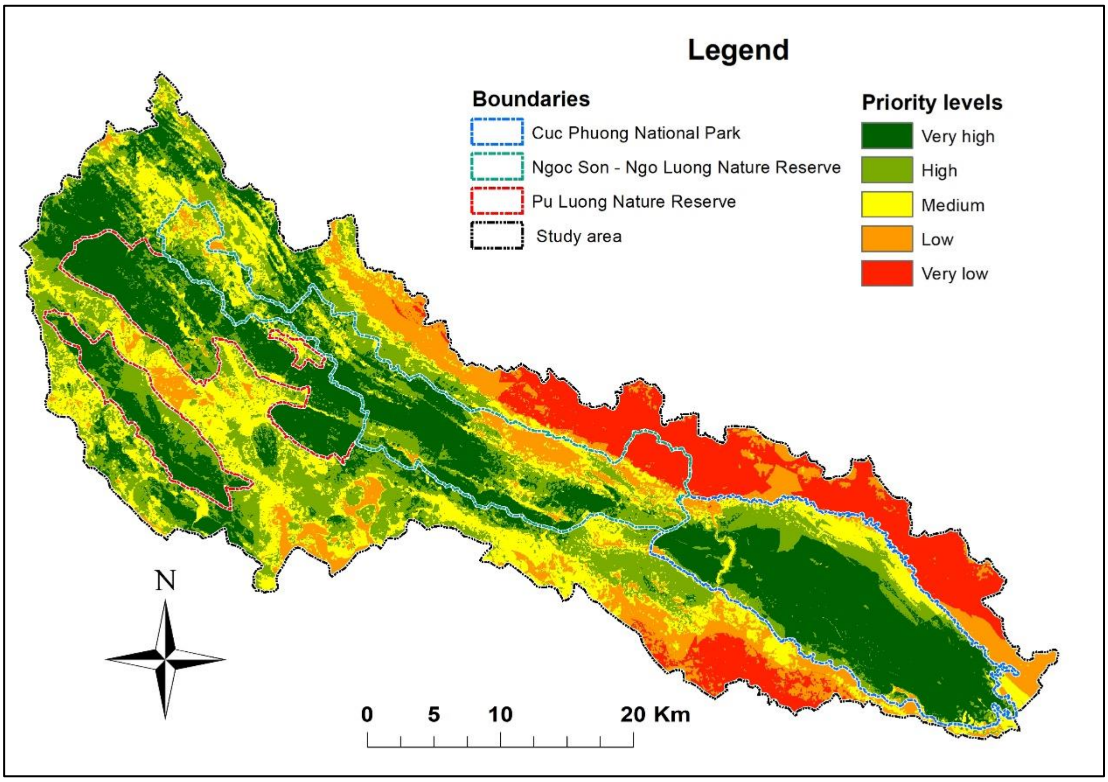


Figure 5.94. Priority areas for biodiversity conservation synthesized by all respondents

Our results have shown the area and location of priority regions for biodiversity conservation in the study area (Figure 5.94). The areas at high or very high priority levels account for 56.1% of the total area with the proportion of the three existing protected areas (CPNP, NSNLNR, PLNR), making up 13.1%, 9.7% and 11.4% respectively (Table 5.19).

Table 5.19 also illustrates priority areas for each existing protected area. The results have indicated that 96% of PLNR are classified as high or very high priorities. The CPNP comprises 84.9% that are categorized as high or very high priorities. NSNLNR covers the smallest proportion (65.9%) at high or very high priority levels. 16.4% of NSNLNR are low or very low priority areas. Also, 21.9% of the total area is classified as high or very high priority areas, which are found outside the three existing protected areas.

Table 5.19. Area statistics of priority levels for biodiversity conservation calculated from all respondents in the study area

Specific regions	Priority levels	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very high	14,756.5	64.7	10.0
	High	4,608.3	20.2	3.1
	Medium	2,514.9	11.0	1.7
	Low	765.9	3.4	0.5
	Very low	146.9	0.6	0.1
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	8,018.7	36.7	5.4
	High	6,382.2	29.2	4.3
	Medium	3,897.7	17.8	2.6
	Low	2,246.7	10.3	1.5
	Very low	1,327.6	6.1	0.9
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	12,405.1	70.9	8.4
	High	4,389.1	25.1	3.0
	Medium	665.4	3.8	0.4
	Low	40.6	0.2	0.0
	Very low	0.0	0.0	0.0
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	9,512.5	11.1	6.4
	High	23,004.4	26.8	15.5
	Medium	21,506.0	25.1	14.5
	Low	15,777.8	18.4	10.7
	Very low	16,030.2	18.7	10.8
	Sum	**85,831.0**	**100.0**	**58.0**
Total	Very high	44,692.8	30.2	30.2
	High	38,384.0	25.9	25.9
	Medium	28,584.0	19.3	19.3
	Low	18,831.0	12.7	12.7
	Very low	17,504.7	11.8	11.8
	Sum	**147,996.4**	**100.0**	**100.0**

SR: Specific region *SA: Study area*

5.2.2. Protected Areas group

The respondents who work in the protected areas (PAs) account for more than 34 % (64 people) of all respondents. This group obtains a number of respondents less than the group of University and Research Institutes. The data achieved through interviews of PAs group were separated for calculating the weight estimated by the Analytic Hierarchy Process (AHP) method.

The weights of three factors, seven criteria, and 15 sub-criteria are shown in appendix II - Table II. 27. The assessment of three factors is similar to the results obtained by asking the opinion of all respondents. However, the impact of human activities was assessed higher than the results of all respondents, with 33 % influencing the selection of priority areas for biodiversity conservation. In which, "Livelihood" sub-criterion still accounts for 14 % that is the highest percentage among sub-criteria.

Table 5.20. Categories of priority levels for biodiversity conservation by PAs group

ID	Priority levels	Thresholds	New values
1	Very high	244.153 – 320.940	5
2	High	206.283 - 244.152	4
3	Medium	164.204 - 206.282	3
4	Low	114.762 - 164.203	2
5	Very low	48.710 -114.761	1

To define the priority areas for biodiversity conservation in the study area, 16 out of 17 criteria were synthesized with the corresponding weights in appendix II - Table II. 27 by the tool of the weighted sum in ArcGIS 10.1. The maps of all criteria were converted to the raster format before the weighted sum method was applied. The result is the raster file with the synthesized values for each pixel. The range of the value is extensive, running from 48.7 to 320.9, as described in Table 5.20.

The thresholds presented in Table 5.18 were applied to the "Protected Areas" group and divided into five groups of priority levels from very low to very high value of biodiversity conservation and assigned an integer number from 1 to 5, respectively. The priority levels for biodiversity conservation in the study area are represented with the spatial locations of color regions on the map, as shown in Figure 5.95.

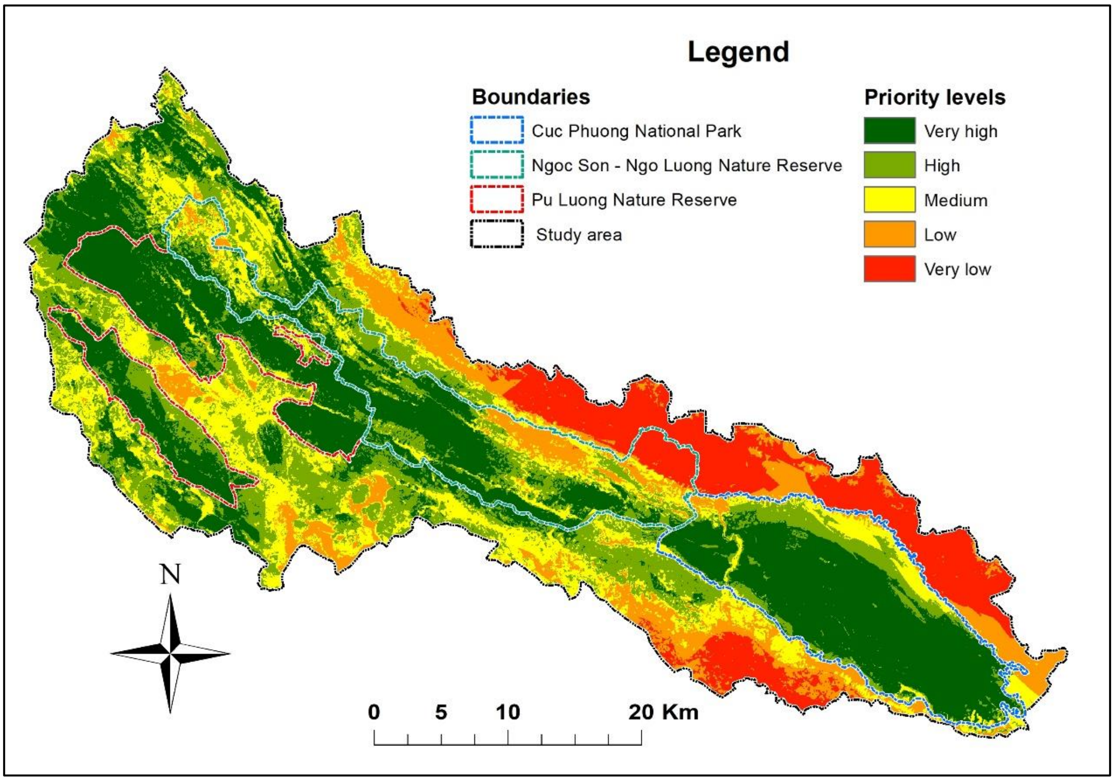


Figure 5.95. Priority areas for biodiversity conservation synthesized by PAs group

Table 5.21 indicates that 58% of the total study area is categorized as high or very high levels of priority for biodiversity conservation, with 23.3% lying outside of the three protected areas. There is only 2.9% of the total study area belonging to the three protected areas that are considered as low or very low levels of priority for protecting biodiversity with the highest area (2.4%) found in NSNLNR. The area at high or very high levels of priority was calculated for each protected area. The results have shown that the proportion of the priority levels for CPNP, PLNR, and NSNLNR are 86.7%, 96.7%, and 66.6%, respectively.

The results show that PLNR and CPNP have managed large areas that were estimated with high or very high priority for biodiversity conservation. In contrast, the areas belonging to high or very high levels in NSNLNR were not covered much. 33.4% of the NSNLNR area needs to be considered again in the planning of management and development.

Table 5.21. Area statistic of priority levels for biodiversity conservation calculated for PAs group in the study area

Specific regions	Priority levels	Area		
		ha	**% (SR)**	**% (SA)**
Cuc Phuong National Park	Very high	15,744.2	69.1	10.6
	High	4,015.7	17.6	2.7
	Medium	2,261.0	9.9	1.5
	Low	634.5	2.8	0.4
	Very low	137.2	0.6	0.1
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	8,857.3	40.5	6.0
	High	5,698.7	26.1	3.9
	Medium	3,777.8	17.3	2.6
	Low	2,201.5	10.1	1.5
	Very low	1,337.6	6.1	0.9
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	13,701.6	78.3	9.3
	High	3,225.8	18.4	2.2
	Medium	549.0	3.1	0.4
	Low	23.6	0.1	0.0
	Very low	0.0	0.0	0.0
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	11,267.7	13.1	7.6
	High	23,247.4	27.1	15.7
	Medium	20,185.3	23.5	13.6
	Low	14,964.0	17.4	10.1
	Very low	16,166.5	18.8	10.9
	Sum	**85,831.0**	**100.0**	**58.0**
Total	Very high	49,570.8	33.5	33.5
	High	36,187.6	24.5	24.5
	Medium	26,773.1	18.1	18.1
	Low	17,823.6	12.0	12.0
	Very low	17,641.2	11.9	11.9
	Sum	**147,996.4**	**100.0**	**100.0**

SR: Specific region *SA: Study area*

5.2.3. Government Organizations group

The number of respondents from the Government Organizations (GOs) group is the lowest, making up around 10% of all respondents. This group plays an essential role in implementing and advising policies and strategies in forest protection and biodiversity conservation. The weights of the GOs group are described in appendix II - Table II. 50.

The results of calculating the weights for the GOs group show that there is very little difference regarding the importance levels of the criteria in comparison with the results of PAs group and all respondents. The pressure criterion related to human activities is the main element that impacts on defining priority areas for biodiversity conservation, making up 30.8%. Among these, criteria of livelihood, population number, population density, and population distribution account for 12.1%, 7.2%, 7.2%, and 4.3%, respectively.

Table 5.22. Categories of priority levels for biodiversity conservation by GOs group

ID	Priority levels	Thresholds	New values
1	Very high	244.153 - 328.640	5
2	High	206.283 - 244.152	4
3	Medium	164.204 - 206.282	3
4	Low	114.762 - 164.203	2
5	Very low	50.520 - 114.761	1

The weights were entered into the weighted sum tool of ArcGIS 10.1 along with the corresponding layers that represent the criteria of biodiversity conservation. The synthesized images achieved values between 50 and 328. The threshold values were used to define five priority levels of the GOs group for biodiversity conservation in the study area, as described in Table 5.22.

The synthesized images of the GOs group were reclassified following five levels from very low to very high priority for biodiversity conservation based on the configurations in Table 5.22. The distribution of priority levels in the study area is shown in Figure 5.96. The map illustrates the distribution of priority areas for biodiversity conservation in the study area with the most areas of a very high priority level lying within the three protected areas. The area accounts for 34.2 % of the study area, in which the three protected areas occupy 27.4% (Table 5.23).

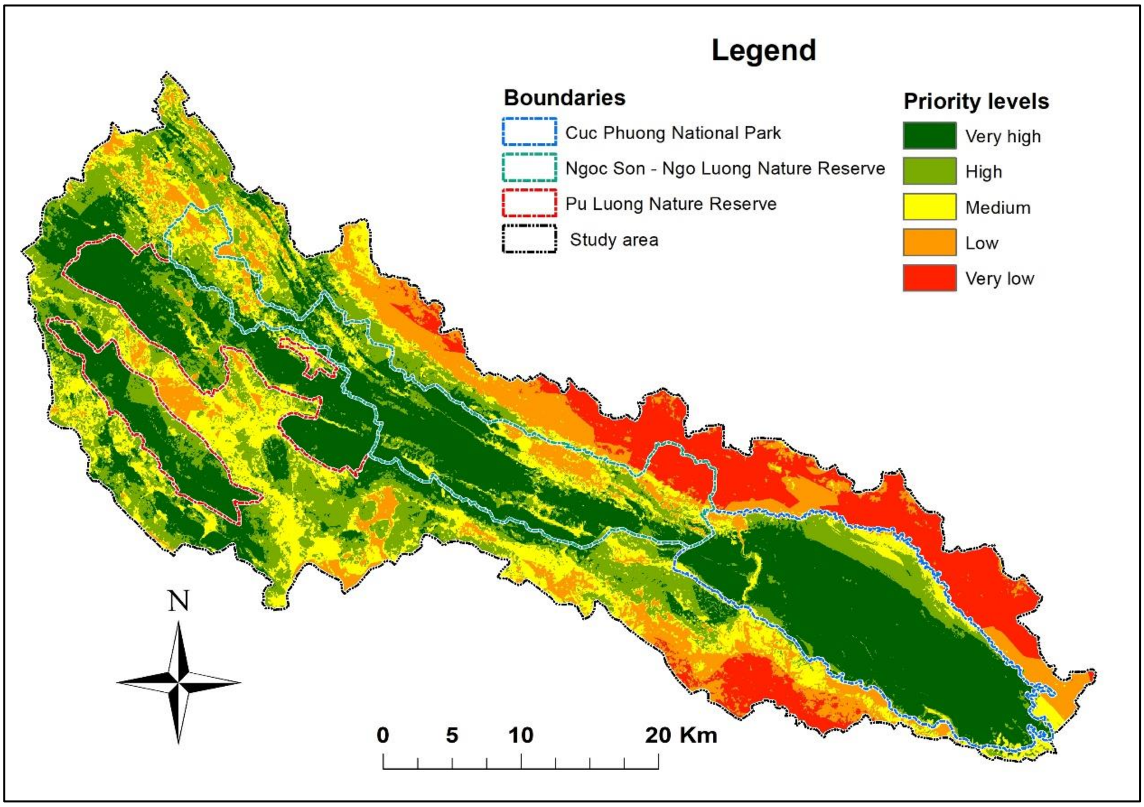


Figure 5.96. Priority areas for biodiversity conservation synthesized by GOs group

Our results have shown that 57.9% of the total area is classified as high or very high priority areas with the proportion of CPNP, NSNLNR, and PLNR, accounting for 13.9%, 10.1%, and 11.3% respectively. The rest (22.5%) is found outside three protected areas with 15.7% of that as high level. We also estimated the areas at very high or high priority levels for each protected area. It is shown that very high or high priority areas account for 90.2%, 68.4%, and 95.9% in CPNP, NSNLNR, PLNR, respectively.

Based on our results, we confirm that both PL NR and CP NP cover most areas at high levels of biodiversity conservation that were synthesized and classified from all selected criteria through the opinions of the GOs group while the high or very high priority areas of NSNLNR are still smaller than other protected areas.

Table 5.23. Area statistic of priority levels for biodiversity conservation calculated from GOs group in the study area

Specific regions	**Priority levels**	**Area**		
		ha	**% (SR)**	**% (SA)**
Cuc Phuong National Park	Very high	17,034.5	74.7	11.5
	High	3,533.8	15.5	2.4
	Medium	1,657.4	7.3	1.1
	Low	451.4	2.0	0.3
	Very low	115.4	0.5	0.1
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	10,357.0	47.4	7.0
	High	4,590.0	21.0	3.1
	Medium	3,775.1	17.3	2.6
	Low	1,879.3	8.6	1.3
	Very low	1,271.5	5.8	0.9
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	13,192.8	75.4	8.9
	High	3,590.1	20.5	2.4
	Medium	629.7	3.6	0.4
	Low	87.5	0.5	0.1
	Very low	0.0	0.0	0.0
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	10,059.2	11.7	6.8
	High	23,301.8	27.1	15.7
	Medium	19,867.8	23.1	13.4
	Low	17,852.5	20.8	12.1
	Very low	14,749.6	17.2	10.0
	Sum	**85,831.0**	**100.0**	**58.0**
Total	Very high	50,643.5	34.2	34.2
	High	35,015.8	23.7	23.7
	Medium	25,930.0	17.5	17.5
	Low	20,270.7	13.7	13.7
	Very low	16,136.5	10.9	10.9
	Sum	**147,996.4**	**100.0**	**100.0**

SR: Specific region *SA: Study area*

5.2.4. Universities and Research Institutes group

The group of Universities and Research Institutes (URIs) had the highest number of respondents, making up 50% of all respondents. The opinions of the URIs group were analyzed, synthesized, and calculated by the Analytic Hierarchy Process (AHP) method. The results have shown the importance levels of criteria for biodiversity conservation in Vietnam (Appendix II - Table II. 73).

The results have shown a significant difference between the URIs group with other cases. The URIs group had a greater focus on the "Response" factor (41%), including the "Education" criterion (17%), the "Law" criterion (13%), and the "Conservation" criterion (11%). In comparison, the "Pressure" factor has a smaller impact level (26%).

The weights are considered as the fundamental element in combining all criteria for defining priority areas for biodiversity conservation in Vietnam (Appendix II - Table II. 73). The layers representing the corresponding criteria were synthesized using the Weighted Sum tool in ArcGIS 10.1.

Table 5.24. Categories of priority levels for biodiversity conservation by URIs group

ID	Priority levels	Thresholds	New values
1	Very high	244.153 – 306.280	5
2	High	206.283 - 244.152	4
3	Medium	164.204 - 206.282	3
4	Low	114.762 - 164.203	2
5	Very low	41.000 -114.761	1

The displayed values on the map synthesized by 16 criteria of the URIs group fluctuate from 41 to around 306.28 (Table 5.24). To group the values into five classes regarding the priority levels for biodiversity conservation, the thresholds created by the data of all respondents in Table 5.18 were applied for the URIs group. The classes are very low, low, medium, high, and very high priority areas and are illustrated in Figure 5.97 after reclassifying the synthesized layers.

Then, area statistics on priority areas for biodiversity conservation in the study area are presented in Table 5.25. Our results show that 42.9% of the total study area is classified as a high or very high priority in the study area. These areas in CPNP, NSNLNR, and PLNR are 12.3%, 7.5%, and 10.2%, respectively. We also estimated the areas for each protected area. Our findings indicate that proportions of high or very high priority areas for CPNP, NSNLNR, and PLNR are 80.1%, 51%, and 85.8%, respectively.

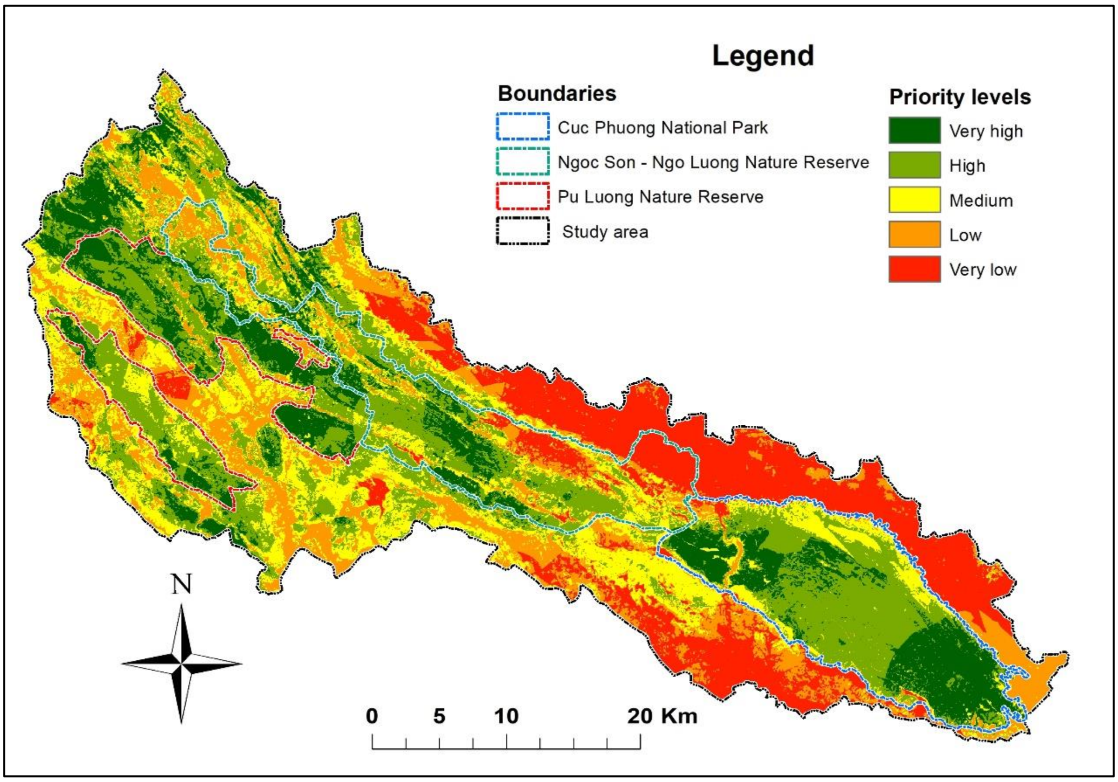


Figure 5.97. Priority areas for biodiversity conservation synthesized by URIs group

In comparison with the rest of the protected areas, NSNLNR has the highest proportion of areas at very low or low priority levels accounting for 29.2% of the area of the reserve. This reserve has the lowest level of the areas at high or very high priority levels that identified using the opinions of the URIs group in comparison with the results of other groups and all respondents. Our results have raised a critical question about the accuracy and rationality of defining priority areas for biodiversity conservation in the Ngoc Son – Ngo Luong nature reserve.

Table 5.25. Area statistics of priority levels for biodiversity conservation calculated for the URIs group in the study area

Specific regions	Priority levels	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very high	7,694.1	33.8	5.2
	High	10,545.1	46.3	7.1
	Medium	3,199.5	14.0	2.2
	Low	810.4	3.6	0.5
	Very low	543.3	2.4	0.4
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	3,310.1	15.1	2.2
	High	7,858.1	35.9	5.3
	Medium	4,314.0	19.7	2.9
	Low	3,546.7	16.2	2.4
	Very low	2,844.0	13.0	1.9
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	6,290.3	35.9	4.3
	High	8,739.7	49.9	5.9
	Medium	1,942.1	11.1	1.3
	Low	519.3	3.0	0.4
	Very low	8.8	0.1	0.0
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	4,979.2	5.8	3.4
	High	14,006.1	16.3	9.5
	Medium	19,984.3	23.3	13.5
	Low	23,232.4	27.1	15.7
	Very low	23,628.9	27.5	16.0
	Sum	**85,831.0**	**100.0**	**58.0**
Total	Very high	22,273.7	15.1	15.1
	High	41,149.1	27.8	27.8
	Medium	29,439.9	19.9	19.9
	Low	28,108.8	19.0	19.0
	Very low	27,025.0	18.3	18.3
	Sum	**147,996.4**	**100.0**	**100.0**

SR: Specific region *SA: Study area*

Chapter 6. Conclusions and recommendations

6.1. Establishment of criteria

Based on the results, a set of criteria was developed to identify priority areas of biodiversity conservation in Vietnam. The criteria system was established through a literature review on biodiversity conservation in the world and Vietnam, and the application of the Pressure-State-Response environmental model to select the suitable criteria for applying in Vietnam.

The set of criteria was hierarchically structured, including four levels. The first level was the critical purposes of biodiversity conservation. The second was three factors of "State," "Pressure," and "Response," which were analyzed in combination with the environmental model. These factors were principally used to identify and zone the priority areas of biodiversity conservation in Vietnam. The third level contained seven criteria assigned by three factors. "Species" and "Ecosystem" are the two criteria of the "State" factor. "Nature" and "Human" belong to "Pressure." "Response" criterion includes elements of "Education," "Law," and "Conservation". The fourth level contained the highest number of components with 15 sub-criteria. "Education" and "Law" did not have any components at the fourth level.

To identify the importance levels of the criteria for biodiversity conservation in Vietnam, a questionnaire was designed to collect information from the experts and scientists in the fields of forestry, biodiversity, and conservation. The respondents were diverse regarding their responsibilities and expertise. They are lecturers and researchers at universities and research institutes, and staffs of governmental institutions such as the Ministry of Agriculture and Rural Development, Forest Management Department, Protected Areas, and rangers from forest protection stations. The field survey in 2017 collected information and opinions from 185 people across Vietnam. Most of the respondents were categorized into three groups, including Government Organizations (GOs), Protected Areas (PAs), and Universities and Research Institutes (URIs) with 19, 64, and 93 respondents, respectively. The data of all respondents and the three sub-groups were used to calculate the weight of each criterion through the Analytic Hierarchy Process (AHP) method. It revealed the different opinions among groups and all respondents regarding importance levels of each criterion in defining priority areas for biodiversity conservation in Vietnam.

To reconfirm the data, two outlier detection methodologies of interquartile range and standard deviation were used to identify any errors, different opinions as well as enthusiasm for replying to the questionnaire by respondents. Most outliers calculated by the standard deviation were also included in the outliers of the interquartile range method. Many of the outliers from respondents are just one or two elements, and the majority are students, as indicated in appendix II - Table II. 2. Two respondents, including one student (no. 83) and one technician (no. 161), were assessed to have 7 and 17 outlying data points. Therefore, their data was removed before processing the next steps.

The survey provided the opinions of respondents regarding the importance levels of the established criteria. To use the AHP for identifying the weights, the value of each pairwise comparison presented the differences of importance level calculated between two criteria in one pairwise. The relations among the criteria formulated 27 pairwise comparisons. They were grouped into three different levels, including the factors, the criteria, and the sub-criteria. There were nine pairwise comparison matrices established, including one matrix in the second level, three matrices of the third level, and five matrices of the fourth one. The Consistency Ratio (CR) was used to identify the consistencies of the pairwise comparison matrices.

The statistics of weight for the groups of respondents played an important role in the analysis and assessment of each factor, criterion, and sub-criterion. Although the different values of weight appeared in a few sectors of each group, they did not represent the opinions of the majority. Table 6.1 shows the percentage values of weights for the three groups as well as all respondents. The assessments of the criteria based on the Universities and Research Institutes group were quite different in comparison with the results of other groups and all respondents, especially regarding the priority levels between "Response" and "Pressure." At the third level under the "Response" factor, the opinion of the Government Organizations group is different from other groups that the "Law" criterion was considered the essential element opposed to "Education" (Table 6.1).

The synthesis of the weights for each group in Table 6.1 illustrates part of the prevailing trend of the different fields, such as research, training, planning, policy, decision making, and implementation. The Protected Areas group assessed the importance level of the factors in the PSR model is similar to the results of all respondents. The results from the Universities and Research Institutes group shows that the most crucial factor is the "Response" factor with 41%. In contrast, the weights of the "Pressure" factor based on the data collected from the Protected Areas group, Government Organizations group, and all respondents account for the most significant percentage of 41%.

Table 6.1. Comparison between the weights of the groups

Factors	Criteria	Sub-criteria	All (%)	PAs (%)	URIs (%)	GOs (%)
Pressure	Nature	*Climate change*	7.7	6.2	5.8	7.7
		Natural disaster	2.6	2.1	2.9	2.6
		Sum	**10.3**	**8.2**	**8.7**	**10.3**
	Human	*Distribution*	4.6	7.1	2.9	4.3
		Density	6.0	5.5	3.4	7.2
		Population	7.1	6.2	4.1	7.2
		Livelihood	13.1	14.0	6.9	12.1
		Sum	**30.8**	**32.8**	**17.3**	**30.8**
	Total		**41.1**	**41.0**	**26.0**	**41.1**
State	Species	*Richness*	2.9	4.4	5.5	4.3
		Rarity	5.8	4.4	10.9	4.3
		Sum	**8.7**	**8.8**	**16.4**	**8.6**
	Ecosystem	*Location*	2.5	2.7	2.4	2.6
		Topography	3.6	4.3	4.0	2.6
		Hydrology	1.7	1.6	1.8	1.4
		Climate	3.6	2.6	4.7	5.7
		Forest type	6.1	6.2	3.5	5.1
		Sum	**17.5**	**17.4**	**16.4**	**17.4**
	Total		**26.2**	**26.2**	**32.8**	**26.0**
Response	Conservation	*Forest management types*	6.4	6.4	7.2	7.7
		Size of forest area	2.1	2.1	3.6	2.6
		Sum	**8.6**	**8.6**	**10.8**	**10.2**
	Education	*Education*	13.5	13.5	16.9	6.5
	Law	*Law*	10.6	10.7	13.5	16.2
	Total		**32.7**	**32.8**	**41.2**	**32.9**
Total			**100.0**	**100.0**	**100.0**	**100.0**

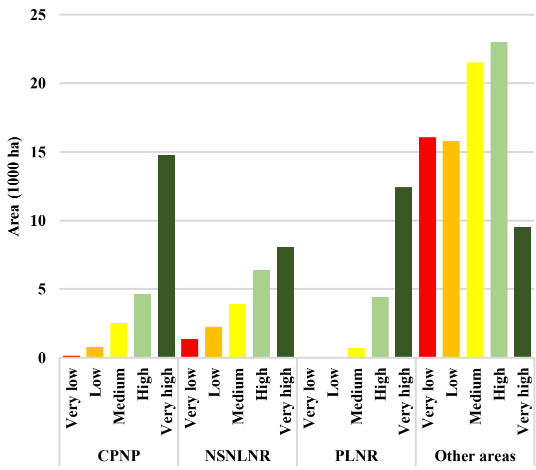
The study area was assessed and classified not only by the opinion of all respondents but also by three specific groups, including Protected Areas, Government Organizations, and Universities and Research Institutes. These groups were categorized based on their characteristics and responsibilities of management, policy, and research. Protected Areas and Government Organizations groups have considered the pressure of humans as the most influential factor in biodiversity conservation. In contrast, the Universities and Research Institutes group has focused on the responses of education, law, and conservation to biodiversity. It leads to varying levels of priority for different criteria by different groups, which influences policy, funding, and research direction.

6.2. Application of criteria

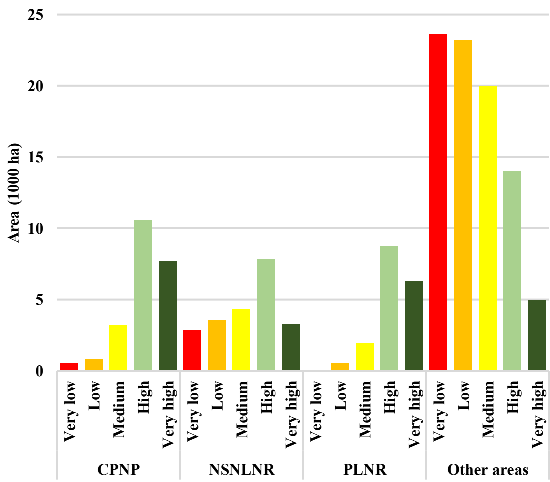
Many recent studies in Vietnam have pointed out that the process for establishing a protected area requires long-term monitoring and investigation of many different factors that impact directly or indirectly on biodiversity. It is a complicated task that needs much time and human resources. Therefore, in this thesis, the application of Geographical Information System (GIS) and Remote Sensing (RS) was used to define the priority areas for biodiversity conservation that could help to define priority areas for establishing new protected areas in Vietnam and reduce the time and human resources needed. As a result, a criteria system was suggested to assess the priority levels for biodiversity conservation in Vietnam. Then this criteria system was applied in Pu Luong – Cuc Phuong area by integrating GIS and RS to define priority areas for biodiversity conservation in this area.

Based on the results of the survey in 2017, seventeen criteria that have a direct or indirect impact on biodiversity conservation in Vietnam were identified with the weights calculated for each criterion. The characteristics of these criteria were analyzed to find out the main elements that help to present the criteria on the map. The database of each criterion was established to fit the collected data as well as suitable methodologies. The criteria were presented in raster format and were classified with five levels of priority areas for biodiversity conservation, consisting of very low, low, medium, high, and very high levels. It helped to have the same form for all criteria before they were synthesized into a unique map defining the essential areas for biodiversity conservation in the study area.

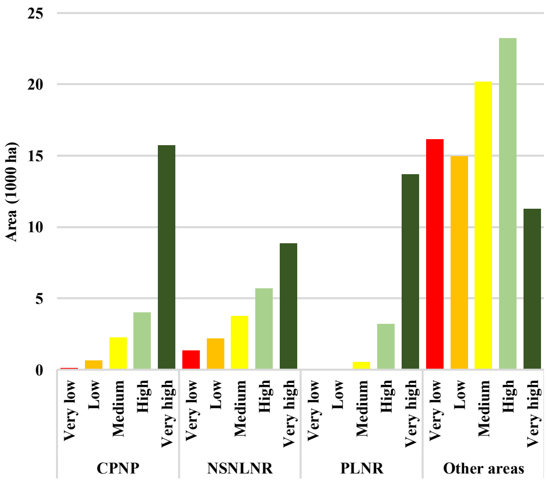
The maps of all criteria were synthesized and performed for four cases to calculate the results based on the calculated weights from the opinions of all respondents and the three main groups. Sixteen out of seventeen maps of criteria were used to synthesize and establish the maps of priority areas for biodiversity conservation in the study area (Pu Luong - Cuc Phuong region). The natural disaster criterion was excluded because there are no significant differences throughout the study area that demonstrated by applying the Kernel Density Estimation method for the location points of natural disasters from 1997 to 2018. The final maps that were calculated for the four cases have expressed the changes of the distribution of priority areas inside three protected areas (Cuc Phuong National Park, Ngoc Son – Ngo Luong Nature Reserve, and Pu Luong Nature Reserve) as well as the entire study area (Figure 6.1). Notably, the differences are quite significant, with the results synthesized by the opinions of the URIs group.



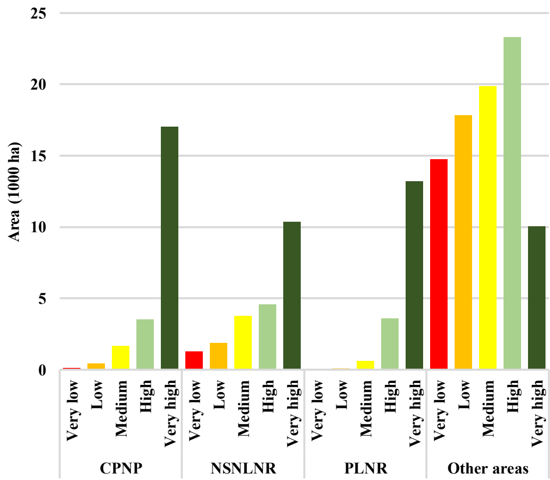
a. Area statistic of priority levels for biodiversity conservation calculated from **all respondents**



b. Area statistic of priority levels for biodiversity conservation calculated from **URIs** group



c. Area statistic of priority levels for biodiversity conservation calculated from **PAs** group



d. Area statistic of priority levels for biodiversity conservation calculated from **GOs** group

Figure 6.1. Area statistics of priority levels for biodiversity conservation based on the weight set of all respondents as well as from three biggest groups

Figure 6.2 illustrates the comparison of the proportion of priority levels among three protected areas and other areas in the study area based on the weight systems calculated for the groups. The results that acquired by synthesizing the weight systems from the opinions of all respondents, as well as the main groups (Protected Areas group, Government Organizations group), are entirely analogous. The percentages of priority areas at high and very high levels have not changed considerably, 85% - 90% for Cuc Phuong National Park, around 96% for Pu Luong Nature Reserve, and 66% - 69% for Ngoc Son – Ngo Luong Nature Reserve. The ratio between the different priority levels, exceptionally high and very high levels, was changed critically in the case of the URIs group. The areas at very high priority level in the study area and within three protected areas make up with 33.8%, 15.1%, and 35.9% in CPNP, NSNLNR, and PLNR, respectively. However, the areas at both high and very high levels within the three protected areas are not small. Respectively, CPNP, PLNR, and NSNLNR account for 80.1%, 85.8%, and 51% out of the total area of each protected area.

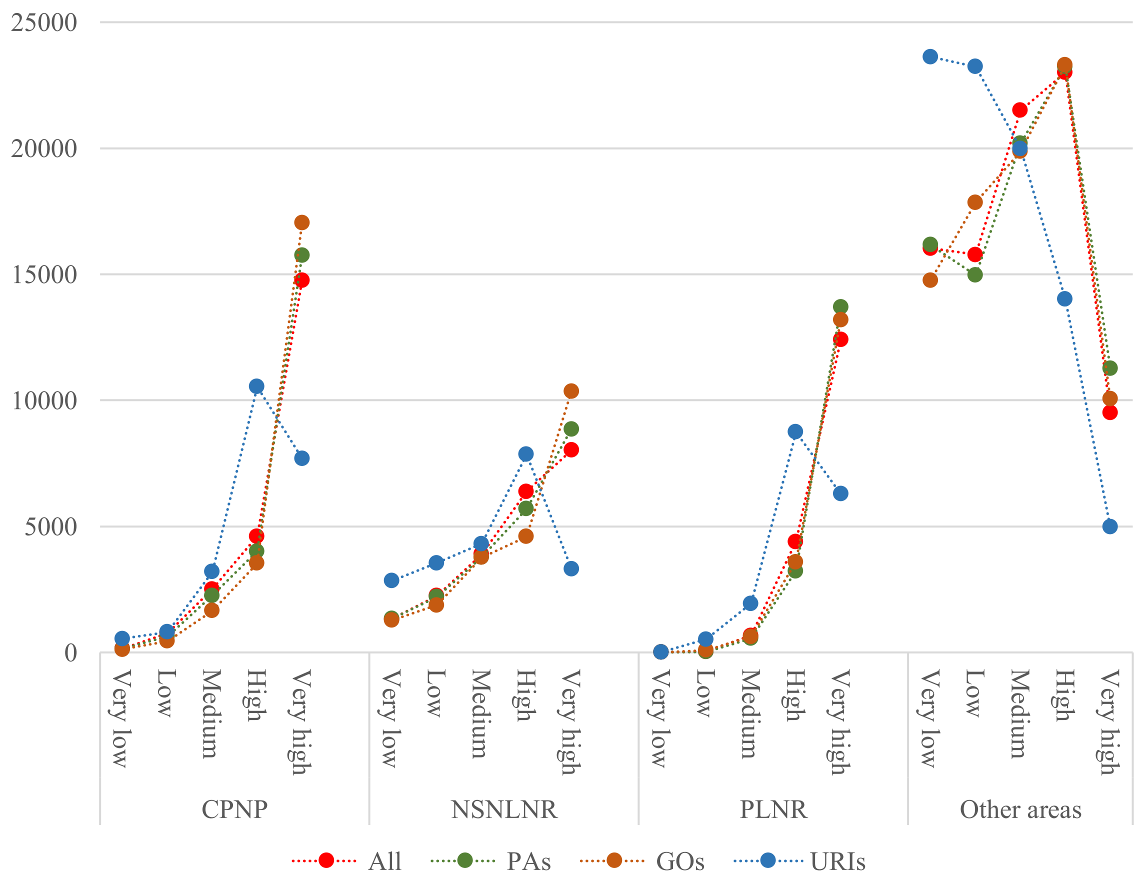


Figure 6.2. Comparison priority levels among protected areas and other areas in the study site based on the weight systems calculated for each group

Table 6.2. Data used for mapping sub-criteria

No	Data	Number	Type	Sub-criteria																
				Richness	Rarity	Location	Topography	Climate	Hydrology	Forest Types	Climate Change	Natural Disasters	Distribution	Density	Population	Livelihood	Forest Management	Size of Forest Areas	Education	Law
1	Landsat 5 TM	4	Image	X			X													
2	Landsat 8 OLI	4	Image	X	X		X	X		X							X	X		
3	Sentinel 2A	3	Image		X				X			X	X	X	X	X			X	X
4	Digital Elevation Model	1	Image		X		X													
5	Maps of Forest	6	Map		X	X			X	X							X	X		X
6	Maps of Land Use - Land Cover	3	Map										X	X	X	X	X		X	X
7	Administrative Maps	3	Map											X	X	X				
8	Terrestrial ecoregions	1	Map			X														
9	Climate change scenarios (2046-2065)	2	Map								X									
10	Data of hydro-meteorological stations	1	Text					X												
11	IUCN Red List	1	Text		X															
12	Vietnam Red Data Book	2	Text		X															
13	Data of natural disasters	1	Text									X								

The selected study area covers three important protected areas in the northern midlands of Vietnam. The results show the more massive proportions of these protected areas that are classified as high and very high priority for biodiversity conservation. These proportions of Cuc Phuong national park and Pu Luong nature reserve occupy at a high rate with more than 80% and 85%, respectively, in all analyzed cases based on all respondents and three separate groups. Exceptionally, the areas were found only from 51% to 58% in the Ngoc Son – Ngo Luong nature reserve. Consequently, it can be recognized that there is a correlation between very high and high priority areas as identified and the existing boundaries of 3 protected areas.

Table 6.2 shows the statistics of all data that were used to establish the maps of criteria in this study. Thirteen data sources are categorized into three categories, including images, maps, and text documents. They were used to map 17 sub-criteria. Satellite images of Landsat and Sentinel played a crucial role in establishing 15 out of 17 sub-criteria. It confirms the importance of GIS and Remote Sensing not only as powerful tools but also as significant inputs for identifying areas for biodiversity conservation.

To accomplish this research, field surveys are crucial in investigating and collecting the data. Field surveys do not only help to gather inputs for the study but also to be an important base to assess the accuracy in mapping the criteria. The results of the priority areas for biodiversity conservation were reassessed based on the comparison with the present state in the field. Consequently, it is required to complement the field surveys in the application of GIS and Remote Sensing to be able to identify priority areas for biodiversity conservation.

6.3. Recommendations

The synthesis and assessments of priority areas for biodiversity conservation at different levels in the Pu Luong – Cuc Phuong region indicate 56% of the total area classified as high and very high importance. It is to confirm that the Pu Luong – Cuc Phuong region is an important ecosystem in maintaining and protecting biodiversity in Vietnam. There is a need to consider the areas classified as high and very high priority for biodiversity conservation to enhance protection as well as prevent loss of biodiversity in the region.

Cuc Phuong national park and Pu Luong nature reserve were assessed and classified with 85% and 96% of the total area of each protected area at high and very high priority levels for biodiversity conservation, respectively. These results are evidence to confirm the high accuracy in identifying the boundaries of these protected areas. Therefore, it is suggested that the boundaries of Cuc Phuong national park and Pu Luong nature reserve should be maintained, and protection should be strengthened to conserve the remaining biodiversity in these areas.

Ngoc Son – Ngo Luong nature reserve was formulated in 2004 as a biodiversity corridor to link Cuc Phuong national park and Pu Luong nature reserve. The results show that the priority areas at high and very high in Ngoc Son – Ngo Luong nature reserve are smaller in comparison with Cuc Phuong national park and Pu Luong nature reserve. 19% of the total area in Ngoc Son – Ngo Luong nature reserve, which ranges at low and very low priority for biodiversity conservation, are cumulated into several large areas inside the protected area. Concerning the boundary of the Ngoc Son – Ngo Luong nature reserve, further biodiversity surveys should be conducted to reappraise biodiversity, its function areas and redefine its boundary appropriately.

Beside three existing protected areas in the study area, the extended area outside these protected areas account for 58% of the total area of the study site, which is considered significant in remaining and protecting biodiversity in Pu Luong – Cuc Phuong. Notably, 38% of the area, that were assessed and identified as a high and very high priority area for biodiversity conservation should be reconsidered for expansion of the existing protected areas or formulation of a new protected area covering these areas. This study provided a system of criteria to support for defining priority areas for biodiversity conservation in Vietnam. These criteria were applied to identify priority areas for biodiversity conservation in Pu Luong - Cuc Phuong region by using a combination of GIS and remote sensing, and field survey.

The results have confirmed the accuracy and rationality in defining the boundaries of CPNP and PLNR. However, this study also shows a need to re-assess and re-define the boundary of NSNL NR that should cover the areas at high or very high priority levels outside the existing protected areas. To expand the application of these criteria in Vietnam, further research is needed in different biodiversity sites. Based on our results, we suggested that these criteria should be used to re-assess boundaries of other existing protected areas or define boundaries of new protected areas.

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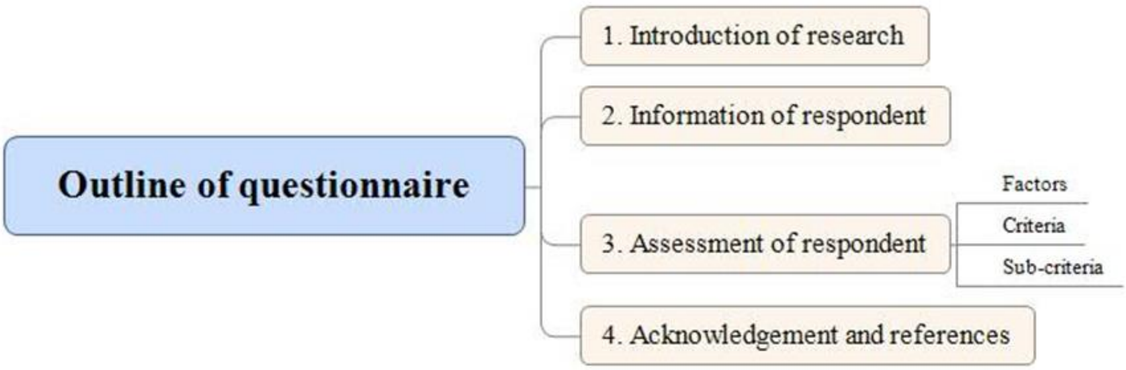
Appendix I. Questionnaire

IDENTIFYING CRITERIA TO DEFINING PRIORITY AREAS FOR BIODIVERSITY CONSERVATION



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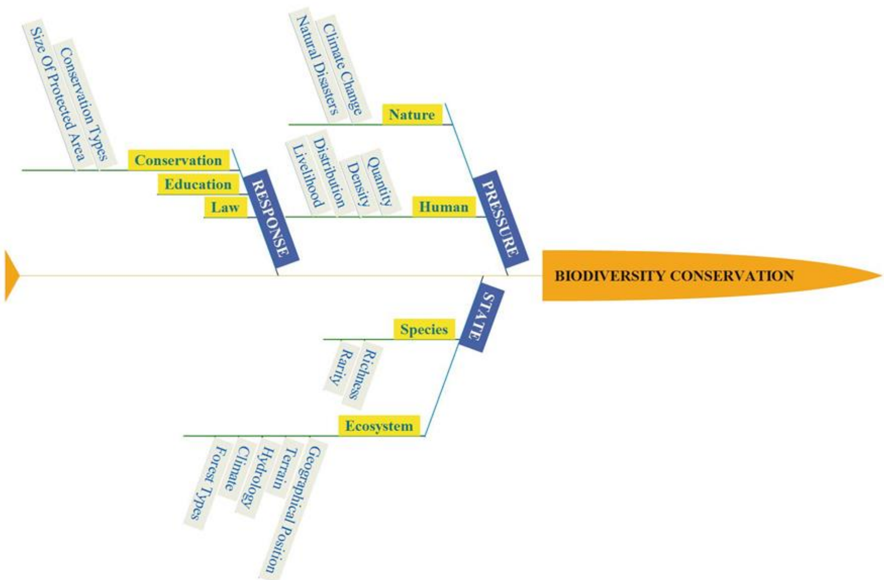
A. Introduction of research

Vietnam has been recognized as one of the 16 countries with high biodiversity in the world and is one of the priority countries for global conservation, with about 10% species worldwide and area accounts for only 1% of the land area of the world (PARC, 2002). Natural protected areas system comprises 164 PAs, including 30 National Parks, 69 Nature Reserves, and 45 landscape protection areas, 20 areas of empirical scientific research (MARD, 2007). Thus, PAs protection and management are of vital significance for biodiversity conservation in Vietnam (Bruner et al. 2001). However, the loss of biodiversity in Vietnam has been very critical, with many species are on the brink of extinction due to human exploitation (Nghia 1999, and Primack et al. 1999).

Vietnamisoneofthecountriesintheworldtobeconsideredasthehighestproportionofthreatened species (Pilgrim&Tu2007). Vietnam has more than 300 species threaten data global level, including 49 species are considered in the case of many Endangered, Threatened, and Rare plant and animal species are at risk on the brink of extinction (WorldBank,2005). In order to identify threats influencing biodiversity conservation needs a conservation strategy based on situational analysis and a biological assessment to formulate the priority landscape (Baltzer2000). The biodiversity assessment process was facing many limitations (Tordoff,2003). One of the root limitations for the biodiversity assessment process in Vietnam is the incomprehensive data set on the conservation status of Vietnam's protected areas. The data of biodiversity is usually identified through personal observation, interviews, and the capacity of institutions responsible for protected areas management. Based on the previous information described before, it is necessary to carry out a study as follows "Application of Geoinformation Science (GIS) to establish a database of biodiversity conservation for regional planning and management of protected areas in the northern region of Vietnam."

The figure of the criteria tree in biodiversity conservation:



B. Information of respondent

Please provide the following general information about you. All personal information will be confidential

1. Full name: *

....

2. Gender:

Male ☐ Female ☐

3. Age:

....

4. Email:

....

5. Phone number:

....

6. Major field: *

....

7. Position in organization*

....

8. Address of organization: *

Please follow the order: House number, street number, commune, district, province

....

....

....

C. **Assessment of respondent**

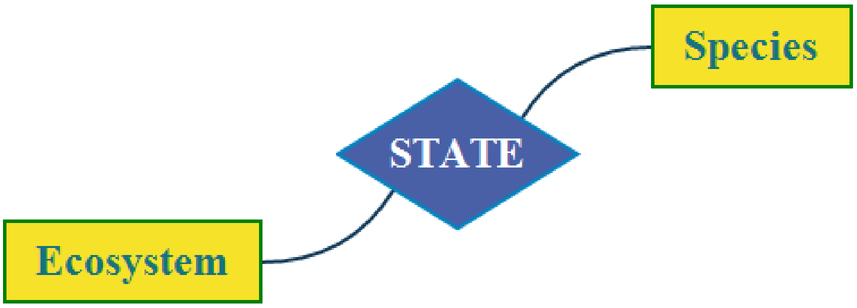
1. In order to assess the priority level in biodiversity conservation, we have three factors, including "State," "Pressure," and "Response." Which importance level do you think are the below factors influencing the priority areas of biodiversity conservation? * *Please give us your opinion about the level of importance for each criterion following nine levels from 1 (non-influence) to 9 (extreme influence)*

	1	2	3	4	5	6	7	8	9
State	○	○	○	○	○	○	○	○	○
Pressure	○	○	○	○	○	○	○	○	○
Response	○	○	○	○	○	○	○	○	○

2. "State" factor includes two criteria are "species" and "ecosystem" state. Which importance level do you think is the below criteria influencing the "State" factor? *

Please give us your opinion about the level of importance for each criterion following nine levels from 1 (non-influence) to 9 (extreme influence)

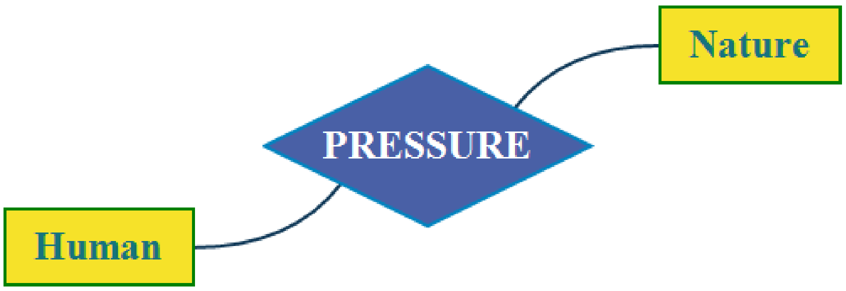
	1	2	3	4	5	6	7	8	9
Species	○	○	○	○	○	○	○	○	○
Ecosystem	○	○	○	○	○	○	○	○	○



3. "Pressure" factor includes two criteria are "Nature" and "Human" pressure. Which importance level do you think is the below criteria influencing the "pressure" factor? *

Please give us your opinion about the level of importance for each criterion following nine levels from 1(non-influence) to 9 (extreme influence)

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Nature	◯	◯	◯	◯	◯	◯	◯	◯	◯
Human	◯	◯	◯	◯	◯	◯	◯	◯	◯



4. "Response" factor includes three criteria is "Conservation," "Education," and "Law." Which importance level do you think is the below criteria influencing the "response" factor? *

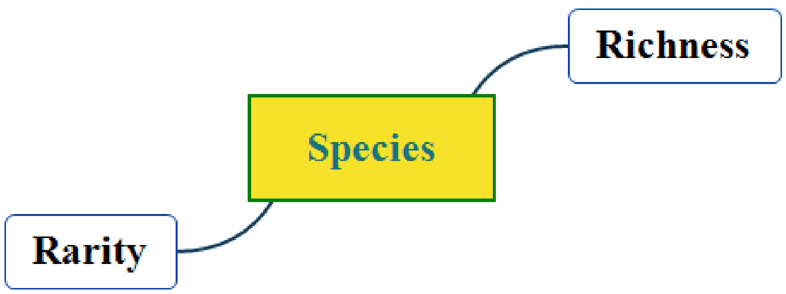
Please give us your opinion about the level of importance for each criterion following nine levels from 1(non-influence) to 9 (extreme influence)

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Conservation	◯	◯	◯	◯	◯	◯	◯	◯	◯
Education	◯	◯	◯	◯	◯	◯	◯	◯	◯
Law	◯	◯	◯	◯	◯	◯	◯	◯	◯

5. "Richness" and "Rarity" are two sub-criteria chosen for showing the "Species" state. Which importance level do you think is the below sub-criteria influencing the "species" criterion? *

Please give us your opinion about the level of importance for each criterion following nine levels from 1(non-influence) to 9 (extreme influence)

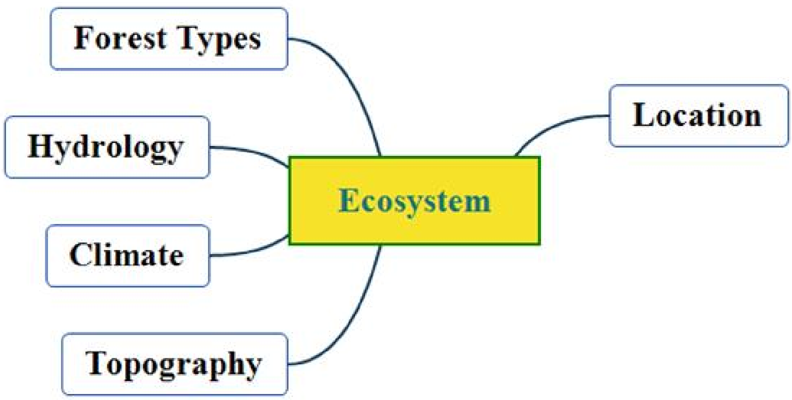
	1	2	3	4	5	6	7	8	9
Richness	○	○	○	○	○	○	○	○	○
Rarity	○	○	○	○	○	○	○	○	○



6. "Location,""Foresttypes,""Climate,""Hydrology,"and"Topography"arethe sub-criteria that impact the selection of the "Ecosystem" condition for biodiversity conservation. Which importance level do you think is the below sub-criteria influencing the "ecosystem" criterion? *

Please give us your opinion about the level of importance for each criterion following nine levels from 1 (non-influence) to 9 (extreme influence)

	1	2	3	4	5	6	7	8	9
Location	○	○	○	○	○	○	○	○	○
Forest types	○	○	○	○	○	○	○	○	○
Climate	○	○	○	○	○	○	○	○	○
Hydrology	○	○	○	○	○	○	○	○	○
Topography	○	○	○	○	○	○	○	○	○



7. **The pressure for biodiversity conservation caused "Nature" is built up by "Climate change" and "Natural disasters" sub-criteria. Which influence level of the sub-criteria is fit for "Nature" pressure? ***

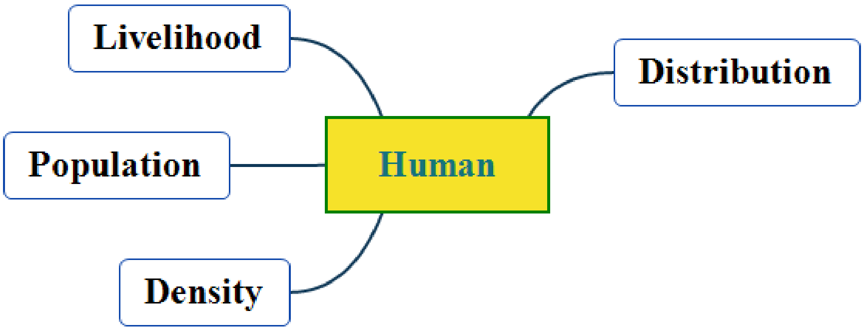
Please give us your opinion about the level of importance for each criterion following nine levels from 1(non-influence) to 9 (extreme influence)

	1	2	3	4	5	6	7	8	9
Climate change	○	○	○	○	○	○	○	○	○
Natural disaster	○	○	○	○	○	○	○	○	○

8. **The pressure for biodiversity conservation caused "Human" is built up by "Distribution," "Density," "Population," and "Livelihood" sub-criteria. Which influence level of the sub-criteria is fit for "Human" pressure? ***

Please give us your opinion about the level of importance for each criterion following nine levels from 1(non-influence) to 9 (extreme influence)

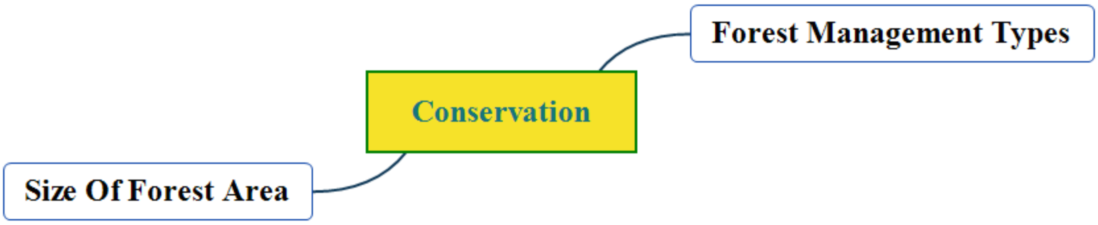
	1	2	3	4	5	6	7	8	9
Distribution	○	○	○	○	○	○	○	○	○
Density	○	○	○	○	○	○	○	○	○
Population	○	○	○	○	○	○	○	○	○
Livelihood	○	○	○	○	○	○	○	○	○



9. **"Forest management types" and "Size of forest area" are two sub-criteria that create a protected area. Which importance level do you think is the below sub-criteria influencing the "Conservation" response? ***

Please give us your opinion about the level of importance for each criterion following nine levels from 1 (non-influence) to 9 (extreme influence)

	1	2	3	4	5	6	7	8	9
Forest management types	◯	◯	◯	◯	◯	◯	◯	◯	◯
Size of forest area	◯	◯	◯	◯	◯	◯	◯	◯	◯



10. **In your opinion, within biodiversity conservation, which other criteria are significant, and which influence levels do you choose for them?**

If you have any opinion for this question, please give us your assessment for the following nine levelsfrom1(non-influence) to 9 (extreme influence)

....

....

....

....

....

D. Acknowledgement

My sincere thanks go to all the respondents of the survey, who supported me with your valuable opinion and knowledge of biodiversity conservation.

I promise that all personal information will be kept confidential.

Sincerely,

Vu Xuan Dinh

Appendix II. Establishment of criteria

Table II. 1. Summary of responses

<table>
<tr><th>No</th><th>Group</th><th>Organizations</th><th colspan="2">Number</th><th colspan="2">Percentage</th><th>Method</th></tr>
<tr><td>1</td><td rowspan="8">Government Organizations</td><td>Bac Giang Department of Agriculture and Rural Development</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td>2</td><td>Dong Nai Department of Environment and Natural Resources</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td>3</td><td>Environment and Natural Resources Department</td><td colspan="2">2</td><td colspan="2">1.08%</td><td>E-mail</td></tr>
<tr><td>4</td><td>Forest Protection Department</td><td colspan="2">7</td><td colspan="2">3.78%</td><td>E-mail</td></tr>
<tr><td>5</td><td>Forest Protection Station</td><td colspan="2">7</td><td colspan="2">3.78%</td><td>E-mail</td></tr>
<tr><td>6</td><td>Ha Giang Department of Agriculture and Rural Development</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Sum</td><td>19</td><td rowspan="2">19</td><td>10.26%</td><td rowspan="2">10.26%</td><td>E-mail</td></tr>
<tr><td>0</td><td>0.00%</td><td>Direct interview</td></tr>
<tr><td>7</td><td rowspan="3">NGOs</td><td>ICRAF Vietnam</td><td colspan="2">4</td><td colspan="2">2.16%</td><td>E-mail</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">Sum</td><td>4</td><td rowspan="2">4</td><td>2.16%</td><td rowspan="2">2.16%</td><td>E-mail</td></tr>
<tr><td>0</td><td>0%</td><td>Direct interview</td></tr>
<tr><td>8</td><td rowspan="4">Other Companies</td><td>Ha An Company</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td>9</td><td>Kim Hoang Company</td><td colspan="2">2</td><td colspan="2">1.08%</td><td>E-mail</td></tr>
<tr><td>10</td><td>Loc Ninh Company</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td>11</td><td>Thuan Phat Company</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">Sum</td><td>5</td><td rowspan="2">5</td><td>2.70%</td><td rowspan="2">2.70%</td><td>E-mail</td></tr>
<tr><td>0</td><td>0%</td><td>Direct interview</td></tr>
<tr><td>12</td><td rowspan="9">Protected areas</td><td>Cat Tien National Park</td><td colspan="2">2</td><td colspan="2">1.08%</td><td>E-mail</td></tr>
<tr><td>13</td><td>Hoang Lien National Park</td><td colspan="2">2</td><td colspan="2">1.08%</td><td>E-mail</td></tr>
<tr><td>14</td><td>Muong La Nature Reserve</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td>15</td><td>Pu Mat National Park</td><td colspan="2">2</td><td colspan="2">1.08%</td><td>E-mail</td></tr>
<tr><td>16</td><td>Song Thanh Nature Reserve</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td>17</td><td>Tam Dao National Park</td><td colspan="2">1</td><td colspan="2">0.54%</td><td>E-mail</td></tr>
<tr><td>18</td><td>Van Long Nature Reserve</td><td colspan="2">4</td><td colspan="2">2.16%</td><td>E-mail</td></tr>
<tr><td>19</td><td>Cuc Phuong National Park</td><td colspan="2">20</td><td colspan="2">10.81%</td><td>Direct interview</td></tr>
<tr><td>20</td><td>Ngoc Son - Ngo Luong Nature Reserve</td><td colspan="2">10</td><td colspan="2">5.41%</td><td>Direct interview</td></tr>
</table>

21		Pu Hu Protected Area		3		1.62%	Direct interview
22		Pu Luong Nature Reserve		18		9.73%	Direct interview
		Sum	**13**	**64**	**8.32%**	**34.59%**	E-mail
			51		**26.27%**		Direct interview
23	**Universities and research institutes**	Can Tho University		2		1.09%	E-mail
24		Environmental Center		1		0.55%	E-mail
25		Hanoi National University		1		0.55%	E-mail
26		Hanoi University of Agriculture		1		0.55%	E-mail
27		Hanoi University of Mining and Geology		1		0.55%	E-mail
28		Hue University of Agriculture and Forestry		1		0.55%	E-mail
29		Land Management Center		1		0.55%	E-mail
30		Tuyen Quang Center of Agroforestry Management and Planning		1		0.55%	E-mail
31		Vietnam Center for Monitoring and Technical Resources		2		1.09%	E-mail
32		Vietnam Institute of geography		3		1.64%	Direct interview
33		Vietnam Institute of forest inventory and planning		2		1.09%	E-mail
34		Vietnam Institute of forest science		1		0.55%	Direct interview
35		Vietnam Institute of Management for Agriculture and Rural Development		2		1.09%	E-mail
36		Vietnam Institute of natural resource inventory and planning		1		0.55%	E-mail
37		Vietnam national university of forestry		73		39.46%	Direct interview
		Sum	**16**	**93**	**8.79%**	**50.41%**	E-mail
			77		**41.62%**		Direct interview
	Total		**57**	**185**	**30.81%**	**100%**	E-mail
			128		**69.19%**		Direct interview

Table II. 2. Statistic of responding questionnaire

<table>
<tr><th colspan="3">Name of criteria</th><th colspan="10">Respondents of important levels</th><th>Min</th><th>Max</th><th>Range</th><th>Mean</th><th>Mode</th><th>Median</th><th colspan="3">Outlier 01</th><th colspan="2">Outlier 02</th></tr>
<tr><th></th><th></th><th></th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th><th>9</th><th>Sum</th><th></th><th></th><th></th><th></th><th></th><th></th><th>Q1</th><th>Q3</th><th>1.5*(Q3-Q1)</th><th>Stdev</th><th>|Z| > 3</th></tr>
<tr><td>Criteria</td><td></td><td>State</td><td>0</td><td>0</td><td>1</td><td>3</td><td>15</td><td>19</td><td>36</td><td>40</td><td>71</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.6</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>161</td><td>1.4</td><td>161</td></tr>
<tr><td></td><td></td><td>Pressure</td><td>0</td><td>1</td><td>2</td><td>2</td><td>14</td><td>21</td><td>33</td><td>53</td><td>59</td><td>185</td><td>2</td><td>9</td><td>7</td><td>7.6</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>46', 58', 161</td><td>1.4</td><td>46', 58',161</td></tr>
<tr><td></td><td></td><td>Response</td><td>0</td><td>1</td><td>8</td><td>6</td><td>15</td><td>10</td><td>33</td><td>39</td><td>73</td><td>185</td><td>2</td><td>9</td><td>7</td><td>7.5</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>77', 81', 83', 106, 120, 126, 140, 152, 161</td><td>1.7</td><td>126</td></tr>
<tr><td>Sub-criteria</td><td>State</td><td>Species</td><td>0</td><td>0</td><td>1</td><td>0</td><td>9</td><td>16</td><td>37</td><td>54</td><td>68</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.8</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>161</td><td>1.2</td><td>161</td></tr>
<tr><td></td><td></td><td>Ecosystem</td><td>1</td><td>1</td><td>1</td><td>4</td><td>4</td><td>9</td><td>32</td><td>51</td><td>82</td><td>185</td><td>1</td><td>9</td><td>8</td><td>7.9</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>34', 138, 161</td><td>1.4</td><td>34, 138, 161</td></tr>
<tr><td></td><td>Pressure</td><td>Nature</td><td>2</td><td>4</td><td>15</td><td>14</td><td>34</td><td>34</td><td>36</td><td>37</td><td>9</td><td>185</td><td>1</td><td>9</td><td>8</td><td>6.0</td><td>8.0</td><td>6.0</td><td>5</td><td>7</td><td>6, 138</td><td>1.8</td><td></td></tr>
<tr><td></td><td></td><td>Human</td><td>0</td><td>0</td><td>1</td><td>1</td><td>1</td><td>8</td><td>21</td><td>35</td><td>118</td><td>185</td><td>3</td><td>9</td><td>6</td><td>8.4</td><td>9.0</td><td>9.0</td><td>8</td><td>9</td><td>49', 59', 77', 78', 81', 82', 83', 95', 97', 108, 161</td><td>1.0</td><td>59', 95', 161</td></tr>
<tr><td></td><td>Response</td><td>Conservation</td><td>0</td><td>0</td><td>4</td><td>2</td><td>6</td><td>17</td><td>37</td><td>53</td><td>66</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.7</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>77', 81', 83', 161</td><td>1.4</td><td>77', 81', 83', 161</td></tr>
<tr><td></td><td></td><td>Education</td><td>0</td><td>0</td><td>1</td><td>0</td><td>7</td><td>18</td><td>26</td><td>42</td><td>91</td><td>185</td><td>3</td><td>9</td><td>6</td><td>8.0</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>161</td><td>1.2</td><td>161</td></tr>
<tr><td></td><td></td><td>Law</td><td>0</td><td>0</td><td>3</td><td>1</td><td>10</td><td>14</td><td>28</td><td>44</td><td>85</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.9</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>59', 161, 174</td><td>1.4</td><td>59', 161, 174</td></tr>
<tr><td>Factors</td><td>Species</td><td>Richness</td><td>0</td><td>0</td><td>1</td><td>1</td><td>15</td><td>26</td><td>45</td><td>44</td><td>53</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.5</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>161</td><td>1.3</td><td>161</td></tr>
<tr><td></td><td></td><td>Rarity</td><td>0</td><td>1</td><td>1</td><td>0</td><td>11</td><td>17</td><td>43</td><td>56</td><td>56</td><td>185</td><td>2</td><td>9</td><td>7</td><td>7.6</td><td>8.0</td><td>8.0</td><td>7</td><td>9</td><td>4, 161</td><td>1.3</td><td>4, 161</td></tr>
<tr><td></td><td>Ecosystem</td><td>Location</td><td>1</td><td>2</td><td>1</td><td>4</td><td>20</td><td>24</td><td>55</td><td>52</td><td>26</td><td>185</td><td>1</td><td>9</td><td>8</td><td>7.0</td><td>7.0</td><td>7.0</td><td>6</td><td>8</td><td>84', 108, 169</td><td>1.5</td><td>84', 108, 169</td></tr>
<tr><td></td><td></td><td>Topography</td><td>0</td><td>0</td><td>1</td><td>7</td><td>20</td><td>20</td><td>60</td><td>41</td><td>36</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.2</td><td>7.0</td><td>7.0</td><td>6</td><td>8</td><td></td><td>1.4</td><td></td></tr>
<tr><td></td><td></td><td>Hydrology</td><td>0</td><td>4</td><td>2</td><td>6</td><td>28</td><td>30</td><td>63</td><td>38</td><td>14</td><td>185</td><td>2</td><td>9</td><td>7</td><td>6.6</td><td>7.0</td><td>7.0</td><td>6</td><td>8</td><td>55', 56', 61',161</td><td>1.5</td><td>55', 56', 61', 161</td></tr>
<tr><td></td><td></td><td>Climate</td><td>0</td><td>0</td><td>3</td><td>2</td><td>21</td><td>26</td><td>50</td><td>43</td><td>40</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.2</td><td>7.0</td><td>7.0</td><td>6</td><td>8</td><td></td><td>1.4</td><td></td></tr>
<tr><td></td><td></td><td>Forest type</td><td>0</td><td>1</td><td>2</td><td>5</td><td>7</td><td>23</td><td>45</td><td>59</td><td>43</td><td>185</td><td>2</td><td>9</td><td>7</td><td>7.4</td><td>8.0</td><td>8.0</td><td>7</td><td>8</td><td>4, 5, 29, 55', 56', 61', 81', 83', 84', 87', 92',108, 129, 133, 161</td><td>1.4</td><td>84', 108, 161</td></tr>
<tr><td></td><td>Nature</td><td>Climate change</td><td>0</td><td>2</td><td>2</td><td>2</td><td>16</td><td>11</td><td>24</td><td>50</td><td>78</td><td>185</td><td>2</td><td>9</td><td>7</td><td>7.8</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>4, 34, 83', 161</td><td>1.5</td><td>4, 34, 83', 161</td></tr>
<tr><td></td><td></td><td>Natural disaster</td><td>0</td><td>6</td><td>5</td><td>10</td><td>15</td><td>32</td><td>40</td><td>49</td><td>28</td><td>185</td><td>2</td><td>9</td><td>7</td><td>6.8</td><td>8.0</td><td>7.0</td><td>6</td><td>8</td><td>4, 65', 101, 106, 133, 161</td><td>1.7</td><td></td></tr>
<tr><td></td><td>Human</td><td>Distribution</td><td>0</td><td>0</td><td>4</td><td>7</td><td>19</td><td>33</td><td>43</td><td>45</td><td>34</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.0</td><td>8.0</td><td>7.0</td><td>6</td><td>8</td><td></td><td>1.5</td><td></td></tr>
<tr><td></td><td></td><td>Density</td><td>0</td><td>2</td><td>4</td><td>5</td><td>24</td><td>31</td><td>43</td><td>45</td><td>31</td><td>185</td><td>2</td><td>9</td><td>7</td><td>6.9</td><td>8.0</td><td>7.0</td><td>6</td><td>8</td><td>83', 161</td><td>1.6</td><td>83', 161</td></tr>
<tr><td></td><td></td><td>Population</td><td>0</td><td>2</td><td>5</td><td>4</td><td>24</td><td>24</td><td>35</td><td>48</td><td>43</td><td>185</td><td>2</td><td>9</td><td>7</td><td>7.1</td><td>8.0</td><td>7.0</td><td>6</td><td>8</td><td>90', 91'[i]</td><td>1.7</td><td>90', 91'</td></tr>
<tr><td></td><td></td><td>Livelihood</td><td>0</td><td>0</td><td>2</td><td>1</td><td>7</td><td>14</td><td>24</td><td>45</td><td>92</td><td>185</td><td>3</td><td>9</td><td>6</td><td>8.0</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>83', 161</td><td>1.3</td><td>83', 108, 161</td></tr>
<tr><td></td><td>Conser</td><td>Forest management types</td><td>0</td><td>0</td><td>2</td><td>5</td><td>8</td><td>21</td><td>38</td><td>45</td><td>66</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.6</td><td>9.0</td><td>8.0</td><td>7</td><td>9</td><td>161, 174</td><td>1.4</td><td>161, 174</td></tr>
<tr><td></td><td></td><td>Size of forest area</td><td>0</td><td>0</td><td>3</td><td>1</td><td>18</td><td>28</td><td>47</td><td>36</td><td>52</td><td>185</td><td>3</td><td>9</td><td>6</td><td>7.3</td><td>9.0</td><td>7.0</td><td>6</td><td>9</td><td></td><td>1.4</td><td>65', 83', 161</td></tr>
<tr><td>Total</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>38</td><td></td><td>22</td></tr>
</table>

':shows the respondents are students

Table II. 3. Synthesizing the numbers of respondents in pairwise

Category		A	A>B									A=B	A<B									B
			Sum	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**		**1/2**	**1/3**	**1/4**	**1/5**	**1/6**	**1/7**	**1/8**	**1/9**	**Sum**	
Factors		**State**	**59**	0	0	2	1	11	5	13	27	**54**	44	12	10	4	0	0	0	0	**70**	**Pressure**
		State	**58**	0	0	2	2	9	9	19	17	**71**	22	13	11	7	1	0	0	0	**54**	**Response**
		Pressure	**61**	0	0	1	3	8	9	15	25	**58**	33	15	5	10	0	1	0	0	**64**	**Response**
Criteria	**State**	**Species**	**48**	1	0	0	1	2	3	5	36	**70**	40	20	4	1	0	0	0	0	**65**	**Ecosystem**
	Pressure	**Nature**	**13**	0	0	0	0	1	0	3	9	**18**	40	26	35	24	10	11	4	2	**152**	**Human**
	Response	**Conservation**	**44**	0	0	0	0	1	3	8	32	**68**	45	14	9	3	0	0	0	0	**71**	**Education**
		Conservation	**38**	0	0	0	1	4	7	8	18	**80**	44	9	7	5	0	0	0	0	**65**	**Law**
		Education	**53**	0	0	2	0	2	4	14	31	**87**	25	14	2	2	0	0	0	0	**43**	**Law**
Sub-criteria	**Species**	**Richness**	**52**	0	0	0	0	2	3	22	25	**58**	41	23	5	3	1	0	0	0	**73**	**Rarity**
	Ecosystem	**Location**	**54**	0	0	0	1	4	3	16	30	**59**	44	19	4	1	0	0	2	0	**70**	**Topography**
		Location	**80**	0	0	0	5	4	5	24	42	**56**	35	6	3	1	0	1	0	1	**47**	**Hydrology**
		Location	**56**	0	0	0	2	1	4	19	30	**56**	41	18	6	4	1	0	0	1	**71**	**Climate**
		Location	**51**	0	0	0	0	2	6	8	35	**46**	45	26	11	2	1	0	0	1	**86**	**Forest type**
		Topography	**80**	0	0	0	0	1	14	23	42	**73**	23	4	1	2	0	0	0	0	**30**	**Hydrology**
		Topography	**65**	0	0	0	0	1	3	22	39	**56**	37	15	3	5	2	0	0	0	**62**	**Climate**
		Topography	**48**	0	1	0	0	1	4	8	34	**56**	49	17	8	5	0	0	0	0	**79**	**Forest type**
		Hydrology	**21**	0	0	0	0	0	1	4	16	**84**	41	26	8	3	0	0	0	0	**78**	**Climate**
		Hydrology	**28**	0	0	1	0	0	1	7	19	**57**	42	36	8	10	2	0	0	0	**98**	**Forest type**
		Climate	**60**	0	0	0	1	1	2	11	45	**50**	37	24	7	5	0	0	0	0	**73**	**Forest type**
	Nature	**Climate change**	**100**	0	1	3	5	4	16	33	38	**58**	14	7	1	3	0	0	0	0	**25**	**Nature disaster**
	Human	**Distribution**	**50**	0	0	1	0	1	8	13	27	**75**	46	11	1	0	0	0	0	0	**58**	**Density**
		Distribution	**47**	0	0	1	0	2	5	17	22	**68**	44	17	7	0	0	0	0	0	**68**	**Quantity**
		Distribution	**19**	0	0	0	0	1	4	2	12	**59**	40	33	21	8	2	1	0	0	**105**	**Livelihood**
		Density	**30**	0	0	0	0	0	0	6	24	**107**	33	9	2	1	1	0	0	0	**46**	**Quantity**
		Density	**21**	0	0	0	0	0	0	4	17	**45**	53	36	15	10	2	1	0	0	**117**	**Livelihood**
		Quantity	**21**	0	0	0	0	0	0	4	17	**45**	53	36	15	10	2	1	0	0	**117**	**Livelihood**
	Conservation	**Conservation type**	**75**	0	0	1	0	4	9	27	34	**55**	34	14	3	0	1	1	0	0	**53**	**Size of PAs**

Calculating weights for all respondents

Table II. 4. The weight set established from all respondents to identify priority areas for biodiversity conservation

ID	Factors		Criteria		Sub-criteria	
	Name	**Weight**	**Name**	**Weight**	**Name**	**Weight**
1	State	26.2%	Species	8.7%	Richness	2.9%
2					Rarity	5.8%
3			Ecosystem	17.5%	Location	2.5%
4					Topography	3.6%
5					Hydrology	1.7%
6					Climate	3.6%
7					Forest type	6.1%
8	Pressure	41.1%	Nature	10.3%	Climate change	7.7%
9					Natural disaster	2.6%
10			Human	30.8%	Distribution	4.6%
11					Density	6.0%
12					Population	7.1%
13					Livelihood	13.1%
14	Response	32.7%	Education	13.5%	Education	13.5%
15			Law	10.7%	Law	10.7%
16			Conservation	8.5%	Forest management types	6.4%
17					Size of forest area	2.1%
	Total	**100.0%**		**100.0%**		**100.0%**

Calculating weights for Protected Areasgroup

Factors

Table II. 5. Pairwise comparison of factors

	State	Pressure	Response
State	1.00	0.50	1.00
Pressure	2.00	1.00	1.00
Response	1.00	1.00	1.00
Sum	**4.00**	**2.50**	**3.00**

Table II. 6. Standardized matrix of factors

	State	Pressure	Response	Weight
State	0.250	0.200	0.333	**26%**
Pressure	0.500	0.400	0.333	**41%**
Response	0.250	0.400	0.333	**33%**
Sum	**1.000**	**1.000**	**1.000**	**100%**

Table II. 7.Consistency test of factors

Compositions	Values
n	3
RI	0.520
λ	3.054
CI	0.027
CR	0.052
Consistency	**Yes**

2. Criteria

Table II. 8. Pairwise comparison of criteria of state

	Species	Ecosystem
Species	1.00	0.50
Ecosystem	2.00	1.00
Sum	**3.00**	**1.50**

Table II. 9. Standardized matrix of criteria of state

	Species	Ecosystem	Weight
Species	0.33	0.33	**33%**
Ecosystem	0.67	0.67	**67%**
Sum	**1.00**	**1.00**	**100%**

Table II. 10. Pairwise comparison of criteria of pressure

	Nature	Human
Nature	1.00	0.25
Human	4.00	1.00
Sum	**5.00**	**1.25**

Table II. 11. Standardized matrix of criteria of pressure

	Nature	Human	Weight
Nature	0.20	0.20	**20%**
Human	0.80	0.80	**80%**
Sum	**1.00**	**1.00**	**100%**

Table II. 12. Pairwise comparison of criteria of response

	Conservation	Education	Law
Conservation	1.00	0.50	1.00
Education	2.00	1.00	1.00
Law	1.00	1.00	1.00
Sum	**4.00**	**2.50**	**3.00**

Table II. 13. Standardized matrix of criteria of response

	Conservation	Education	Law	Weight
Conservation	0.25	0.20	0.33	**26%**
Education	0.50	0.40	0.33	**41%**
Law	0.25	0.40	0.33	**33%**
Sum	**1.00**	**1.00**	**1.00**	**100%**

Table II. 14. Consistency test of criteria of response

Compositions	Values
n	3
RI	0.520
λ	3.054
CI	0.027
CR	0.052
Consistency	**Yes**

3. Sub-criteria

Table II. 15. Pairwise comparison of sub-criteria of species

	Richness	Rarity
Richness	1.00	1.00
Rarity	1.00	1.00
Sum	**2.00**	**2.00**

Table II. 16. Standardized matrix of sub-criteria of species

	Richness	Rarity	Weight
Richness	0.50	0.50	**50%**
Rarity	0.50	0.50	**50%**
Sum	**1.00**	**1.00**	**100%**

Table II. 17. Pairwise comparison of sub-criteria of ecosystem

	Location	Topography	Hydrology	Climate	Forest type
Location	1.00	0.50	3.00	0.50	0.50
Topography	2.00	1.00	3.00	2.00	0.50
Hydrology	0.33	0.33	1.00	1.00	0.33
Climate	2.00	0.50	1.00	1.00	0.33
Forest type	2.00	2.00	3.00	3.00	1.00
Sum	**7.33**	**4.33**	**11.00**	**7.50**	**2.67**

Table II. 18. Standardized matrix of sub-criteria of ecosystem

	Location	Topography	Hydrology	Climate	Forest type	Weight
Location	0.14	0.12	0.27	0.07	0.19	**15%**
Topography	0.27	0.23	0.27	0.27	0.19	**25%**
Hydrology	0.05	0.08	0.09	0.13	0.13	**9%**
Climate	0.27	0.12	0.09	0.13	0.13	**15%**
Forest type	0.27	0.46	0.27	0.40	0.38	**36%**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

Table II. 19. Consistency test of sub-criteria of ecosystem

Compositions	Values
n	5
RI	1.110
λ	5.298
CI	0.074
CR	0.067
Consistency	**Yes**

Table II. 20. Pairwise comparison of sub-criteria of nature

	Climate change	Natural disaster
Climate change	1.00	3.00
Natural disaster	0.33	1.00
Sum	**1.33**	**4.00**

Table II. 21. Standardized matrix of sub-criteria of nature

	Climate change	Natural disaster	Weight
Climate change	0.75	0.75	**75%**
Natural disaster	0.25	0.25	**25%**
Sum	**1.00**	**1.00**	**100%**

Table II. 22. Pairwise comparison of sub-criteria of human

	Distribution	Density	Population	Livelihood
Distribution	1.00	2.00	1.00	0.33
Density	0.50	1.00	1.00	0.50
Population	1.00	1.00	1.00	0.50
Livelihood	3.00	2.00	2.00	1.00
Sum	**5.50**	**6.00**	**5.00**	**2.30**

Table II. 23. Standardized matrix of sub-criteria of human

	Distribution	Density	Population	Livelihood	Weight
Distribution	0.18	0.33	0.20	0.14	**21%**
Density	0.09	0.17	0.20	0.21	**17%**
Population	0.18	0.17	0.20	0.21	**19%**
Livelihood	0.55	0.33	0.40	0.43	**43%**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

Table II. 24. Consistency test of sub-criteria of human

Compositions	Values
n	4
RI	0.890
λ	4.119
CI	0.040
CR	0.045
Consistency	**Yes**

Table II. 25. Pairwise comparison of sub-criteria of conservation

	Forest management types	Size of forest area
Forest management types	1.00	3.00
Size of forest area	0.33	1.00
Sum	**1.33**	**4.00**

Table II. 26. Standardized matrix of sub-criteria of conservation

	Forest management types	Size of forest area	Weight
Forest management types	0.75	0.75	**75%**
Size of forest area	0.25	0.25	**25%**
Sum	**1.00**	**1.00**	**100%**

Table II. 27. The weight set established from the respondents of Protected Areas group

ID	Factors		Criteria		Sub-criteria	
	Name	**Weight**	**Name**	**Weight**	**Name**	**Weight**
1	State	26.2%	Species	8.8%	Richness	4.4%
2					Rarity	4.4%
3			Ecosystem	17.4%	Location	2.7%
4					Topography	4.3%
5					Hydrology	1.6%
6					Climate	2.6%
7					Forest type	6.2%
8	Pressure	41.1%	Nature	8.3%	Climate change	6.2%
9					Natural disaster	2.1%
10			Human	32.8%	Distribution	7.1%
11					Density	5.5%
12					Population	6.2%
13					Livelihood	14.0%
14	Response	32.7%	Education	13.5%	Education	13.5%
15			Law	10.7%	Law	10.7%
16			Conservation	8.5%	Forest management types	6.4%
17					Size of forest area	2.1%
	Total	**100.0%**		**100.0%**		**100.0%**

Calculating weights for Government Organizationsgroup

Factors

Table II. 28. Pairwise comparison of factors

	State	Pressure	Response
State	1.00	0.50	1.00
Pressure	2.00	1.00	1.00
Response	1.00	1.00	1.00
Sum	**4.00**	**2.50**	**3.00**

Table II. 29. Standardized matrix of factors

	State	Pressure	Response	Weight
State	0.25	0.20	0.33	**26%**
Pressure	0.50	0.40	0.33	**41%**
Response	0.25	0.40	0.33	**33%**
Sum	**1.00**	**1.00**	**1.00**	**100%**

Table II. 30. Consistency test of factors

Compositions	Values
n	3
RI	0.520
λ	3.054
CI	0.027
CR	0.052
Consistency	**Yes**

Criteria

Table II. 31. Pairwise comparison of criteria of state

	Species	Ecosystem
Species	1.00	0.50
Ecosystem	2.00	1.00
Sum	**3.00**	**1.50**

Table II. 32. Standardized matrix of criteria of state

	Species	Ecosystem	Weight
Species	0.33	0.33	**33%**
Ecosystem	0.67	0.67	**67%**
Sum	**1.00**	**1.00**	**100%**

Table II. 33. Pairwise comparison of criteria of pressure

	Nature	Human
Nature	1.00	0.33
Human	3.00	1.00
Sum	**4.00**	**1.33**

Table II. 34. Standardized matrix of criteria of pressure

	Nature	Human	Weight
Nature	0.25	0.25	**25%**
Human	0.75	0.75	**75%**
Sum	**1.00**	**1.00**	**100%**

Table II. 35. Pairwise comparison of criteria of response

	Conservation	Education	Law
Conservation	1.00	2.00	0.50
Education	0.50	1.00	0.50
Law	2.00	2.00	1.00
Sum	**3.50**	**5.00**	**2.00**

Table II. 36. Standardized matrix of criteria of response

	Conservation	Education	Law	Weight
Conservation	0.29	0.40	0.25	**31%**
Education	0.14	0.20	0.25	**20%**
Law	0.57	0.40	0.50	**49%**
Sum	**1.00**	**1.00**	**1.00**	**100%**

Table II. 37. Consistency test of criteria of response

Compositions	Values
n	3
RI	0.520
λ	3.054
CI	0.027
CR	0.052
Consistency	**Yes**

3. Sub-criteria

Table II. 38. Pairwise comparison of sub-criteria of species

	Richness	Rarity
Richness	1.00	1.00
Rarity	1.00	1.00
Sum	**2.00**	**2.00**

Table II. 39. Standardized matrix of sub-criteria of species

	Richness	Rarity	Weight
Richness	0.50	0.50	**50%**
Rarity	0.50	0.50	**50%**
Sum	**1.00**	**1.00**	**100%**

Table II. 40. Pairwise comparison of sub-criteria of ecosystem

	Location	Topography	Hydrology	Climate	Forest type
Location	1.00	1.00	3.00	0.50	0.25
Topography	1.00	1.00	2.00	0.50	0.50
Hydrology	0.33	0.50	1.00	0.33	0.33
Climate	2.00	2.00	3.00	1.00	2.00
Forest type	4.00	2.00	3.00	0.50	1.00
Sum	**8.33**	**6.50**	**12.00**	**2.83**	**4.08**

Table II. 41. Standardized matrix of sub-criteria of ecosystem

	Location	Topography	Hydrology	Climate	Forest type	Weight
Location	0.12	0.15	0.25	0.18	0.06	**15%**
Topography	0.12	0.15	0.17	0.18	0.12	**15%**
Hydrology	0.04	0.08	0.08	0.12	0.08	**8%**
Climate	0.24	0.31	0.25	0.35	0.49	**33%**
Forest type	0.48	0.31	0.25	0.18	0.25	**29%**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

Table II. 42. Consistency test of sub-criteria of ecosystem

Compositions	**Values**
n	5
RI	1.110
λ	5.256
CI	0.064
CR	0.058
Consistency	**Yes**

Table II. 43. Pairwise comparison of sub-criteria of nature

	Climate change	**Natural disaster**
Climate change	1.00	3.00
Natural disaster	0.33	1.00
Sum	**1.33**	**4.00**

Table II. 44. Standardized matrix of sub-criteria of nature

	Climate change	**Natural disaster**	**Weight**
Climate change	0.75	0.75	**75%**
Natural disaster	0.25	0.25	**25%**
Sum	**1.00**	**1.00**	**100%**

Table II. 45. Pairwise comparison of sub-criteria of human

	Distribution	**Density**	**Population**	**Livelihood**
Distribution	1.00	0.50	0.50	0.50
Density	2.00	1.00	1.00	0.50
Population	2.00	1.00	1.00	0.50
Livelihood	2.00	2.00	2.00	1.00
Sum	**7.00**	**4.50**	**4.50**	**2.50**

Table II. 46. Standardized matrix of sub-criteria of human

	Distribution	Density	Population	Livelihood	Weight
Distribution	0.14	0.11	0.11	0.20	**14%**
Density	0.29	0.22	0.22	0.20	**23%**
Population	0.29	0.22	0.22	0.20	**23%**
Livelihood	0.29	0.44	0.44	0.40	**40%**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

Table II. 47. Consistency test of sub-criteria of human

Compositions	Values
n	4
RI	0.890
λ	4.061
CI	0.020
CR	0.023
Consistency	**Yes**

Table II. 48. Pairwise comparison of sub-criteria of conservation

	Forest management types	Size of forest area
Forest management types	1.00	3.00
Size of forest area	0.33	1.00
Sum	**1.33**	**4.00**

Table II. 49. Standardized matrix of sub-criteria of conservation

	Forest management types	Size of forest area	Weight
Forest management types	0.75	0.75	**75%**
Size of forest area	0.25	0.25	**25%**
Sum	**1.00**	**1.00**	**100%**

Table II. 50. The weight set established from the respondents of GOs group

ID	Factors		Criteria		Sub-criteria	
	Name	**Weight**	**Name**	**Weight**	**Name**	**Weight**
1	State	26.0%	Species	8.6%	Richness	4.3%
2					Rarity	4.3%
3			Ecosystem	17.4%	Location	2.6%
4					Topography	2.6%
5					Hydrology	1.4%
6					Climate	5.7%
7					Forest type	5.1%
8	Pressure	41.1%	Nature	10.3%	Climate change	7.7%
9					Natural disaster	2.6%
10			Human	30.8%	Distribution	4.3%
11					Density	7.2%
12					Population	7.2%
13					Livelihood	12.1%
14	Response	32.9%	Education	6.5%	Education	6.5%
15			Law	16.1%	Law	16.1%
16			Conservation	10.3%	Forest management types	7.7%
17					Size of forest area	2.6%
	Total	**100.0%**		**100.0%**		**100.0%**

Calculating weights for Universities and Research Institutesgroup

Factors

Table II. 51. Pairwise comparison of factors

	State	Pressure	Response
State	1.00	1.00	1.00
Pressure	1.00	1.00	0.50
Response	1.00	2.00	1.00
Sum	**3.00**	**4.00**	**2.50**

Table II. 52. Standardized matrix of factors

	State	Pressure	Response	Weight
State	0.33	0.25	0.40	**33%**
Pressure	0.33	0.25	0.20	**26%**
Response	0.33	0.50	0.40	**41%**
Sum	**1.00**	**1.00**	**1.00**	**100%**

Table II. 53. Consistency test of factors

Compositions	Values
n	3
RI	0.520
λ	3.054
CI	0.027
CR	0.052
Consistency	**Yes**

2. Criteria

Table II. 54. Pairwise comparison of criteria of state

	Species	**Ecosystem**
Species	1.00	1.00
Ecosystem	1.00	1.00
Sum	**2.00**	**2.00**

Table II. 55. Standardized matrix of criteria of state

	Species	**Ecosystem**	**Weight**
Species	0.50	0.50	**50%**
Ecosystem	0.50	0.50	**50%**
Sum	**1.00**	**1.00**	**100%**

Table II. 56. Pairwise comparison of criteria of pressure

	Nature	**Human**
Nature	1.00	0.50
Human	2.00	1.00
Sum	**3.00**	**1.50**

Table II. 57. Standardized matrix of criteria of pressure

	Nature	**Human**	**Weight**
Nature	0.33	0.33	**33%**
Human	0.67	0.67	**67%**
Sum	**1.00**	**1.00**	**100%**

Table II. 58. Pairwise comparison of criteria of response

	Conservation	Education	Law
Conservation	1.00	0.50	1.00
Education	2.00	1.00	1.00
Law	1.00	1.00	1.00
Sum	**4.00**	**2.50**	**3.00**

Table II. 59. Standardized matrix of criteria of response

	Conservation	Education	Law	Weight
Conservation	0.25	0.20	0.33	**26%**
Education	0.50	0.40	0.33	**41%**
Law	0.25	0.40	0.33	**33%**
Sum	**1.00**	**1.00**	**1.00**	**100%**

Table II. 60. Consistency test of criteria of response

Compositions	Values
n	3
RI	0.520
λ	3.054
CI	0.027
CR	0.052
Consistency	**Yes**

3. Sub-criteria

Table II. 61. Pairwise comparison of sub-criteria of species

	Richness	Rarity
Richness	1.00	0.50
Rarity	2.00	1.00
Sum	**3.00**	**1.50**

Table II. 62. Standardized matrix of sub-criteria of species

	Richness	Rarity	Weight
Richness	0.33	0.33	**33%**
Rarity	0.67	0.67	**67%**
Sum	**1.00**	**1.00**	**100%**

Table II. 63. Pairwise comparison of sub-criteria of ecosystem

	Location	Topography	Hydrology	Climate	Forest type
Location	1.00	0.50	2.00	0.50	0.50
Topography	2.00	1.00	2.00	1.00	1.00
Hydrology	0.50	0.50	1.00	0.50	0.50
Climate	2.00	1.00	2.00	1.00	2.00
Forest type	2.00	1.00	2.00	0.50	1.00
Sum	**7.50**	**4.00**	**9.00**	**3.50**	**5.00**

Table II. 64. Standardized matrix of sub-criteria of ecosystem

	Location	Topography	Hydrology	Climate	Forest type	Weight
Location	0.13	0.13	0.22	0.14	0.10	**15%**
Topography	0.27	0.25	0.22	0.29	0.20	**24%**
Hydrology	0.07	0.13	0.11	0.14	0.10	**11%**
Climate	0.27	0.25	0.22	0.29	0.40	**28%**
Forest type	0.27	0.25	0.22	0.14	0.20	**22%**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

Table II. 65. Consistency test of sub-criteria of ecosystem

Compositions	Values
n	5
RI	1.110
λ	5.117
CI	0.029
CR	0.026
Consistency	**Yes**

Table II. 66. Pairwise comparison of sub-criteria of nature

	Climate change	Natural disaster
Climate change	1.00	2.00
Natural disaster	0.50	1.00
Sum	**1.50**	**3.00**

Table II. 67. Standardized matrix of sub-criteria of nature

	Climate change	Natural disaster	Weight
Climate change	0.67	0.67	**67%**
Natural disaster	0.33	0.33	**33%**
Sum	**1.00**	**1.00**	**100%**

Table II. 68. Pairwise comparison of sub-criteria of human

	Distribution	Density	Population	Livelihood
Distribution	1.00	1.00	0.50	0.50
Density	1.00	1.00	1.00	0.50
Population	2.00	1.00	1.00	0.50
Livelihood	2.00	2.00	2.00	1.00
Sum	**6.00**	**5.00**	**4.50**	**2.50**

Table II. 69.Standardized matrix of sub-criteria of human

	Distribution	Density	Population	Livelihood	Weight
Distribution	0.17	0.20	0.11	0.20	**17%**
Density	0.17	0.20	0.22	0.20	**20%**
Population	0.33	0.20	0.22	0.20	**24%**
Livelihood	0.33	0.40	0.44	0.40	**39%**
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**100%**

Table II. 70. Consistency test of sub-criteria of human

Compositions	Values
n	4
RI	0.890
λ	4.061
CI	0.020
CR	0.023
Consistency	**Yes**

Table II. 71.Pairwise comparison of sub-criteria of conservation

	Forest management types	Size of forest area
Forest management types	1.00	2.00
Size of PA	0.50	1.00
Sum	1.50	3.00

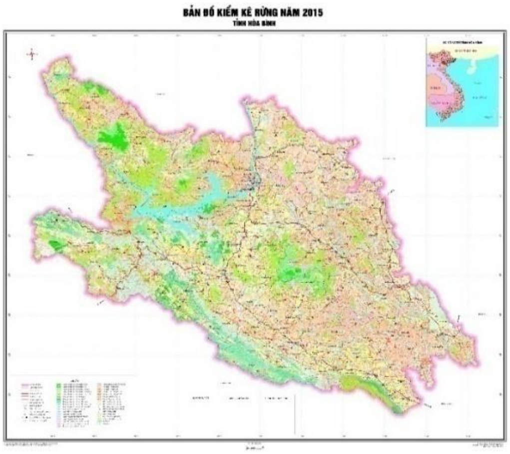
Table II. 72. Standardized matrix of sub-criteria of conservation

	Forest management types	Size of forest area	Weight
Forest management types	0.67	0.67	**67%**
Size of forest area	0.33	0.33	**33%**
Sum	**1.00**	**1.00**	**100%**

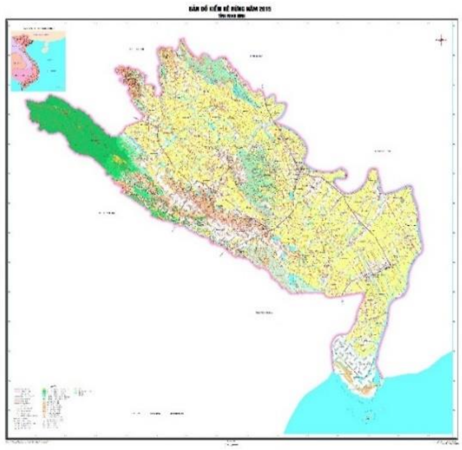
Table II. 73. The weight set established from the respondents of URIs group

ID	Factors		Criteria		Sub-criteria	
	Name	Weight	Name	Weight	Name	Weight
1	State	32.8%	Species	16.4%	Richness	5.5%
2					Rarity	10.9%
3			Ecosystem	16.4%	Location	2.4%
4					Topography	4.0%
5					Hydrology	1.8%
6					Climate	4.7%
7					Forest type	3.5%
8	Pressure	26.0%	Nature	8.7%	Climate change	5.8%
9					Natural disaster	2.9%
10			Human	17.3%	Distribution	2.9%
11					Density	3.4%
12					Population	4.1%
13					Livelihood	6.9%
14	Response	41.2%	Education	16.9%	Education	16.9%
15			Law	13.5%	Law	13.5%
16			Conservation	10.8%	Forest management types	7.2%
17					Size of forest area	3.6%
	Total	**100.0%**		**100.0%**		**100.0%**

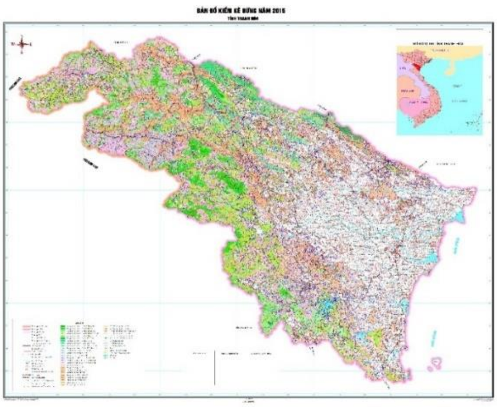
Appendix III. Application of criteria



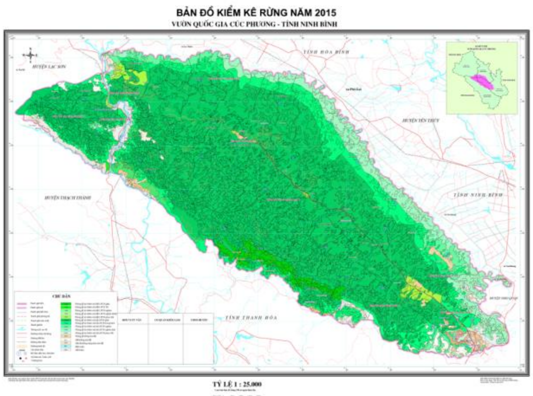
Thanh Hoa Map of forest statistic in 2015



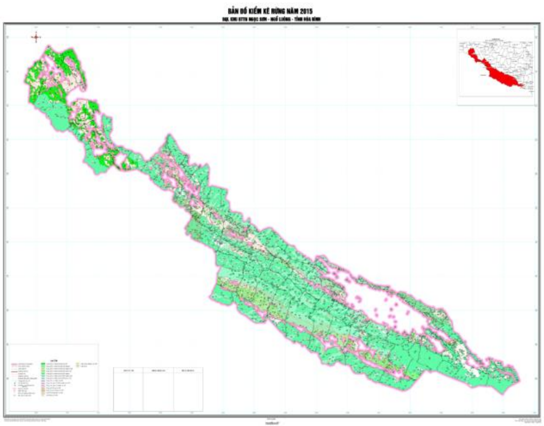
Hoa Binh Map of forest statistic in 2015



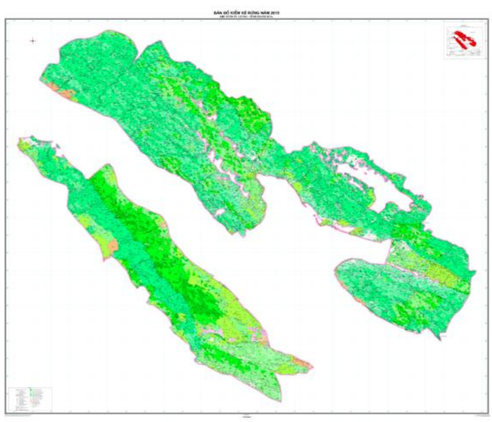
Ninh Binh Map of forest statistic in 2015



Cuc Phuong Map of forest statistic in 2015

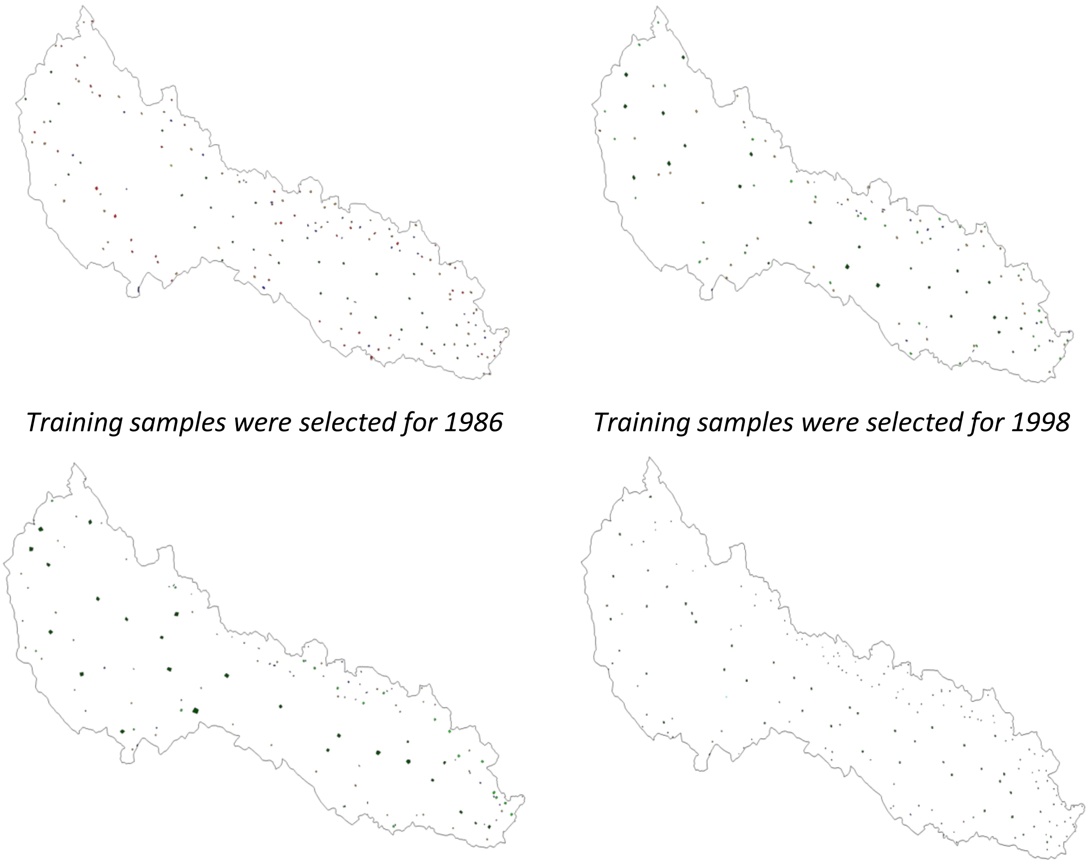


NSNL Map of forest statistic in 2015



Pu Luong Map of forest statistic in 2015

Figure III. 1: Example of the old maps archived on the fieldwork in 2017



Training samples were selected for 1986 *Training samples were selected for 1998*

Training samples were selected for 2007 *Training samples were selected for 2017*

Figure III. 2: Samples for supervised classification in 1986, 1998, 2007, and 2017

Table III. 1: Overall accuracy of classifications in 1986, 1998, 2007, and 2017

LULC classes		**Reference data**				**Total pixels**	**Classification accuracy (%)**		**Kappa statistic**	**Overall accuracy (%)**
		Forest	**Grassland**	**Soil**	**Water**		**Producer accuracy**	**User accuracy**		
1986	Forest	48	0	0	0	48	100.0	100.0	1.00	**97.0**
	Grassland	0	69	1	0	70	98.6	95.8	0.94	
	Soil	0	3	69	3	75	92.0	98.6	0.98	
	Water	0	0	0	38	38	100.0	92.7	0.91	
1998	Forest	56	0	0	0	56	100.0	96.6	0.96	**95.3**
	Grassland	2	76	0	0	78	97.4	87.4	0.82	
	Soil	0	11	79	0	90	87.8	100.0	1.00	
	Water	0	0	0	54	54	100.0	100.0	1.00	
2007	Forest	55	0	0	0	55	100.0	100.0	1.00	**96.7**
	Grassland	0	41	0	0	41	100.0	93.2	0.92	
	Soil	0	3	83	0	86	96.5	93.3	0.90	
	Water	0	0	6	82	88	93.2	100.0	1.00	
2017	Forest	54	0	0	0	54	100.0	87.1	0.83	**92.2**
	Grassland	8	65	0	0	73	89.0	95.6	0.94	
	Soil	0	3	62	1	66	93.9	91.2	0.88	
	Water	0	0	6	33	39	84.6	97.1	0.96	

Table III. 2: Area statistic of LULC changes of specific regions in 1986, 1998, 2007, and 2017

Regions	Years	Forest		Grassland		Soil		Water		Total	
		ha	%	ha	%	ha	%	ha	%	ha	%
Cuc Phuong National Park	1986	20,144.3	88.4	1,973.9	8.7	586.1	2.6	88.3	0.4	22,792.6	100.0
	1998	19,894.6	87.3	2,642.5	11.6	224.6	1.0	30.8	0.1	22,792.6	100.0
	2007	19,246.0	84.4	2,061.9	9.0	1,375.2	6.0	109.5	0.5	22,792.6	100.0
	2017	21,197.9	93.0	1,292.6	5.7	266.1	1.2	35.9	0.2	22,792.6	100.0
Ngoc Son – Ngo Luong Nature Reserve	1986	14,453.9	66.1	5,660.4	25.9	1,561.9	7.1	196.6	0.9	21,872.8	100.0
	1998	13,320.9	60.9	7,293.2	33.3	1,204.9	5.5	53.7	0.2	21,872.8	100.0
	2007	12,891.4	58.9	4,791.2	21.9	3,953.1	18.1	237.1	1.1	21,872.8	100.0
	2017	16,162.9	73.9	4,914.9	22.5	748.5	3.4	46.5	0.2	21,872.8	100.0
Pu Luong Nature Reserve	1986	13,177.2	75.3	3,726.7	21.3	567.2	3.2	29.0	0.2	17,500.1	100.0
	1998	14,621.1	83.5	2,749.5	15.7	128.6	0.7	1.0	0.0	17,500.1	100.0
	2007	15,243.9	87.1	1,205.3	6.9	1,001.7	5.7	49.1	0.3	17,500.1	100.0
	2017	16,264.1	92.9	1,102.6	6.3	129.6	0.7	3.7	0.0	17,500.1	100.0
Other areas	1986	33,998.5	39.6	34,051.1	39.7	15,556.4	18.1	2,225.3	2.6	85,831.3	100.0
	1998	31,323.1	36.5	41,473.4	48.3	12,406.5	14.5	628.2	0.7	85,831.3	100.0
	2007	29,145.5	34.0	28,123.2	32.8	26,905.9	31.3	1,656.6	1.9	85,831.3	100.0
	2017	45,075.0	52.5	33,335.5	38.8	6,685.4	7.8	735.3	0.9	85,831.3	100.0

Table III. 3: Characteristics of rare species cited by IUCN and VNRB in the study area

No	Name	IUCN	VNRB	Land cover	Altitude (m)	Others
I	**Rare animals**					
1	*Scotomanesbeaulieui*	Least Concern	Vulnerable	Forest	≤ 2200	
2	*Nycticebuspygmaeus*	Vulnerable	Vulnerable	Evergreen, semi-evergreen, limestone forest	≤ 1500	
3	*Trachypithecusdelacouri*	Critically Endangered	Critically Endangered	Limestone karst forest, evergreen shrub	≤ 1000	
4	*Trachypithecusbarbei*	Data Deficient	Vulnerable	Forest		Not in the mix bamboo forest
5	*Hemigalusowstoni*	Endangered	Vulnerable	Suitable forests include some on limestone and some dominated by bamboo.	≤ 2600	
6	*Arctogalidiatrivirgata*	Least Concern	Lower Risk	Evergreen, semi-evergreen forest	≥ 600	
II	**Rare plants**					
7	*Alangiumtonkinense*	Data Deficient	Vulnerable	Sparse, secondary forest	≤ 500	Foot of limestone karst mountain
8	*Polyalthiapraeflorens*	Data Deficient	Endangered	Primary forest	≤ 300	
9	*Vernonia bonapartei*	Data Deficient	Vulnerable	Sparse, secondary forest on soil mountain	50 - 500	
10	*Balanophoracucphuongensis*	Data Deficient	Endangered	Primary forest on limestone mountain	200 - 300	
11	*Balanophoralaxiflora*	Data Deficient	Endangered	Forest	600 - 2300	High moisture

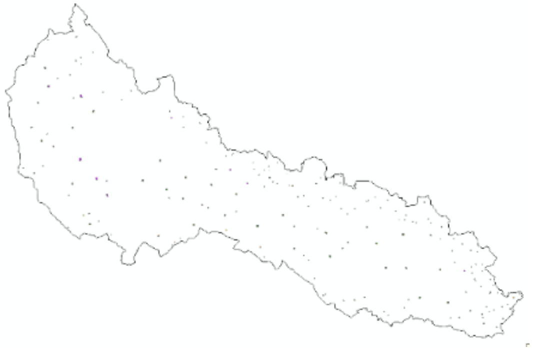
12	*Rhopalocnemisphalloides*	Data Deficient	Vulnerable	Primary forest	500 - 2000	
13	*Bursera tonkinensis*	Vulnerable	Vulnerable	Primary and secondary evergreen forest on limestone mountains	500 - 700	
14	*Canariumtramdenum*	Data Deficient	Vulnerable	Primary and secondary evergreen forest	≤ 700	
15	*Codonopsisjavanica*	Data Deficient	Vulnerable	Secondary forest	600 - 2000	
16	*Vaticasubglabra*	Endangered	Endangered	Evergreen forest	300 - 600	Near rivers, streams
17	*Annamocaryasinensis*	Endangered	Endangered	Primary forest on limestone mountains	400 - 1000	Near rivers, valleys
18	*Cinnamomumbalansae*	Endangered	Vulnerable	Primary evergreen forest	≤ 200	
19	*Cinnamomumcambodianum*	Data Deficient	Vulnerable	Evergreen forest		
20	*Aglaia spectabilis*	Data Deficient	Vulnerable	Primary, secondary forest	≤ 700	
21	*Dysoxylumcauliflorum*	Data Deficient	Vulnerable	Primary, secondary evergreen forest on limestone mountain, valley	≤ 700	
22	*Dysoxylumloureiri*	Data Deficient	Vulnerable	Primary, secondary evergreen forest	≤ 1000	
23	*Ardisia silvestris*	Data Deficient	Vulnerable	Forest	400 - 1200	Dominated by shadow, moisture, humus, around rivers and streams
24	*Rothmanniavietnamensis*	Data Deficient	Vulnerable	Sparse, secondary forest on limestone mountains	≈ 400	

25	*Sinoradlkofera minor*	Vulnerable	Endangered	Evergreen forest on limestone mountains and valleys		
26	*Amorphophallus interruptus*	Critically Endangered	Lower Risk	Limestone forest	300 - 500	Dominated by humus
27	*Amorphophallus verticillatus*	Vulnerable	Lower Risk	Evergreen forest on limestone mountain	300 - 450	Dominated by moisture
28	*Calamus platyacanthus*	Data Deficient	Vulnerable	Primary, secondary evergreen forest	400 - 900	Dominated by light, moisture
29	*Disporopsislongifolia*	Data Deficient	Vulnerable	Evergreen forest on limestone mountain	400 - 1500	Dominated by moisture, shadow
30	*Dendrobium wardianum*	Data Deficient	Vulnerable	Forest	500 - 600	
31	*Smilax elegantissima*	Data Deficient	Vulnerable	Secondary evergreen forest		Creek, valley, slope mountain
32	*Stemonasaxorum*	Data Deficient	Vulnerable	Forest	$\leq$ 600	Moisture, light, and near rivers, streams
33	*Calocedrusmacrolepis*	Near Threatened	Endangered	Evergreen forest	800 - 2000	
34	*Cantharelluscibarius*	Data Deficient	Endangered	Forest		

❖ *IUCN: International Union for Conservation of Nature*

❖ *VNRB: Vietnam Red Data Book*

a. Training samples 6. 2017



b. Training samples 8. 2017

c. Training samples 10. 2017

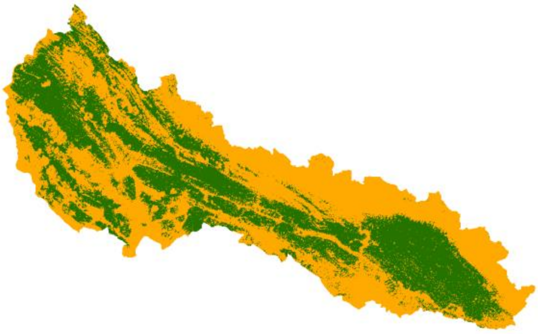
d. Training samples 12. 2017

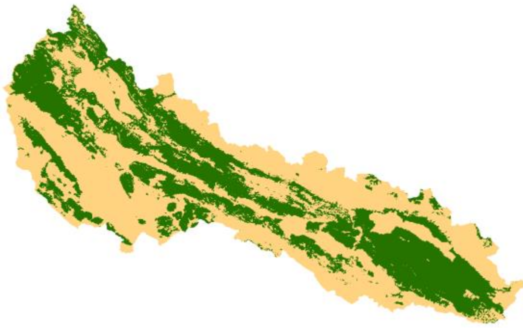
e. Training samples 4. 2018

Figure III. 3: Training samples for classifications in five months

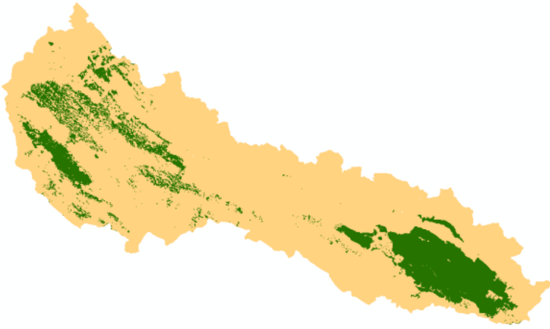
Table III. 4: Error matrices and total classification accuracy in five months

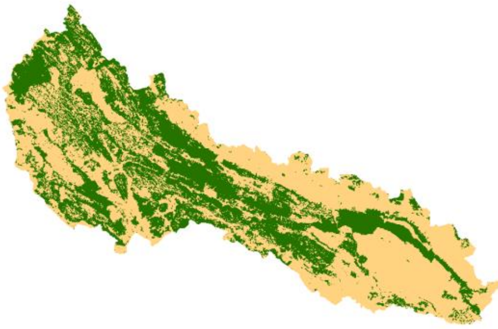
LULC classes		**Reference data**				**Total pixels**	**Classification accuracy (%)**		**Kappa statistic**	**Overall accuracy (%)**
		Forest	**Grassland**	**Soil**	**Water**		**Producer accuracy**	**User accuracy**		
June 2017	Forest	54	0	0	0	54	100.0	87.1	0.83	**92.2**
	Grassland	8	65	0	0	73	89.0	95.6	0.94	
	Soil	0	3	62	1	66	93.9	91.2	0.88	
	Water	0	0	6	33	39	84.6	97.1	0.96	
August 2017	Forest	50	2	0	0	52	96.2	100.0	1.00	**88.9**
	Grassland	0	73	1	0	74	98.6	80.2	0.72	
	Soil	0	15	44	1	61	72.1	95.7	0.94	
	Water	0	1	0	39	40	97.5	83.0	0.80	
October 2017	Forest	49	2	1	0	52	94.2	100.0	1.00	**93.8**
	Grassland	0	45	3	0	48	93.8	88.2	0.85	
	Soil	0	4	86	0	90	95.6	90.5	0.85	
	Water	0	0	5	46	51	90.2	100.0	1.00	
December 2017	Forest	52	0	0	0	52	100.0	98.1	0.98	**98.5**
	Grassland	1	69	1	0	71	97.2	98.6	0.98	
	Soil	0	1	88	0	89	98.9	97.8	0.97	
	Water	0	0	1	50	51	98.0	100.0	1.00	
April 2018	Forest	45	7	0	0	52	86.5	100.0	1.00	**84.2**
	Grassland	0	38	9	1	48	79.2	63.3	0.54	
	Soil	0	10	81	0	91	89.0	84.4	0.75	
	Water	0	5	6	39	50	78.0	97.5	0.97	



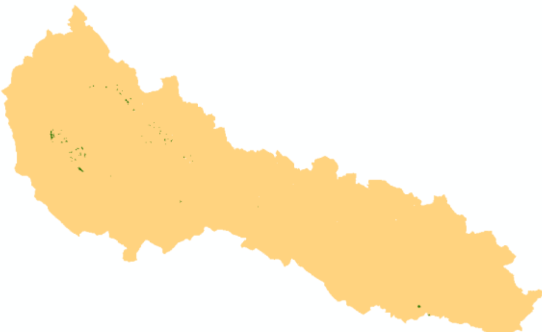


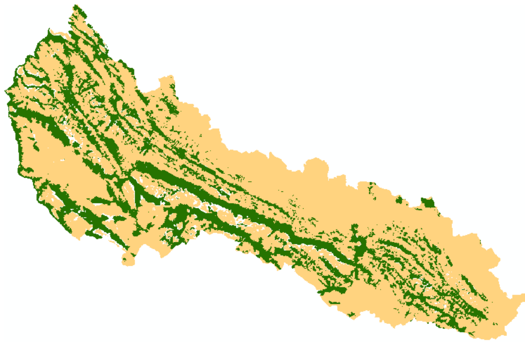
Evergreen forest *Limestone*



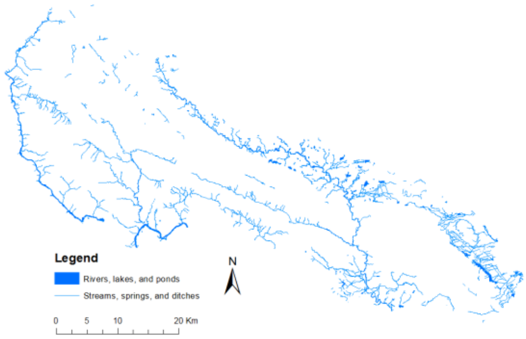


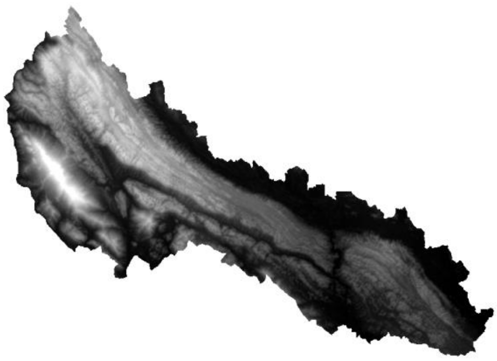
Primary forest *Secondary forest*





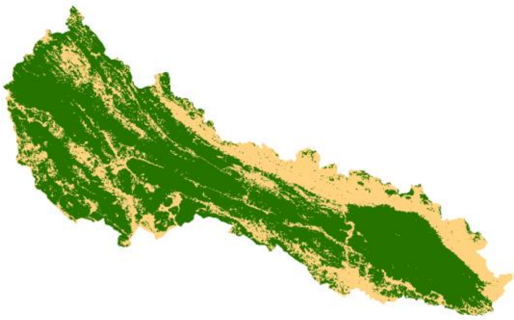
Bamboo forest *Valley*



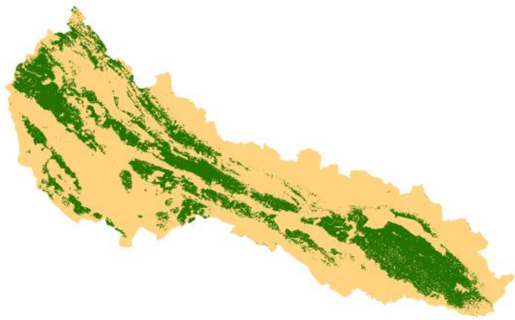


Hydrology *Digital elevation model*

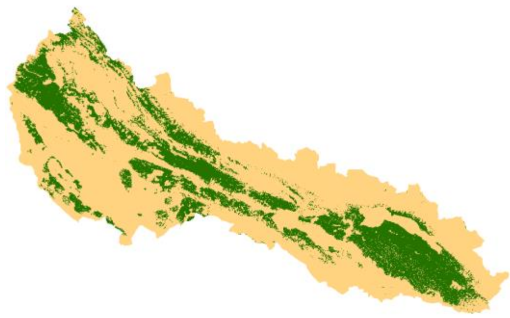
Figure III. 4: Layers used to define the suitable habitats of rare species in the study area



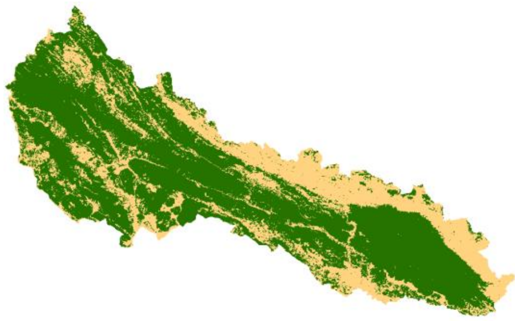
1. *Scotomanes beaulieui*



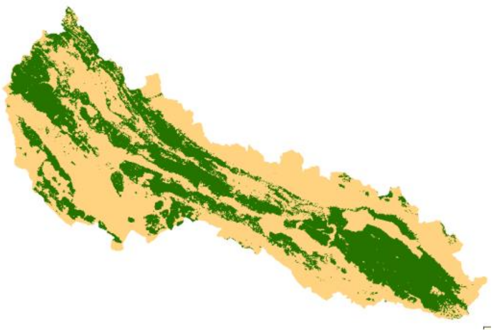
2. *Nycticebus pygmaeus*



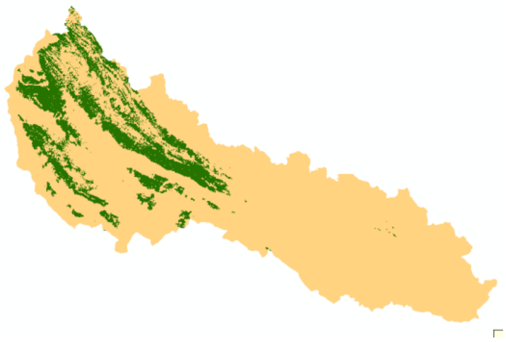
3. *Trachypithecus delacouri*



4. *Trachypithecus barbei*



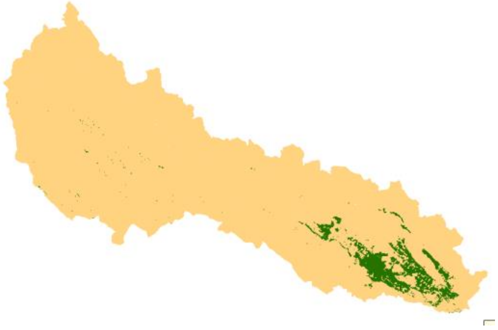
5. *Hemigalus owstoni*



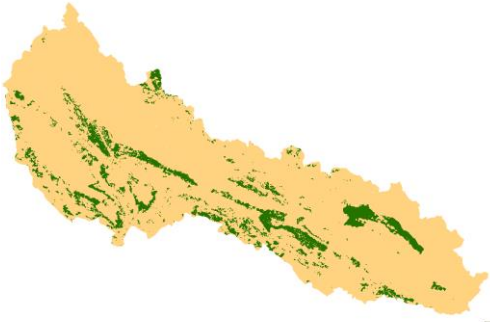
6. *Arctogalidia trivirgata*

Figure III. 5: Habitat areas of rare animals in the study area

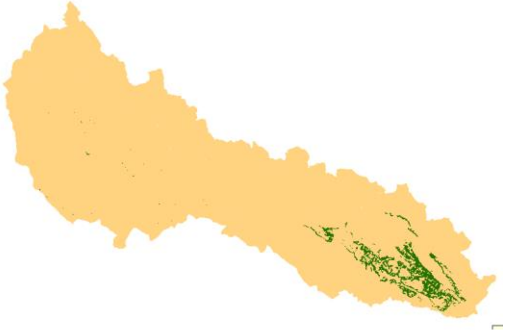
1. *Alangium tonkinense*



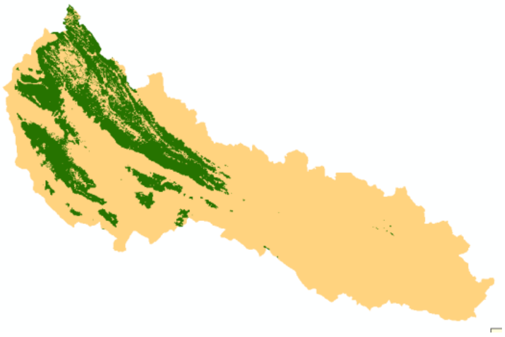
2. *Polyalthia praeflorens*



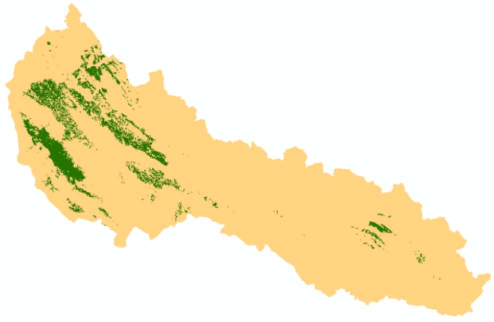
3. *Vernonia bonapartei*



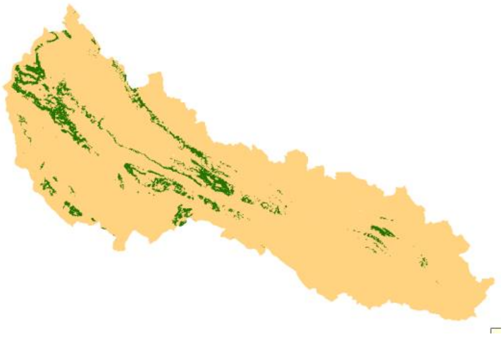
4. *Balanophora cucphuongensis*



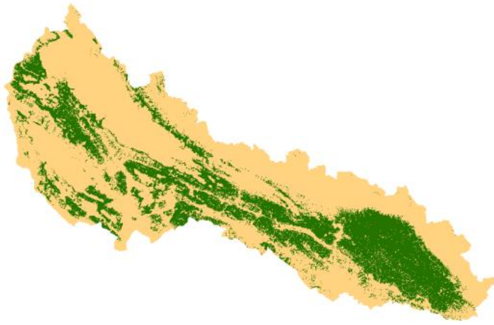
5. *Balanophora laxiflora*



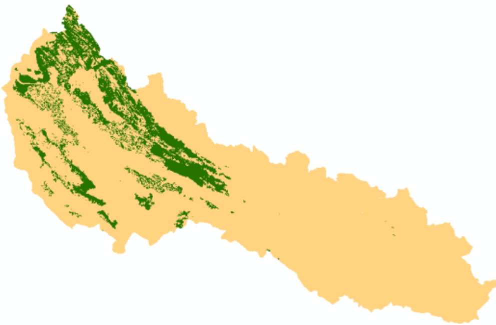
6. *Rhopalocnemis phalloides*



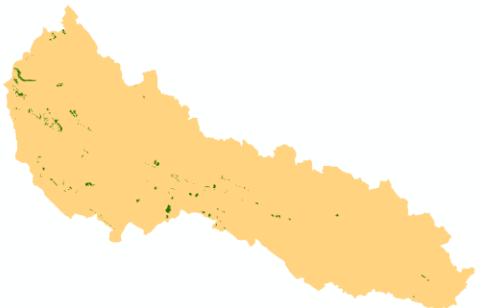
7. *Bursera tonkinensis*



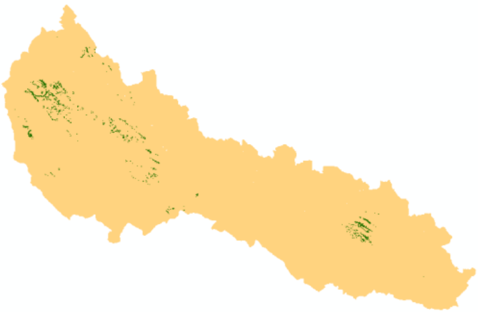
8. *Canarium tramdenum*



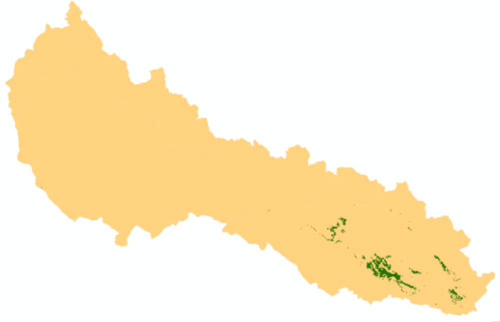
9. *Codonopsis javanica*



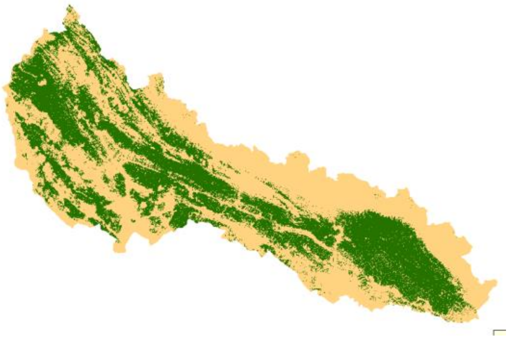
10. *Vatica subglabra*



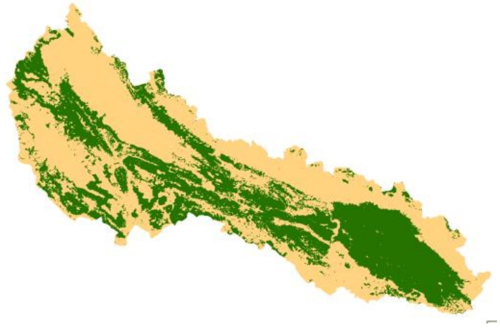
11. Annamocarya sinensis



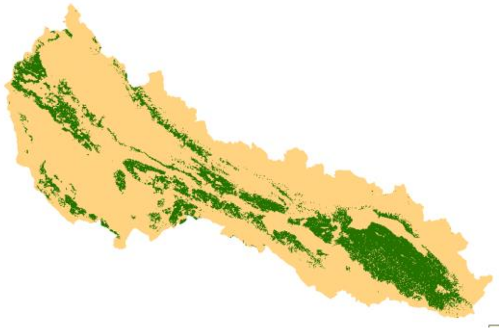
12. Cinnamomum balansae



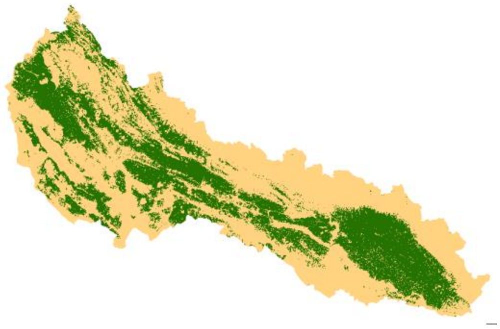
13. Cinnamomum cambodianum



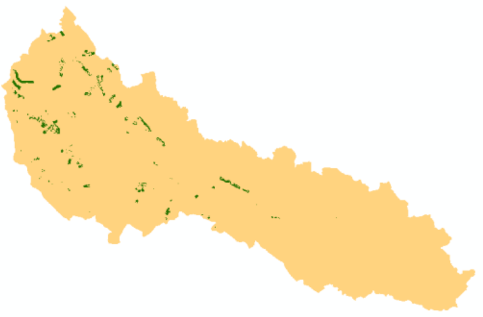
14. Aglaia spectabilis



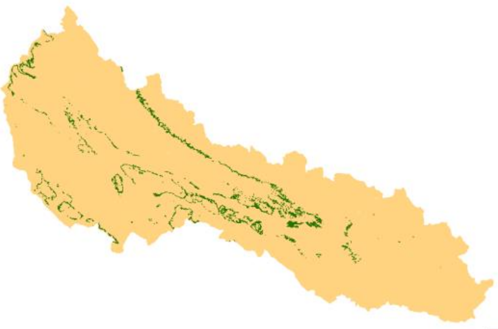
15. Dysoxylum cauliflorum



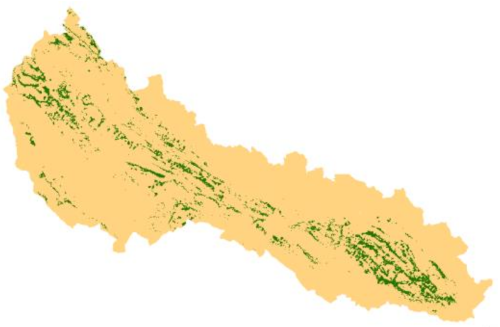
16. Dysoxylum loureiri



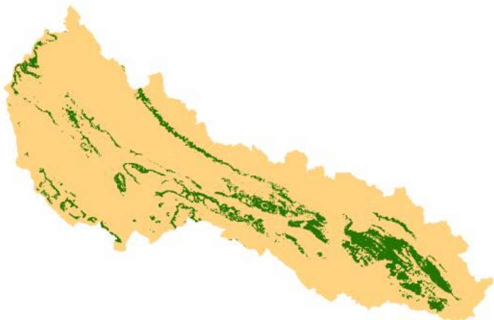
17. Ardisia silvestris



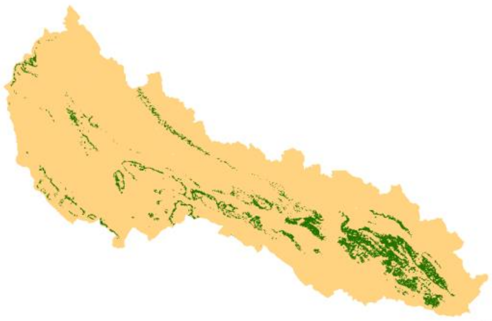
18. Rothmannia vietnamensis



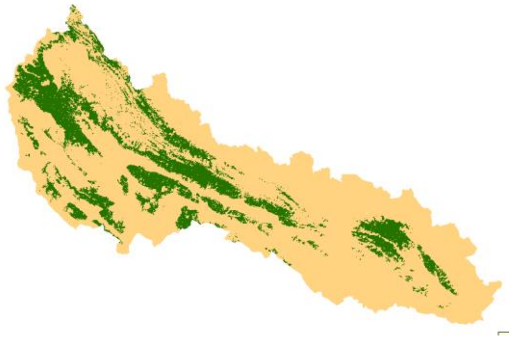
19. Sinoradlkofera minor



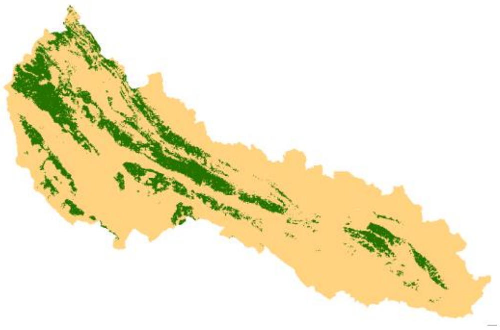
20. Amorphophallus interruptus



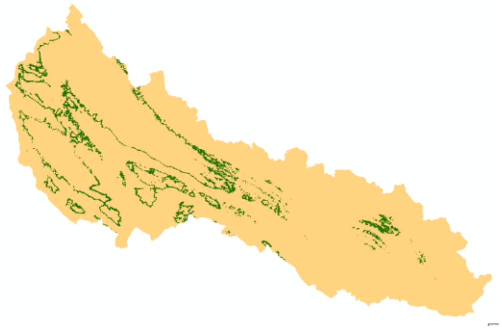
21. Amorphophallus verticillatus



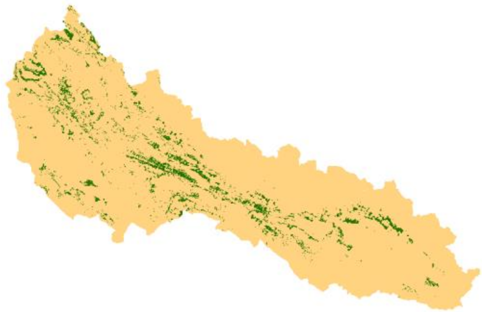
22. Calamus platyacanthus



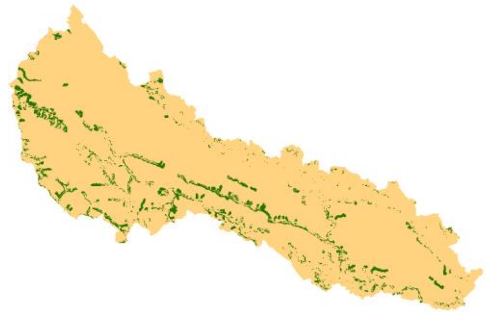
23. Disporopsis longifolia



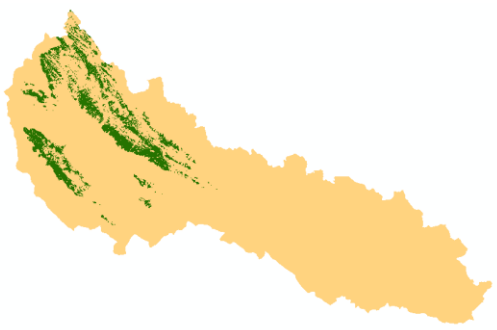
24. Dendrobium wardianum



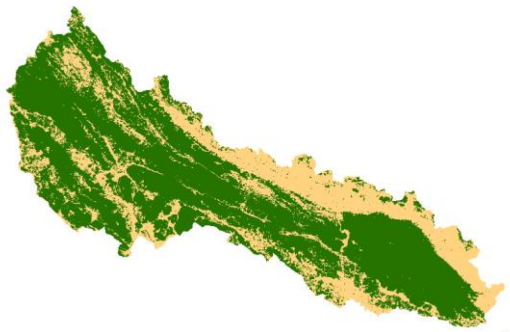
25. Smilax elegantissima



26. Stemona saxorum



27. Calocedrus macrolepis



28. Cantharellus cibarius

Figure III. 6: Habitat areas of rare plants in the study area

Table III. 5: Statistic of LULC areas for selecting the priority levels of slope and altitude

Topography		1986				1998				2007				2017			
		Forest	Grassland	Soil	Water	Forest	Grassland	Soil	Water	Forest	Grassland	Soil	Water	Forest	Grassland	Soil	Water
Slope (Degree)	**10**	9886.5	15714.7	12220.9	2028.1	8620.1	19363.0	11285.7	581.5	8331.0	13276.7	16947.1	1295.6	12107.6	21452.6	5615.3	674.9
	20	21741.8	15226.7	3876.1	430.6	20366.8	18245.0	2498.4	164.9	19800.4	11395.4	9499.4	580.0	26942.8	12371.6	1777.8	183.0
	30	24090.8	9997.6	1657.3	87.5	23628.0	11784.8	387.6	32.7	22990.1	7571.2	5060.0	211.7	29667.0	5576.7	550.2	39.2
	40	17975.4	4215.6	692.9	40.2	18041.4	4796.8	76.6	9.3	17294.7	3591.0	1952.5	85.8	20925.0	1809.1	175.7	14.3
	50	7667.5	1067.4	189.8	33.8	7710.2	1224.0	19.6	4.7	7337.3	1073.3	517.3	30.4	8532.0	371.2	48.9	6.3
	60	1331.7	149.2	38.0	25.5	1382.5	152.5	6.1	3.2	1303.9	158.7	71.5	10.2	1495.1	39.3	9.3	0.6
	70	65.2	7.8	2.5	7.3	72.8	6.8	1.0	2.2	67.7	9.8	3.5	1.8	79.2	2.1	1.5	0.0
	80	0.4	0.1	0.4	0.0	0.7	0.2	0.1	0.0	0.7	0.2	0.1	0.0	0.9	0.1	0.0	0.0
	90	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Altitude (m)	**100**	3100.9	14034.2	12025.9	2180.4	1228.6	18074.3	11263.7	774.8	768.3	12445.8	16616.9	1510.4	3876.2	21030.5	5593.7	840.9
	200	9562.7	9828.9	2279.2	221.8	7606.6	12831.0	1439.8	15.2	6285.5	9752.2	5725.3	129.6	13283.9	7109.0	1442.8	56.9
	300	12261.0	5086.3	1012.5	29.1	11965.0	6128.0	294.7	1.2	11119.1	4695.1	2517.7	57.1	15494.5	2691.4	195.0	8.0
	400	13020.4	2930.6	786.8	37.1	12648.4	3866.8	259.5	0.2	12256.9	2816.5	1644.0	57.4	14877.1	1710.6	183.2	3.9
	500	11794.3	2772.9	967.4	62.4	11584.8	3615.9	394.7	1.5	11226.1	2496.1	1810.5	64.2	13362.9	1984.2	246.2	3.6
	600	7501.9	1650.2	423.4	24.1	7753.4	1742.3	101.7	2.2	7644.6	1060.9	856.8	37.3	8487.2	986.9	124.7	0.8
	700	6716.6	1350.5	309.5	26.7	6928.2	1345.6	126.8	2.6	6857.1	869.3	642.8	34.1	7490.9	806.9	105.5	0.1
	800	6423.3	2080.5	258.9	5.2	6573.8	2111.0	82.9	0.2	6845.5	1118.7	777.1	26.5	7700.3	984.8	82.0	0.7
	900	5159.1	2618.2	353.0	52.3	5393.7	2556.1	232.8		5651.7	1014.3	1441.3	75.3	6455.2	1638.9	88.1	0.4
	1000	3739.6	2324.0	186.5	7.8	4169.5	2031.0	57.2	0.2	4284.5	545.3	1291.2	136.9	4631.7	1568.8	57.3	0.2
	1100	1818.4	1243.7	63.2	4.1	2118.8	993.9	16.5	0.2	2197.4	235.0	622.1	74.9	2287.6	804.1	36.2	1.4
	1200	628.8	346.3	11.0	1.2	760.1	225.8	1.4	0.0	844.4	27.1	104.1	11.8	782.4	193.2	11.0	0.8
	1300	383.2	85.2	0.2	0.3	427.3	39.3	2.3	0.0	467.6	0.1	1.0	0.2	380.3	83.1	4.6	0.8
	1400	360.5	26.1	0.1	0.1	377.2	8.5	1.0	0.0	386.7	0.0	0.0	0.0	355.9	26.3	4.5	0.0
	1500	189.4	1.7	0.1	0.0	188.2	2.9	0.0	0.0	190.5	0.0	0.7	0.0	186.3	2.4	2.5	0.0
	1600	91.8	0.0	0.2	0.4	91.3	0.8	0.2	0.2	92.4	0.0	0.1	0.0	89.5	1.6	1.4	0.0
	1700	7.6	0.0	0.0	0.0	7.6	0.0	0.0	0.0	7.6	0.0	0.0	0.0	7.6	0.0	0.0	0.0

Table III. 6: Area statistics of priority levels of richness of specific regions

Regions	Levels of richness	Area (ha)	%(SR)	%(SA)
Pu Luong Nature Reserve	Very low	1,236.0	7.1	0.8
	Low	1,406.5	8.0	1.0
	Medium	1,025.9	5.9	0.7
	High	1,523.0	8.7	1.0
	Very high	12,308.7	70.3	8.3
	Sum	**17,500.1**	**100.0**	**11.8**
Ngoc Son - Ngo Luong Nature Reserve	Very low	5,710.0	26.1	3.9
	Low	3,679.2	16.8	2.5
	Medium	745.5	3.4	0.5
	High	652.4	3.0	0.4
	Very high	11,085.8	50.7	7.5
	Sum	**21,872.8**	**100.0**	**14.8**
Cuc Phuong National Park	Very low	1,594.6	7.0	1.1
	Low	1,971.6	8.7	1.3
	Medium	261.7	1.1	0.2
	High	524.0	2.3	0.4
	Very high	18,440.6	80.9	12.5
	Sum	**22,792.6**	**100.0**	**15.4**
Other areas	Very low	40,756.2	47.5	27.5
	Low	17,287.9	20.1	11.7
	Medium	3,078.6	3.6	2.1
	High	2,562.1	3.0	1.7
	Very high	22,146.4	25.8	15.0
	Sum	**85,831.3**	**100.0**	**58.0**
Total	Very low	49,296.8	33.3	33.3
	Low	24,345.2	16.4	16.4
	Medium	5,111.7	3.5	3.5
	High	5,261.5	3.6	3.6
	Very high	63,981.4	43.2	43.2
	Sum	**147,996.7**	**100.0**	**100.0**

SR: Specific region *SA: Study area*

Table III. 7: Area statistic of priority levels of rarity in the study area

Specific Regions	Levels of rarity	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very low	1,513.1	6.6	1.0
	Low	2,600.3	11.4	1.8
	Medium	4,408.8	19.3	3.0
	High	13,367.2	58.6	9.0
	Very high	903.1	4.0	.6
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very low	5,623.2	25.7	3.8
	Low	5,397.9	24.7	3.6
	Medium	3,229.3	14.8	2.2
	High	5,335.2	24.4	3.6
	Very high	2,287.3	10.5	1.5
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very low	1,156.7	6.6	.8
	Low	3,145.3	18.0	2.1
	Medium	5,637.7	32.2	3.8
	High	4,610.8	26.3	3.1
	Very high	2,949.6	16.9	2.0
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very low	40,852.4	47.6	27.6
	Low	22,018.5	25.7	14.9
	Medium	11,103.5	12.9	7.5
	High	7,920.4	9.2	5.4
	Very high	3,936.5	4.6	2.7
	Sum	**85,831.3**	**100.0**	**58.0**
Total	Very low	49,145.3	33.2	33.2
	Low	33,162.0	22.4	22.4
	Medium	24,379.2	16.5	16.5
	High	31,233.7	21.1	21.1
	Very high	10,076.6	6.8	6.8
	Sum	**147,996.7**	**100.0**	**100.0**

Table III. 8: Area statistic of priority levels of location in the study area

Specific regions	**Priority levels**	**Area**		
		ha	**% (SR)**	**% (SA)**
Cuc Phuong National Park	Low	1,646.3	7.2	1.1
	Medium	14,899.9	65.4	10.1
	High	6,246.3	27.4	4.2
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Low	0.0	0.0	0.0
	Medium	10,829.9	49.5	7.3
	High	11,042.9	50.5	7.5
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Low	0.0	0.0	0.0
	Medium	7,870.4	45.0	5.3
	High	9,629.7	55.0	6.5
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Low	9,035.5	10.5	6.1
	Medium	55,076.8	64.2	37.2
	High	21,718.9	25.3	14.7
	Sum	**85,831.2**	**100.0**	**58.0**
Total	Low	10,681.8	7.2	7.2
	Medium	88,677.0	59.9	59.9
	High	48,637.9	32.9	32.9
	Sum	**147,996.6**	**100.0**	**100.0**

Table III. 9: Area statistic of priority levels of topography in the study area

Specific regions	Levels of topography	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very low	1,808.60	7.9	1.2
	Low	4,531.20	19.9	3.1
	Medium	6,091.70	26.7	4.1
	High	8,113.20	35.6	5.5
	Very high	2,247.80	9.9	1.5
	Sum	**22,792.50**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very low	8,728.40	39.9	5.9
	Low	3,984.10	18.2	2.7
	Medium	5,559.00	25.4	3.8
	High	3,283.70	15.0	2.2
	Very high	317.60	1.5	.2
	Sum	**21,872.80**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very low	6,109.30	34.9	4.1
	Low	5,417.00	31.0	3.7
	Medium	4,931.80	28.2	3.3
	High	976.50	5.6	.7
	Very high	65.50	.4	.0
	Sum	**17,500.10**	**100.0**	**11.8**
Other areas	Very low	46,752.60	54.5	31.6
	Low	11,293.00	13.2	7.6
	Medium	13,030.50	15.2	8.8
	High	8,652.10	10.1	5.8
	Very high	6,103.00	7.1	4.1
	Sum	**85,831.20**	**100.0**	**58.0**
Total	Very low	63,398.70	42.8	42.8
	Low	25,225.30	17.0	17.0
	Medium	29,613.20	20.0	20.0
	High	21,025.60	14.2	14.2
	Very high	8,733.90	5.9	5.9
	Sum	**147,996.70**	**100.0**	**100.0**

Table III. 10: Area statistic of priority levels of climate in the study area

Specific regions	Stable levels of temperature	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very low	921.0	4.0	.6
	Low	4,413.6	19.4	3.0
	Medium	5,800.0	25.4	3.9
	High	8,458.0	37.1	5.7
	Very high	3,199.8	14.0	2.2
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very low	516.2	2.4	.3
	Low	6,310.9	28.9	4.3
	Medium	8,046.0	36.8	5.4
	High	5,347.1	24.4	3.6
	Very high	1,652.7	7.6	1.1
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very low	154.0	.9	.1
	Low	1,658.6	9.5	1.1
	Medium	4,736.8	27.1	3.2
	High	6,758.3	38.6	4.6
	Very high	4,192.4	24.0	2.8
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very low	6,989.6	8.1	4.7
	Low	17,222.3	20.1	11.6
	Medium	21,433.6	25.0	14.5
	High	25,124.9	29.3	17.0
	Very high	15,060.9	17.5	10.2
	Sum	**85,831.2**	**100.0**	**58.0**
Total	Very low	8,580.8	5.8	5.8
	Low	29,605.5	20.0	20.0
	Medium	40,016.4	27.0	27.0
	High	45,688.2	30.9	30.9
	Very high	24,105.8	16.3	16.3
	Sum	**147,996.7**	**100.0**	**100.0**

Table III. 11: Area statistic of priority levels of hydrology in the study area

Specific regions	Priority levels of hydrology	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very low	12,661.6	55.6	8.6
	Low	4,565.8	20.0	3.1
	Medium	3,731.4	16.4	2.5
	High	1,768.7	7.8	1.2
	Very high	65.0	0.3	0.0
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very low	16,509.2	75.5	11.2
	Low	3,197.3	14.6	2.2
	Medium	977.1	4.5	.7
	High	728.5	3.3	.5
	Very high	460.8	2.1	.3
	Sum	**21,872.9**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very low	15,454.7	88.3	10.4
	Low	1,884.5	10.8	1.3
	Medium	160.9	0.9	0.1
	High	-	0.0	0.0
	Very high	-	0.0	0.0
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very low	28,830.4	33.6	19.5
	Low	18,143.9	21.1	12.3
	Medium	17,809.1	20.7	12.0
	High	12,675.2	14.8	8.6
	Very high	8,372.7	9.8	5.7
	Sum	**85,831.3**	**100.0**	**58.0**
Total	Very low	73,455.9	49.6	49.6
	Low	27,791.4	18.8	18.8
	Medium	22,678.5	15.3	15.3
	High	15,172.4	10.3	10.3
	Very high	8,898.4	6.0	6.0
	Sum	**147,996.7**	**100.0**	**100.0**

Table III. 12: Categories of forest types based on maps of forest statistic in three provinces

ID	English Categories	Levels	Vietnamese categories	Code	Weight	Area (ha)	Area (%)
1	Natural forest on limestone mountain	Rich	Rừnggỗtựnhiênnúi đá LRTX giàu	TXDG	4	11,781.05	7.13
2		Medium	Rừnggỗtựnhiênnúi đá LRTX TB	TXDB	3	9,033.35	5.47
3		Poor	Rừnggỗtựnhiênnúi đá LRTX nghèo	TXDN	2	17,816.29	10.78
4		Rehabilitation	Rừnggỗtựnhiênnúi đá LRTX phụchồi	TXDP	2	12,276.05	7.43
5			Đấtcócâygỗtáisinhnúi đá	DT2D	2	1,156.16	0.70
6		Very poor	Rừnggỗtựnhiênnúi đá LRTX nghèokiệt	TXDK	1	10,348.08	6.26
7	Mixed forest on limestone mountain		Rừnghỗngiaotựnhiênnúi đá	HGD	2	19.58	0.01
8	Natural forest on soil mountain	Rich	Rừnggỗtựnhiênnúi đất LRTX giàu	TXG	3	449.28	0.27
9		Medium	Rừnggỗtựnhiênnúi đất LRTX TB	TXB	2	3,646.12	2.21
10		Poor	Rừnggỗtựnhiênnúi đất LRTX nghèo	TXN	1	6,919.56	4.19
11		Rehabilitation	Rừnggỗtựnhiênnúi đất LRTX phụchồi	TXP	1	9,522.97	5.76
12			Đấtcócâygỗtáisinhnúi đất	DT2	1	531.29	0.32
13		Very poor	Rừnggỗtựnhiênnúi đất LRTX nghèokiệt	TXK	0	4,634.94	2.80
14	Mixed forest on soil mountain		Rừnghỗngiao G-TN tựnhiênnúi đất	HG1	1	465.70	0.28
15			Rừnghỗngiao TN-G tựnhiênnúi đất	HG2	1	91.51	0.06
16	Natural forest of Palm on soil mountain		Rừngcaudừatựnhiênnúi đất	CD	1	6.14	0.00

17	Plantation forest on limestone mountain		Rừnggỗtrồngnúi đá	RTGD	2	53.05	0.03
18	Plantation forest on soil mountain		Rừnggỗtrồngnúi đất	RTG	1	22,573.90	13.66
19			Rừngtrồngkhácnúi đất	RTK	1	17.81	0.01
20			Đất đã trồngrừngtrênnúi đất	DTR	1	2,634.48	1.59
21	Plantation forest of Palm		Rừngcaudừatrồng cạn	RTCD	1	92.08	0.06
22	Bamboo forest on limestone mountain		Rừngtrenứatrồngnúi đá	RTTND	2	156.08	0.09
23	Bamboo forest on soil mountain		Rừngnứatựnhiênnúi đất	NUA	1	19.59	0.01
24			Rừngvầutựnhiênnúi đất	VAU	1	49.94	0.03
25			Rừngtre/luồngtựnhiênnúi đất	TLU	1	97.53	0.06
26			Rừngtrenứatrồngnúi đất	RTTN	1	5,291.70	3.20
27	Water		Mặtnớc	MN	0	32.03	0.02
28	Agricultural land		Đấtnôngnghiệpnúi đất	NN	0	2,374.18	1.44
29			Đấtnôngnghiệpnúi đá	NND	0	31.64	0.02
30	Bare land		Đấttrốngnúi đất	DT1	0	22,414.27	13.56
31			Đấttrốngnúi đá	DT1D	0	449.60	0.27
32	Other Lands		Đấtkhác	DK	0	20,265.16	12.27
	Total					**165,251.09**	**100.00**

Table III. 13: Area statistic of priority levels of forest types in the study area

Specific regions	Priority levels	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very low	1,220.2	5.4	0.8
	Low	4,837.2	21.2	3.3
	Medium	3,279.6	14.4	2.2
	High	1,848.0	8.1	1.2
	Very high	11,607.5	50.9	7.8
	Sum	**22,792.6**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very low	7,237.2	33.1	4.9
	Low	6,998.4	32.0	4.7
	Medium	7,560.2	34.6	5.1
	High	77.0	0.4	0.1
	Very high	0.0	0.0	0.0
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very low	1,176.2	6.7	0.8
	Low	4,598.9	26.3	3.1
	Medium	5,769.8	33.0	3.9
	High	5,955.2	34.0	4.0
	Very high	0.0	0.0	0.0
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very low	26,220.3	30.5	17.7
	Low	40,585.1	47.3	27.4
	Medium	17,432.8	20.3	11.8
	High	1,552.6	1.8	1.0
	Very high	40.4	0.0	0.0
	Sum	**85,831.3**	**100.0**	**58.0**
Total	Very low	35,853.9	24.2	24.2
	Low	57,019.7	38.5	38.5
	Medium	34,042.5	23.0	23.0
	High	9,432.8	6.4	6.4
	Very high	11,647.9	7.9	7.9
	Sum	**147,996.7**	**100.0**	**100.0**

Table III. 14: Area statistic of pressure of climate change in the study area

Specific regions	**Pressure of Climate Change**	**Area**		
		ha	**% (SR)**	**% (SA)**
Cuc Phuong National Park	Low	21,245.5	93.2	14.4
	Medium	272.5	1.2	0.2
	High	1,274.5	5.6	0.9
	Very high	0.0	0.0	0.0
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Low	331.2	1.5	.2
	Medium	6,112.2	27.9	4.1
	High	11,924.8	54.5	8.1
	Very high	3,504.7	16.0	2.4
	Sum	**21,872.9**	**100.0**	**14.8**
Pu Luong Nature Reserve	Low	607.5	3.5	0.4
	Medium	10,469.2	59.8	7.1
	High	5,683.0	32.5	3.8
	Very high	740.5	4.2	0.5
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Low	21,023.8	24.5	14.2
	Medium	25,609.7	29.8	17.3
	High	36,465.6	42.5	24.6
	Very high	2,732.1	3.2	1.8
	Sum	**85,831.3**	**100.0**	**58.0**
Total	Low	43,207.9	29.2	29.2
	Medium	42,463.6	28.7	28.7
	High	55,347.9	37.4	37.4
	Very high	6,977.3	4.7	4.7
	Sum	**147,996.8**	**100.0**	**100.0**

Table III. 15: Information on natural disasters in Vietnam from 1997 to 2018

ID	Event	Date	Latitude	Longitude	Weight
1	Tropical cyclone	2018/8/14	18.671	105.692	2
2	Flood	2018/7/18	22.289	103.489	3
3	Flood	2018/6/23	22.776	104.969	3
4	Tropical cyclone	2017/12/25	10.833	106.650	2
5	Tropical cyclone	2017/11/4	14.058	108.277	2
6	Flood	2017/11/2	13.499	108.622	3
7	Flash flood	2017/10/11	14.058	108.277	2
8	Tropical cyclone	2017/9/14	17.918	106.169	2
9	Flood	2017/8/27	21.908	105.641	3
10	Flash flood	2017/8/3	21.714	104.900	2
11	Tropical cyclone	2017/7/25	17.500	106.500	2
12	Flood	2016/12/13	15.199	108.793	3
13	Tropical cyclone	2016/10/13	17.482	106.584	2
14	Epidemic	2016/4/12	14.058	108.277	1
15	Drought	2015/10/1	14.058	108.277	2
16	Flood	2015/7/26	20.977	107.038	3
17	Other	2015/3/2	10.434	107.145	1
18	Tropical cyclone	2014/7/20	22.426	104.200	2
19	Flood	2013/11/14	14.058	108.277	3
20	Tropical cyclone	2013/11/8	14.058	108.277	2
21	Tropical cyclone	2013/10/15	14.058	108.277	2
22	Tropical cyclone	2013/10/1	14.058	108.277	2
23	Tropical cyclone	2013/9/24	14.058	108.277	2
24	Flood	2013/9/6	14.058	108.277	3
25	Tropical cyclone	2012/10/29	14.058	108.277	2
26	Flood	2012/9/7	19.809	105.777	3
27	Tropical cyclone	2012/8/17	14.058	108.277	2
28	Severe local storm	2012/4/23	14.058	108.277	1
29	Epidemic	2012/3/15	14.058	108.277	1
30	Flood	2011/11/6	14.058	108.277	3
31	Tropical cyclone	2011/9/30	14.058	108.277	2
32	Flood	2011/9/12	14.072	108.958	3
33	Epidemic	2011/8/1	14.058	108.277	1
34	Flood	2010/11/29	14.058	108.277	3
35	Flood	2010/11/17	21.017	105.842	3
36	Flood	2010/10/4	14.058	108.277	3
37	Tropical cyclone	2010/8/24	14.058	108.277	2
38	Tropical cyclone	2010/7/17	20.861	106.680	2

39	Flood	2010/5/13	22.655	106.064	3
40	Tropical cyclone	2009/11/4	14.058	108.277	2
41	Flood	2009/9/28	14.058	108.277	3
42	Tropical cyclone	2009/9/30	14.058	108.277	2
43	Flood	2009/7/5	14.058	108.277	3
44	Tropical cyclone	2008/11/18	14.058	108.277	2
45	Flash flood	2008/11/1	14.058	108.277	2
46	Flash flood	2008/10/20	14.058	108.277	2
47	Tropical cyclone	2008/10/1	14.058	108.277	2
48	Flash flood	2008/9/25	14.058	108.277	2
49	Flood	2008/8/26	14.058	108.277	3
50	Flash flood	2008/8/8	14.058	108.277	2
51	Flood	2007/10/17	15.124	108.812	3
52	Flash flood	2007/10/28	14.058	108.277	2
53	Flood	2007/10/28	14.058	108.277	3
54	Tropical cyclone	2007/10/3	14.058	108.277	2
55	Flood	2007/8/6	14.058	108.277	3
56	Tropical cyclone	2006/5/17	14.058	108.277	2
57	Tropical cyclone	2006/12/5	14.058	108.277	2
58	Tropical cyclone	2006/10/1	14.058	108.277	2
59	Flood	2006/8/20	14.058	108.277	3
60	Tropical cyclone	2006/7/11	14.058	108.277	2
61	Tropical cyclone	2006/5/22	14.058	108.277	2
62	Tropical cyclone	2005/11/18	19.807	105.785	2
63	Tropical cyclone	2005/11/2	14.058	108.277	2
64	Flash flood	2005/12/14	14.058	108.277	2
65	Tropical cyclone	2005/11/2	15.539	108.019	2
66	Flood	2005/10/28	14.058	108.277	3
67	Tropical cyclone	2005/9/27	14.058	108.277	2
68	Flood	2005/9/10	14.058	108.277	3
69	Flood	2004/10/5	14.058	108.277	3
70	Tropical cyclone	2004/11/27	15.539	108.019	2
71	Flash flood	2004/7/23	22.803	104.978	2
72	Tropical cyclone	2004/6/14	14.058	108.277	2
73	Flood	2003/10/15	21.017	105.842	3
74	Tropical cyclone	2003/7/23	14.058	108.277	2
75	Severe local storm	2002/10/0	14.058	108.277	1
76	Tech. Disaster	2002/10/29	10.823	106.630	1
77	Flood	2002/9/20	18.341	105.907	3
78	Flood	2002/9/0	10.787	105.190	3
79	Flood	2002/8/1	14.058	108.277	3

80	Wildfire	2002/3/23	9.599	105.091	2
81	Drought	2002/3/0	14.058	108.277	2
82	Tropical cyclone	2001/8/11	18.341	105.907	2
83	Tropical cyclone	2001/11/12	14.058	108.277	2
84	Flood	2001/11/4	14.058	108.277	3
85	Severe local storm	2001/11/12	14.058	108.277	1
86	Tech. Disaster	2001/11/11	10.965	107.432	1
87	Flood	2001/10/24	15.441	108.695	3
88	Tech. Disaster	2001/10/15	11.674	108.863	1
89	Flood	2001/8/28	14.058	108.277	3
90	Severe local storm	2001/8/11	14.058	108.277	1
91	Flood	2001/6/30	14.058	108.277	3
92	Tech. Disaster	2001/6/6	14.058	108.277	1
93	Severe local storm	2001/7/4	21.571	105.551	1
94	Tech. Disaster	2001/6/13	21.684	104.566	1
95	Tech. Disaster	2001/4/13	14.058	108.277	1
96	Tech. Disaster	2001/4/7	14.058	108.277	1
97	Tropical cyclone	2000/8/20	14.058	108.277	2
98	Flood	2000/11/0	14.058	108.277	3
99	Slide	2000/10/3	14.058	108.277	2
100	Severe local storm	2000/9/10	18.294	105.675	1
101	Severe local storm	2000/8/24	9.092	104.968	1
102	Severe local storm	2000/8/24	10.022	105.091	1
103	Severe local storm	2000/8/24	10.377	106.344	1
104	Severe local storm	2000/8/20	14.058	108.277	1
105	Severe local storm	2000/7/10	9.972	105.688	1
106	Slide	2000/7/22	14.058	108.277	2
107	Flood	2000/7/7	14.058	108.277	3
108	Severe local storm	2000/6/12	20.231	106.464	1
109	Tech. Disaster	2000/2/14	19.234	104.920	1
110	Flood	1999/12/6	14.058	108.277	3
111	Flood	1999/10/18	14.058	108.277	3
112	Flood	1999/8/0	14.058	108.277	3
113	Drought	1999/3/0	14.058	108.277	2
114	Severe local storm	1998/11/0	14.058	108.277	1
115	Flood	1998/10/0	14.058	108.277	3
116	Drought	1998/5/0	14.058	108.277	2
117	Severe local storm	1997/11/2	14.058	108.277	1
118	Tropical cyclone	1997/9/20	16.052	108.215	2
119	Tropical cyclone	1997/11/2	14.058	108.277	2

Source: *http://www.glidenumber.net*

Table III. 16: Area statistic of settlements in the study area

Specific regions	Types of settlement	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Urban settlement	0.0	0.0	0.0
	Rural settlement	143.2	0.6	0.1
	Other lands	22,649.4	99.4	15.3
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Urban settlement	0.0	0.0	0.0
	Rural settlement	1,128.1	5.2	0.8
	Other lands	20,744.5	94.8	14.0
	Sum	**21,872.6**	**100.0**	**14.8**
Pu Luong Nature Reserve	Urban settlement	0.0	0.0	0.0
	Rural settlement	57.2	0.3	0.0
	Other lands	17,442.9	99.7	11.8
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Urban settlement	183.2	0.2	0.1
	Rural settlement	6,779.3	7.9	4.6
	Other lands	78,868.7	91.9	53.3
	Sum	**85,831.3**	**100.0**	**58.0**
Total	Urban settlement	183.2	0.1	0.1
	Rural settlement	8,107.8	5.5	5.5
	Other lands	139,705.5	94.4	94.4
	Sum	**147,996.5**	**100.0**	**100.0**

Table III. 17: Area statistic of pressure of population distribution in the study area

Specific regions	**Pressure of population distribution**	**Area**		
		ha	**% (SR)**	**% (SA)**
Cuc Phuong National Park	Very high	64.1	0.3	0.0
	High	792.2	3.5	0.5
	Medium	2,385.0	10.5	1.6
	Low	4,438.8	19.5	3.0
	Very low	15,112.5	66.3	10.2
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	671.0	3.1	0.5
	High	1,679.5	7.7	1.1
	Medium	2,377.9	10.9	1.6
	Low	7,560.1	34.6	5.1
	Very low	9,584.3	43.8	6.5
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	0.0	0.0	0.0
	High	0.0	0.0	0.0
	Medium	0.0	0.0	0.0
	Low	3,676.2	21.0	2.5
	Very low	13,823.8	79.0	9.3
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	10,473.7	12.2	7.1
	High	11,117.9	13.0	7.5
	Medium	11,906.6	13.9	8.0
	Low	27,485.4	32.0	18.6
	Very low	24,847.7	28.9	16.8
	Sum	**85,831.2**	**100.0**	**58.0**
Total	Very high	11,208.8	7.6	7.6
	High	13,589.6	9.2	9.2
	Medium	16,669.5	11.3	11.3
	Low	43,160.5	29.2	29.2
	Very low	63,368.4	42.8	42.8
	Sum	**147,996.6**	**100.0**	**100.0**

Table III. 18: The population and area of communes in and around the study area

Provinces	**Districts**	**Communes**	**Population**	**Area**(ha)
HoaBinh	Lac Son	AnNghia	6,210	2,693.3
		Chi Dao	2,233	1,086.9
		Chi Thien	2,298	717.9
		Dinh Cu	3,833	1,099.2
		Huong Nhuong	2,646	1,189.9
		Lien Vu	4,041	1,097.2
		Ngoc Lau	2,164	3,042.7
		Ngoc Son	1,785	3,358.2
		Phu Luong	2,248	2,171.5
		Tan My	5,562	3,143.6
		Tu Do	2,044	5,058.3
		Vu Lam	3,480	744.8
		Yen Nghiep	4,746	2,320.2
		Total	**43,290**	**27,723.4**
	Mai Chau	Chieng Chau	3,518	1,715.6
		Mai Ha	2,495	1,753.6
		Nong Luong	1,314	1,610.2
		Pu Pin	1,432	2,147.6
		ThungKhe	1,518	1,853.8
		Van Mai	3,061	3,553.5
		Total	**13,338**	**12,634.2**
	Tan Lac	Bac Son	1,139	1,405.9
		Do Nhan	2,158	1,864.3
		Gia Mo	2,694	1,986.8
		Lo Son	2,860	1,667.9
		Lung Van	1,484	2,134.7
		Nam Son	1,435	2,034.5
		Ngo Luong	1,221	3,845.4
		QuyetChien	1,340	2,614.5
		Total	**14,331**	**17,554.0**
	Yen Thuy	Lac Thinh	5,066	3,132.3
		Ngoc Luong	7,735	2,535.6
		Phu Lai	2,824	1,177.3

		TT. Hang Tram	3,526	188.9
		Yen Lac	8,187	3,010.0
		Yen Tri	6,004	1,747.5
		Total	**33,342**	**11,791.6**
NinhBinh	Nho Quan	Cuc Phuong	2,729	12,348.2
		Van Phuong	4,076	883.6
		Yen Quang	5,884	1,069.8
		Total	**12,689**	**14,301.6**
Thanh Hoa	Ba Thuoc	Ban Cong	5,802	4,270.7
		Co Lung	3,386	4,896.3
		Ha Trung	2,686	3,734.7
		Lung Cao	4,903	7,903.7
		Lung Niem	2,705	1,389.9
		Luong Noi	3,538	5,680.3
		Tan Lap	2,700	1,338.0
		Thanh Lam	3,216	2,759.7
		Thanh Son	3,899	3,964.0
		Total	**32,835**	**35,937.3**
	Quan Hoa	Hoi Xuan	2,989	7,004.7
		Phu Le	1,988	4,305.7
		Phu Nghiem	981	1,926.7
		Phu Thanh	1,583	3,005.9
		Phu Xuan	1,943	2,524.4
		Thanh Xuan	2,753	7,742.4
		TT. Quan Hoa	2,676	389.1
		Total	**14,913**	**26,898.9**
	Thach Thanh	Thach Lam	2,288	6,504.3
		Thach Quang	4,956	2,033.2
		Thach Tuong	3,116	3,865.4
		Thanh My	3,994	2,236.6
		Thanh Yen	2,906	4,388.9
		Total	**17,260**	**19,028.3**

(Source: General Statistics Office of Vietnam)

Table III. 19: Area statistic of pressure of population density in the study area

Specific regions	Pressure of population density	Area		
		Area	% (SR)	% (SA)
Cuc Phuong National Park	Very high	0.0	0.0	0.0
	High	313.0	1.4	0.2
	Medium	2,683.1	11.8	1.8
	Low	5,858.7	25.7	4.0
	Very low	13,937.7	61.2	9.4
	Sum	**22,792.5**	**100**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	0.0	0.0	0.0
	High	828.7	3.8	0.6
	Medium	1,498.4	6.9	1.0
	Low	10,203.5	46.6	6.9
	Very low	9,342.3	42.7	6.3
	Sum	**21,872.8**	**100**	**14.8**
Pu Luong Nature Reserve	Very high	0.0	0.0	0.0
	High	0.0	0.0	0.0
	Medium	22.0	0.1	0.0
	Low	8,668.7	49.5	5.9
	Very low	8,809.4	50.3	6.0
	Sum	**17,500.1**	**100**	**11.8**
Other areas	Very high	620.4	0.7	0.4
	High	12,040.2	14	8.1
	Medium	18,549.2	21.6	12.5
	Low	42,254.2	49.2	28.6
	Very low	12,367.3	14.4	8.4
	Sum	**85,831.2**	**100**	**58**
Total	Very high	620.4	0.4	0.4
	High	13,181.9	8.9	8.9
	Medium	22,752.6	15.4	15.4
	Low	66,985.2	45.3	45.3
	Very low	44,456.7	30.0	30.0
	Sum	**147,996.7**	**100**	**100**

Table III. 20: Area statistic of pressure of population in the study area

Specific regions	Pressure of population density	Area		
		Area	% (SR)	% (SA)
Cuc Phuong National Park	Very high	1.8	0.0	0.0
	High	683.4	3.0	0.5
	Medium	2,529.5	11.1	1.7
	Low	5,389.2	23.6	3.6
	Very low	14,188.6	62.3	9.6
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	131.6	0.6	0.1
	High	1,044.5	4.8	0.7
	Medium	857.3	3.9	0.6
	Low	4,573.2	20.9	3.1
	Very low	15,266.2	69.8	10.3
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	0.0	0.0	0.0
	High	0.0	0.0	0.0
	Medium	0.0	0.0	0.0
	Low	2,874.3	16.4	1.9
	Very low	14,625.8	83.6	9.9
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	3,592.5	4.2	2.4
	High	8,550.2	10.0	5.8
	Medium	14,376.0	16.7	9.7
	Low	23,382.8	27.2	15.8
	Very low	35,929.7	41.9	24.3
	Sum	**85,831.2**	**100.0**	**58.0**
Total	Very high	3,726.0	2.5	2.5
	High	10,278.1	6.9	6.9
	Medium	17,762.8	12.0	12.0
	Low	36,219.6	24.5	24.5
	Very low	80,010.3	54.1	54.1
	Sum	**147,996.7**	**100.0**	**100.0**

Table III. 21: Summary of population and LULC areas of communes around the study area

ID	Province	District	Commune	Population	Forest	Plantation & Rehabilitation	Agriculture	Settlement	Bare land	Others	Total
A	Hoa Binh	**Total**		**104,301**	**39,630.2**	**2,327.9**	**2,159.9**	**5,618.9**	**5,507.9**	**14,733.8**	**69,978.6**
I		Lac Son	**Sum**	**43,290**	**14,802.7**	**703.2**	**803.8**	**2,820.8**	**2,296.8**	**6,394.7**	**27,821.9**
1			AnNghia	6,210	1,176.1	39.0	119.1	380.1	209.9	776.3	2,700.5
2			Chi Dao	2,233	410.2	56.9	62.0	199.9	35.5	330.0	1,094.4
3			Chi Thien	2,298	180.8	95.2	40.6	164.5	13.4	223.4	717.9
4			Dinh Cu	3,833	331.1	74.4	9.9	198.7	72.2	423.0	1,109.4
5			Huong Nhuong	2,646	145.3	235.2	139.8	188.1	127.3	369.2	1,204.9
6			Lien Vu	4,041	339.0	72.9	25.8	174.1	57.8	430.0	1,099.6
7			Ngoc Lau	2,164	1,802.3	8.2	10.7	171.3	623.8	428.7	3,045.0
8			Ngoc Son	1,785	2,390.5	0.9	0.0	238.1	264.3	465.2	3,359.0
9			Phu Luong	2,248	1,132.2	42.2	5.1	303.1	173.2	515.6	2,171.5
10			Tan My	5,562	1,336.4	14.6	265.2	334.3	443.1	789.1	3,182.7
11			Tu Do	2,044	4,379.8	0.6	0.0	81.0	270.0	329.4	5,060.7
12			Vu Lam	3,480	165.8	32.1	23.2	163.4	2.0	368.9	755.4
13			Yen Nghiep	4,746	1,013.1	31.1	102.4	224.3	4.3	946.0	2,321.1
II		Mai Chau	**Sum**	**13,338**	**9,550.6**	**41.9**	**558.4**	**123.1**	**986.6**	**1,396.5**	**12,657.0**
14			Chieng Chau	3,518	1,187.4	0.0	30.8	16.7	207.6	273.1	1,715.5
15			Mai Ha	2,495	1,276.4	0.0	13.7	0.0	164.6	298.9	1,753.6
16			Nong Luong	1,314	1,078.0	0.0	152.0	43.9	154.8	181.5	1,610.1
17			Pu Pin	1,432	1,524.5	0.0	117.0	36.8	253.1	217.1	2,148.4
18			ThungKhe	1,518	1,369.3	3.8	241.1	23.4	93.1	123.2	1,853.9
19			Van Mai	3,061	3,115.0	38.1	3.8	2.3	113.4	302.8	3,575.3

III		Tan Lac	**Sum**	**14,331**	**10,770.8**	**706.0**	**489.9**	**965.8**	**2,107.3**	**2,652.3**	**17,692.0**
20			Bac Son	1,139	631.9	0.0	0.2	140.2	433.1	200.6	1,405.9
21			Do Nhan	2,158	1,383.3	10.4	0.0	173.5	122.7	211.0	1,901.0
22			Gia Mo	2,694	1,138.1	209.5	19.3	191.2	92.5	381.3	2,032.0
23			Lo Son	2,860	593.0	464.1	5.0	159.2	94.9	400.7	1,717.0
24			Lung Van	1,484	1,092.8	18.3	310.7	78.9	274.3	359.7	2,134.7
25			Nam Son	1,435	1,129.1	0.8	6.7	114.1	409.3	374.4	2,034.5
26			Ngo Luong	1,221	2,802.0	0.0	0.2	55.5	578.5	409.2	3,845.4
27			QuyetChien	1,340	2,000.6	2.9	147.7	53.1	102.0	315.3	2,621.5
IV		Yen Thuy	**Sum**	**33,342**	**4,506.2**	**876.8**	**307.9**	**1,709.3**	**117.3**	**4,290.4**	**11,807.7**
28			Lac Thinh	5,066	1,630.6	149.9	267.1	202.2	4.9	884.3	3,139.0
29			Ngoc Luong	7,735	524.7	176.9	0.8	569.3	72.9	1,196.6	2,541.2
30			Phu Lai	2,824	452.5	55.2	11.7	141.9	5.4	510.8	1,177.5
31			TT. Hang Tram	3,526	0.0	0.0	0.0	110.1	0.0	78.8	188.9
32			Yen Lac	8,187	1,333.4	489.6	10.2	296.3	1.1	881.0	3,011.5
33			Yen Tri	6,004	565.0	5.1	18.0	389.6	33.0	738.9	1,749.7
B	Ninh Binh	**Total**		**12,689**	**11,276.8**	**38.8**	**39.0**	**439.0**	**102.4**	**2,431.4**	**14,327.3**
I		Nho Quan	**Sum**	**12,689**	**11,276.8**	**38.8**	**39.0**	**439.0**	**102.4**	**2,431.4**	**14,327.3**
34			Cuc Phuong	2,729	11,217.0	31.6	39.0	147.4	85.1	851.1	12,371.2
35			Van Phuong	4,076	50.1	7.1	0.0	124.1	17.3	685.3	883.9
36			Yen Quang	5,884	9.6	0.0	0.0	167.5	0.0	895.1	1,072.2
C	Thanh Hoa	**Total**		**65,008**	**60,977.5**	**1,850.0**	**79.0**	**2,676.3**	**5,140.0**	**11,767.6**	**82,490.4**
I		Ba Thuoc	**Sum**	**32,835**	**25,992.4**	**1,074.3**	**34.6**	**1,304.1**	**1,781.2**	**5,752.9**	**35,939.4**
37			Ban Cong	5,802	2,720.2	268.0	1.5	323.1	165.0	793.9	4,271.6
38			Co Lung	3,386	3,792.1	148.9	4.0	113.5	391.9	446.1	4,896.4
39			Ha Trung	2,686	2,845.0	63.6	1.9	155.0	71.4	598.1	3,735.1
40			Lung Cao	4,903	6,680.1	126.9	23.0	154.1	187.5	732.9	7,904.4

41			Lung Niem	2,705	681.7	17.7	0.0	48.0	50.0	592.6	1,389.9
42			Luong Noi	3,538	3,869.3	74.7	0.8	135.4	765.5	834.6	5,680.2
43			Tan Lap	2,700	618.3	36.7	2.6	101.7	62.6	516.2	1,338.0
44			Thanh Lam	3,216	1,951.4	279.8	0.2	133.3	11.5	383.6	2,759.7
45			Thanh Son	3,899	2,834.4	58.1	0.7	140.1	75.8	854.9	3,964.0
II		Quan Hoa	**Sum**	**14,913**	**22,142.7**	**344.6**	**32.9**	**208.6**	**2,046.9**	**2,560.4**	**27,336.0**
46			Hoi Xuan	2,989	5,806.4	48.8	9.1	55.8	470.1	614.6	7,004.7
47			Phu Le	1,988	3,778.3	42.3	0.7	22.7	193.0	268.8	4,305.7
48			Phu Nghiem	981	1,647.7	25.9	6.2	34.3	28.3	184.3	1,926.7
49			Phu Thanh	1,583	2,856.4	63.2	15.3	11.4	271.0	225.4	3,442.6
50			Phu Xuan	1,943	1,994.6	72.6	0.0	5.9	55.2	396.0	2,524.4
51			Thanh Xuan	2,753	5,835.1	91.7	1.6	25.3	1,027.3	761.7	7,742.7
52			TT. Quan Hoa	2,676	224.2	0.0	0.0	53.3	2.1	109.6	389.1
III		Thach Thanh	**Sum**	**17,260**	**12,842.4**	**431.2**	**11.6**	**1,163.6**	**1,312.0**	**3,454.3**	**19,215.1**
53			Thach Lam	2,288	5,358.6	208.2	0.4	62.9	483.1	392.2	6,505.3
54			Thach Quang	4,956	693.1	11.8	2.8	325.6	120.6	879.4	2,033.4
55			Thach Tuong	3,116	2,194.1	41.3	3.9	379.8	373.5	1,058.3	4,050.8
56			Thanh My	3,994	965.5	145.2	1.4	287.2	37.8	799.6	2,236.6
57			Thanh Yen	2,906	3,631.2	24.6	3.1	108.2	297.0	324.8	4,388.9
	Total			**398,403**	**281,220.5**	**9,618.7**	**3,870.2**	**17,762.8**	**24,446.3**	**65,670.1**	**402,588.6**

Table III. 22: Area statistic of pressure of livelihood in the study area

Specific regions	Pressure of livelihood	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very high	45.0	0.2	0.0
	High	572.7	2.5	0.4
	Medium	1,873.0	8.2	1.3
	Low	5,797.1	25.4	3.9
	Very low	14,504.7	63.6	9.8
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	0.0	0.0	0.0
	High	915.0	4.2	0.6
	Medium	2,147.5	9.8	1.5
	Low	8,298.4	37.9	5.6
	Very low	10,512.0	48.1	7.1
	Sum	**21,872.9**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	0.0	0.0	0.0
	High	0.0	0.0	0.0
	Medium	0.0	0.0	0.0
	Low	4,961.4	28.4	3.4
	Very low	12,538.7	71.6	8.5
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	2,882.2	3.4	1.9
	High	10,805.1	12.6	7.3
	Medium	17,577.3	20.5	11.9
	Low	28,723.6	33.5	19.4
	Very low	25,843.0	30.1	17.5
	Sum	**85,831.2**	**100.0**	**58.0**
Total	Very high	2,927.2	2.0	2.0
	High	12,292.8	8.3	8.3
	Medium	21,597.8	14.6	14.6
	Low	47,780.5	32.3	32.3
	Very low	63,398.3	42.8	42.8
	Sum	**147,996.6**	**100.0**	**100.0**

Table III. 23: Area statistic of priority levels of forest management types in the study area

Specific regions	Protection levels	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very high	20,992.9	92.1	14.2
	High	0.6	0.0	0.0
	Medium	828.0	3.6	0.6
	Low	64.4	0.3	0.0
	Very low	906.6	4.0	0.6
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	33.5	0.2	0.0
	High	15,380.5	70.3	10.4
	Medium	1,081.5	4.9	0.7
	Low	581.2	2.7	0.4
	Very low	4,796.1	21.9	3.2
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	0.0	0.0	0.0
	High	16,759.8	95.8	11.3
	Medium	18.2	0.1	0.0
	Low	56.2	0.3	0.0
	Very low	665.9	3.8	0.4
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	386.9	0.5	0.3
	High	125.9	0.1	0.1
	Medium	26,116.4	30.4	17.6
	Low	22,236.2	25.9	15.0
	Very low	36,965.5	43.1	25.0
	Sum	**85,831.0**	**100.0**	**58.0**
Total	Very high	21,413.4	14.5	14.5
	High	32,266.8	21.8	21.8
	Medium	28,044.1	18.9	18.9
	Low	22,938.0	15.5	15.5
	Very low	43,334.1	29.3	29.3
	Sum	**147,996.4**	**100.0**	**100.0**

Table III. 24. Area statistic of priority levels of forest size in the study area

Specific regions	Priority levels of sizes	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very high	20,874.4	91.6	14.1
	High	300.5	1.3	0.2
	Medium	30.1	0.1	0.0
	Low	481.3	2.1	0.3
	Very low	1,106.2	4.9	0.7
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	15,285.6	69.9	10.3
	High	919.9	4.2	0.6
	Medium	112.2	0.5	0.1
	Low	0.0	0.0	0.0
	Very low	5,555.2	25.4	3.8
	Sum	**21,872.8**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	11,300.1	64.6	7.6
	High	12.4	0.1	0.0
	Medium	5,430.4	31.0	3.7
	Low	26.8	0.2	0.0
	Very low	730.4	4.2	0.5
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	464.2	0.5	0.3
	High	12,729.3	14.8	8.6
	Medium	7,980.0	9.3	5.4
	Low	10,606.2	12.4	7.2
	Very low	54,051.6	63.0	36.5
	Sum	**85,831.3**	**100.0**	**58.0**
Total	Very high	47,924.2	32.4	32.4
	High	13,962.1	9.4	9.4
	Medium	13,552.7	9.2	9.2
	Low	11,114.3	7.5	7.5
	Very low	61,443.4	41.5	41.5
	Sum	**147,996.7**	**100.0**	**100.0**

Table III. 25. Area statistic of priority levels of education in the study area

Specific regions	**Impact levels of education**	**Area**		
		ha	**% (SR)**	**% (SA)**
Cuc Phuong National Park	Very high	0.0	0.0	0.0
	High	55.4	0.2	0.0
	Medium	1,184.9	5.2	0.8
	Low	4,902.1	21.5	3.3
	Very low	16,650.2	73.1	11.3
	Sum	**22,792.5**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	16.4	0.1	0.0
	High	3,541.7	16.2	2.4
	Medium	1,169.4	5.3	0.8
	Low	4,033.0	18.4	2.7
	Very low	13,112.5	59.9	8.9
	Sum	**21,872.9**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	0.0	0.0	0.0
	High	1,844.5	10.5	1.2
	Medium	8,625.0	49.3	5.8
	Low	6,694.0	38.3	4.5
	Very low	336.7	1.9	0.2
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	5,536.6	6.5	3.7
	High	13,159.2	15.3	8.9
	Medium	21,595.3	25.2	14.6
	Low	21,672.5	25.3	14.6
	Very low	23,867.5	27.8	16.1
	Sum	**85,831.1**	**100.0**	**58.0**
Total	Very high	5,552.9	3.8	3.8
	High	18,600.8	12.6	12.6
	Medium	32,574.5	22.0	22.0
	Low	37,301.5	25.2	25.2
	Very low	53,966.9	36.5	36.5
	Sum	**147,996.7**	**100.0**	**100.0**

Table III. 26. Area statistic of priority levels of law in the study area

Specific regions	Impact levels of law	Area		
		ha	% (SR)	% (SA)
Cuc Phuong National Park	Very high	3,267.8	14.3	2.2
	High	6,422.4	28.2	4.3
	Medium	12,951.9	56.8	8.8
	Low	150.4	0.7	0.1
	Very low	0.0	0.0	0.0
	Sum	**22,792.6**	**100.0**	**15.4**
Ngoc Son - Ngo Luong Nature Reserve	Very high	114.7	0.5	0.1
	High	4,042.6	18.5	2.7
	Medium	6,037.7	27.6	4.1
	Low	9,370.8	42.8	6.3
	Very low	2,307.0	10.5	1.6
	Sum	**21,872.9**	**100.0**	**14.8**
Pu Luong Nature Reserve	Very high	226.1	1.3	0.2
	High	3,428.0	19.6	2.3
	Medium	5,205.3	29.7	3.5
	Low	5,803.6	33.2	3.9
	Very low	2,837.2	16.2	1.9
	Sum	**17,500.1**	**100.0**	**11.8**
Other areas	Very high	6,130.2	7.1	4.1
	High	12,934.4	15.1	8.7
	Medium	23,294.7	27.1	15.7
	Low	28,203.9	32.9	19.1
	Very low	15,268.0	17.8	10.3
	Sum	**85,831.2**	**100.0**	**58.0**
Total	Very high	9,738.8	6.6	6.6
	High	26,827.4	18.1	18.1
	Medium	47,489.5	32.1	32.1
	Low	43,528.8	29.4	29.4
	Very low	20,412.2	13.8	13.8
	Sum	**147,996.7**	**100.0**	**100.0**