Feasibility Study On Climate Change, Food, and Nutrition Security, Conservation and Land-Use in Enga Province of Papua New Guinea

Final Assessment Part 3

Improved Biodiversity and Land/Forest Ecosystem Conservation, Restoration, and Sustainable Use

United Nations Development Programme (UNDP)

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LIST OF ABBREVIATIONS AND ACRONYMS

ACT	Artemisinin Based Therapy
AOI	Area of Interest
AZE	Alliance for Zero Extinction
BAU	Business as usual
BIO	Bioclimatic variable
CA	Conservation area
CCDA	Climate Change and Development Authority
CCDS	Climate Compatible Development Strategy
CEPA	Conservation and Environment Protection Agency
CR	Critically endangered species
CWD	Consecutive wet days (CWD)
DAL	Department of Agriculture and Livestock
DEM	Digital Elevation Model
EN	Endangered species
ENSO	"El Niño" Southern Oscillation system
EROS	Earth Resources Observation and Science
GCM	Global Climate Models
GDP	Gross domestic product
GFW	Global Forest Watch
GIS	Geographical Information System

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GoPNG	Government of Papua New Guinea
HCV	High conservation value
IBA	Important Bird Area
INDC	Intended Nationally Determined Contribution
IPPC6	Intergovernmental Panel on Climate Change Sixth Assessment
IRS	Indoor Residual Spraying
IUCN	International Union for Conservation of Nature
KBA	Key Biodiversity Areas
KPI	Key Performance Indicator
LLIN	Insecticide-treated bed net distribution
LMMA	Locally managed marine area
LULUCF	Land use, Land-use Change and Forestry
MCA	Multi-criteria analysis
MPA	Marine Protected Area
NASA	National Aeronautics and Space Administration
NDC	National Disaster Centre
NFI	National Forest Inventory
NRI	National Research Institute
PA	Protected area
PA	Provincial Authority
PDRC	Provincial Disaster Risk Committee
PNG	Papua New Guinea
PNGFA	Papua New Guinea Forest Authority
PNGFA	Papua New Guinea Forest Authority
PPP	Purchasing Power Parity
PRCPTOT	Total annual precipitation
PV	Solar photovoltaic cells
RCP	Representative Concentration Pathways
REDD	Reduction of emissions from deforestation and forest degradation

REDD+	Reducing Emissions from Deforestation, forest Degradation and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks
RF	Random Forest
RIL	Reduced-impact logging
SDM	Species Distribution Models
SFA	Strategic Focus Areas
SFM	Sustainable Forest Management
SOC	Soil organic carbon stock
SPCZ	South Pacific Convergence Zone
SSP	Shared socio-economic pathway
SSP	Socio-economic Shared Pathways
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
VU	Vulnerable species
WASH	Water, Sanitation and hygiene
WB	World Bank
WGF	Women's Focus Group Discussion

EXECUTIVE SUMMARY

Introduction and objectives

The project "Strengthening Integrated Sustainable Landscape Management in Enga Province Papua New Guinea" for the period 2021- 2025 will support the country in its continuing efforts to address climate change. It will assist in strengthening the sustainable and inclusive economic development of the Enga Province of Papua New Guinea (PNG) by three components/objectives: i) improving climate change mitigation and adaptation; ii) strengthening food and nutrition security and iii) improving biodiversity and land/forest conservation.

This report focuses on Component 3: Improved biodiversity and land/forest ecosystems conservation restoration and sustainable use. This component focuses on enhanced action on conservation, restoration and sustainable use of high-value areas within the landscape. These will be achieved by combining an enhanced mandate and capacity of environmental officers at the provincial level as part of Conservation and Environment Protection Authority's (CEPA) decentralization process and strengthening and coordinating provincial environment, climate change, and forest management committees. Moreover, it would be important that the committees work with the economic development committees, and targeted action at the community level to establish Community Conservation Areas and undertake reforestation, rehabilitation and woodlot development activities.

The current report includes an (i) introduction and review of the biodiversity, forestry and conservation context in Enga province, (ii) results from a spatial analysis of biodiversity, land use and conservation, as well as household surveys and interviews with provincial authorities regarding these issues, (iii) review of current provincial development plans, institutional and stakeholder identification, (iv) monitoring indicators and (v) recommendations. For the spatial analysis of biodiversity and forests, different primary and secondary data sources were accessed, including satellite imagery, land-cover maps, presence of species under threat, as well as topographic, soil and climate layers. The consultant team performed over 450 surveys from households in all Enga districts for the household surveys. The questionnaire aimed to reveal biodiversity and forest information such as non-timber forest products and their uses, forest ownership, distance to forests, forest product markets, agroforestry, protected areas, land-use planning, deforestation and forest degradation, and changes in forest vegetation cover and wildlife, etc.

Review of biodiversity, forestry and conservation context

Even though PNG has around 36.1 million hectares (ha) of forested land (78% of the total land area), the forest sector barely contributes to PNG's economy. Estimates for the number of vascular plant species for the entire island of New Guinea range from 11,000 to 25,000 species. Endemism probably exceeds 30% for Papua New Guinea and is well over 70% for Papuasia. PNG Guinea harbours an estimated 150,000 species of insects, 314 species of freshwater fishes (82 endemics), 641 species of amphibians and reptiles (328 endemics), 740 species of birds (77 endemics), and 276 species of mammals (69 endemics). The current status of species in Papua New Guinea includes one extinct, 36 critically endangered, 49 endangered, 365 vulnerable, and 288 near threatened (CBD

2022). Enga province, located in PNG Highlands, is mainly covered by lower and upper montane forests and alpine and subalpine grasslands, which host a myriad of fauna and flora species. There are currently no official protected areas designated within Enga province; nevertheless, during meetings with stakeholders, conservation initiatives exist in Enga, including Kazedi and Lemban conservation areas.

In the Enga province, some potential mitigation options in the forest sector include:

- The conservation and protection of forests.
- Implementation of sustainable forest management (SFM).
- Implementation of Reduced Deforestation and Forest Degradation (REDD) schemes.
- Sustainable and participatory land-use planning and increase forest areas through reforestation and afforestation activities.

More than 90% of Enga province area is covered by forest land (FinnOC, 2022), which presents opportunities for mitigation through reducing emissions from deforestation and forest degradation (REDD), supporting sustainable management conservation and enhancement of forest carbon stocks.

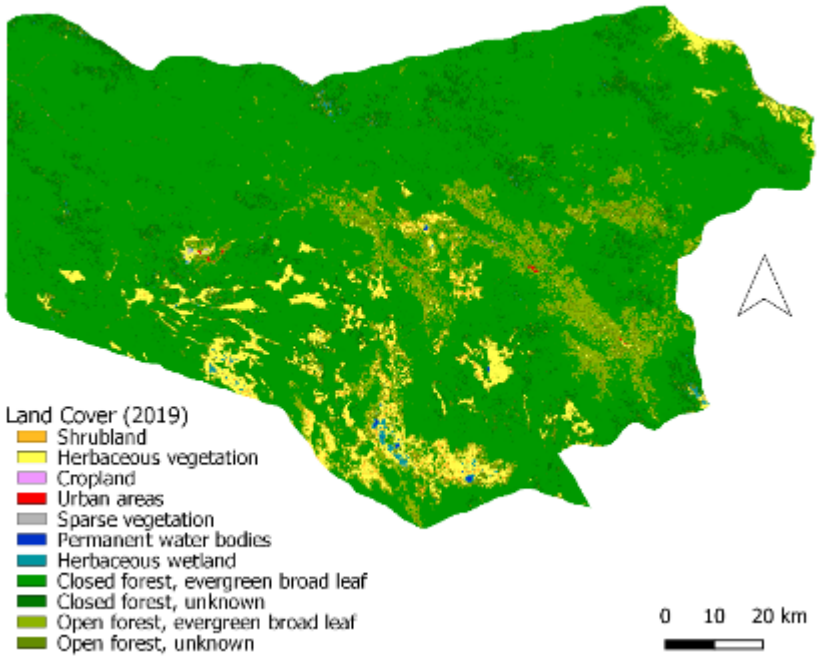

Figure 1. Land cover in Enga province

Results from the household surveys on biodiversity, forests and conservation

Based on household surveys done by the consultant, forests are mainly owned by communities in all five Enga districts. In Enga, deforestation and forest degradation are common events mainly due to agriculture subsistence clearing and population expansion. People in Enga are aware of changes in vegetation cover and wildlife in the last years, mainly to increased economic activities. A common

perception in Enga districts is that there are not enough conservation or protected areas, even though there are no formal established protected areas

Agroforestry is practised in all the districts in Enga, but mainly as a subsistence practice. Common trees used in agroforestry include: casuarina trees (*Casuarina spp.*), yar (*Casuarina oligodon*), tanget (*Cordyline fruticosaguava*), avocado (*Persea spp.*), pandanus (*Pandanus sp.*), guava (*Psidium sp.*), gumtree and eucalyptus (*Eucalyptus spp.*) among others. Different cash crops and other crops are mixed with trees in Enga, including taro, coffee, banana, kaukau, beans, etc. A big proportion of forest resources are collected for firewood and timber, followed by edible plants and fruits. These products are mainly for self-sustaining families. Nevertheless, some of these (firewood, fruits, etc.) are also sold in markets, but seldomly throughout the year.

Spatial biodiversity analysis

There are currently no formal protected areas within Enga province; nevertheless, based on the PNG Climate Change and Forest Monitoring Web-Portal, there are seven areas that need conservation assessments and six areas with priority conservation purposes. Similarly, during conversations with the Enga Provincial Authority (EPA), there are ongoing initiatives such as Lembena and Kumul conservation projects. There are three key biodiversity areas (KBAs) within a 1 km buffer of Enga Province (Hagen-Giluwe, Porgera and Salir River Jimi Valley). Similarly, there are ongoing conservation efforts that aim at establishing protected areas in the province.

There are seventy (70) species (including plants, animals, and fungi) under threat categories in the IUCN red list, potentially occurring within 50 km of Enga province. Eight species (7 plants, one animal) are critically endangered (CR), 26 (21 plants, three animals and two fungi) are endangered (EN), and 36 (23 plants and 13 animals) are vulnerable (VU). After downloading the occurrence records of these key species, we modelled their distribution throughout Enga province and derived a species richness map that will allow defining potential conservation areas.

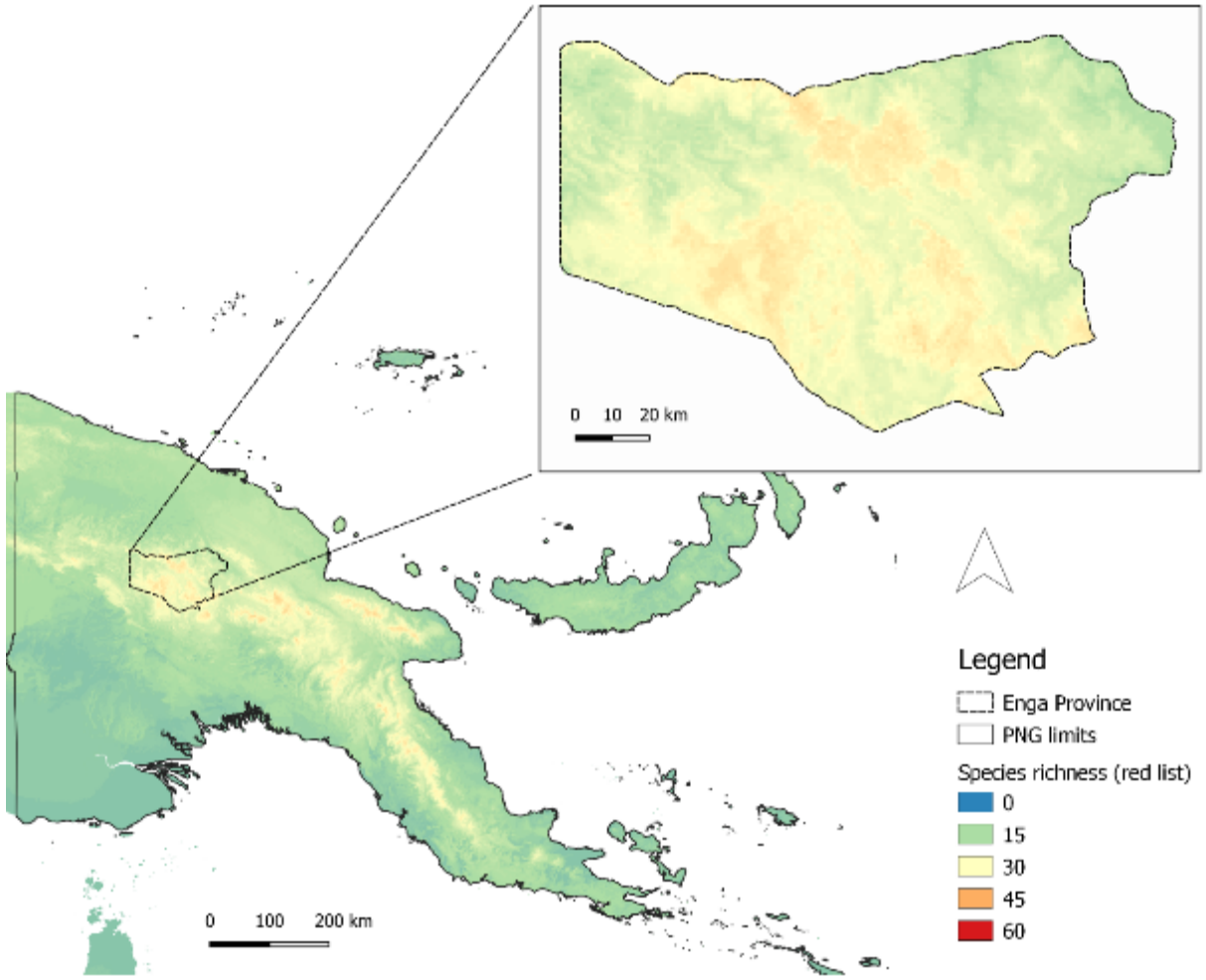

Figure 2. Number of threatened species (species richness) with potential to occur in Enga Province

Based on available land-use cover maps, the consultant team identified that changes in land cover between 2015-2019 in Enga Province impacted mainly forest areas, followed by herbaceous vegetation and shrublands in terms of natural vegetation. Our results suggest that structural connectivity has decreased (and fragmentation increased) in the forests, shrublands and grasslands in Enga Province. Annual forest loss between 2001-2020 in Enga Province ranged between 345 ha reported in 2001 and 3485 reported in 2016. The mean annual loss in that period in Enga Province was approximately 1568 ha. A total of 31353 ha were deforested in Enga Province between 2001-2020. Areas that have lost soil organic stock, forest cover and areas that have changed land cover (especially loss of natural vegetation such as shrublands) are considered potentially degraded areas in Enga Province.

Institutional and governance opportunities

The main struggles that the government institutions at the provincial level face regarding forestry, biodiversity and conservation are lack of funding, lack of manpower and lack of capacity building and training on biodiversity issues. Provincial-level authorities could provide technical assistance to resource owners and increase extension services to remote villages by having more resources. For instance, the Enga PNG Forest Authority is planning to identify and further develop three afforestation and reforestation locations throughout Enga province and rehabilitating tree nurseries, both private and communal. The consultant team will give technical support for improving the existing plans and policies in the forestry sector in Enga. We recommend giving specific training to staff from PNG Forest Authority in terms of Geographic Information Systems (GIS), data management and data collection (e.g. using the OpenDataKit-ODK software)

Recommendations

The consultant team proposes using a spatial-multicriteria analysis for identifying potential conservation areas in Enga. Some of these criteria include but are not limited to: (i) conservation needs assessment areas, (ii) biodiversity priority areas, (iii) species richness (red list), (iv) tree cover, (v) variation in temperature and (vi) variation in rainfall. These are preliminary criteria that could be improved or modified in future studies.

An important part of this project is the development of plans at the provincial level. Therefore, we recommend that management plans for economically and traditionally important tree species are drafted, such as "karuka" (*Pandanus julianetti*), "kapiak" (*Ficus dammaropsis*) and "breadfruit" (*Artocarpus altilis*). These species provide habitat and food for fauna and are also important for food security and economic support in Enga.


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1 INTRODUCTION

1.1 Background and objectives

In November 2020, UNDP Country Office and European Union signed a Contribution Agreement to implement the project "Strengthening Integrated Sustainable Landscape Management in Enga Province Papua New Guinea" for 2021- 2025. The project will support the country in its continuing efforts to address climate change. It will assist in strengthening the sustainable and inclusive economic development of the Enga Province of Papua New Guinea (PNG) by three components/objectives:

i) improving climate change mitigation and adaptation.
ii) strengthening food and nutrition security and
iii) improving biodiversity and land/forest conservation.

The Project will achieve the objectives by delivering an innovative approach to rural development that brings together government systems, the private sector, and community groups to establish climate-compatible green growth models.

The current assignment is intended to closely work with the Climate Change and Development Authority (CCDA), a lead government agency and project partner and Enga Provincial Government to undertake feasibility studies within the above three project components and set a baseline for implementing the project activities on the ground.

Under the overall supervision of the UNDP International Technical Advisor and the technical guidance of the CCDA and in close coordination with Enga Provincial Administration, the Consultant will be responsible for conducting feasibility studies of the above mentioned three components.

The following report tackles feasibility studies of component 3 (Improved biodiversity and land/forest ecosystem conservation, restoration and sustainable use). This component focuses on enhanced action on conservation, restoration and sustainable use of high-value areas within the landscape. These will be achieved by combining an enhanced mandate and capacity of environmental officers at the provincial level as part of CEPA's decentralization process and strengthening and coordinating provincial environment, climate change, and forest management committees. Moreover, it would be important that the committees work with the economic development committees, and targeted action at the community level to establish Community Conservation Areas and undertake reforestation, rehabilitation and woodlot development activities.

The report consists of the following structure:

1. Executive summary
2. Introduction to improved biodiversity and land/forest ecosystem conservation, restoration and sustainable use

3. Methodological framework
4. Review of improved biodiversity and land/forest ecosystem conservation, restoration and sustainable use
5. Analysis of biodiversity, land-use and forest ecosystems
6. Review of current provincial development plans
7. Recommendations

1.2 Enga Province Context

1.2.1 General information

Enga occupies 11,800 km^2 of the PNG highlands (**Figure 3**), and there are 295,031 inhabitants. In the north of the province, the Central Range is part of the main divide of PNG. The Lagaip River drains into the Fly River and the Coral Sea, while the Lai River drains into the Sepik River and the Bismarck Sea. The upper valleys of both rivers support very high population densities and intensive agriculture with continuous cultivation in some places. These areas are some of the most densely settled in the country. There are large swamp areas and intensive agriculture around Kandep in the province's south. The altitude varies from 400m at the Yuat River in the province's northeast to over 3,700 meters along the Central Range (**Figure 4**). More people in Enga live above 2,000 meters than in any other province. These environments are prone to frost and disruptions to the subsistence food supply. The upper altitudinal limit of agriculture is around 2,800 meters. Average annual rainfall varies between 2,300 and 3,800mm, increasing from south to north.[1]

[1] Hanson L.W., Allen B.J., Bourke R.M. & McCarthy T.J. 2001. Papua New Guinea Rural Development Handbook. The Australian National University.

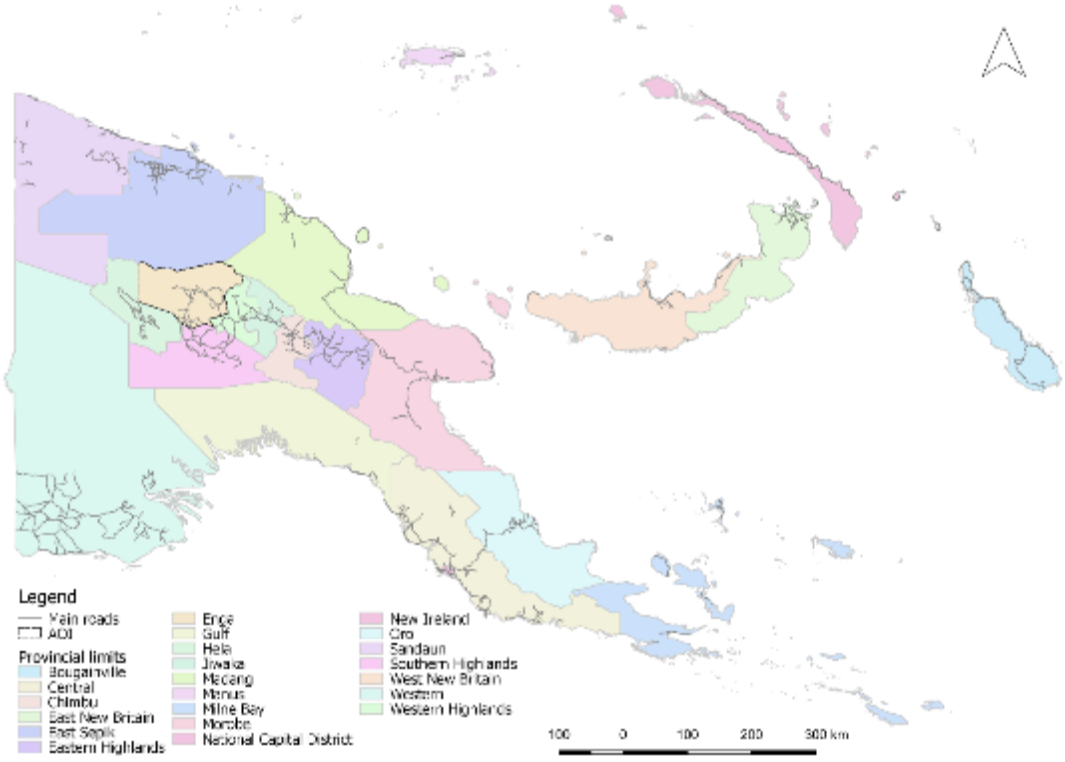

Figure 3. Provincial limits in Papua New Guinea

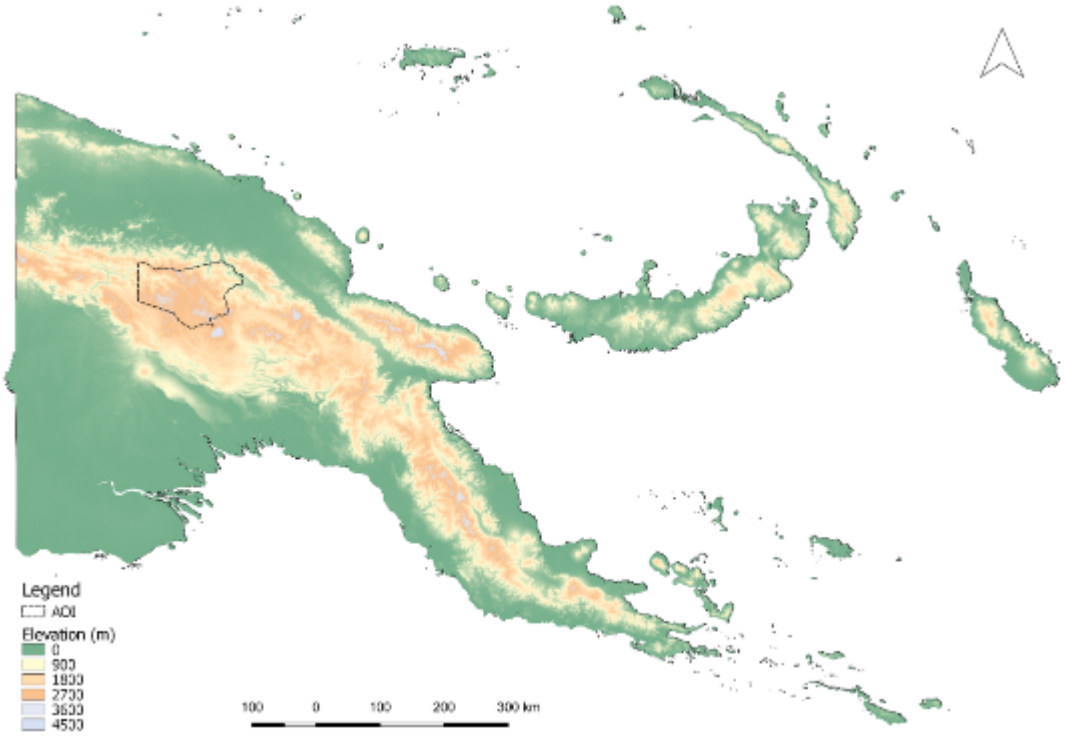

Figure 4. Elevation gradient in Papua New Guinea and Enga Province (dashed polygon)

The five districts in Enga are Kandep, Kompiam-Ambum, Lagaip-Porgera, Wabag and Wapenamanda. The main language spoken in Enga Province by all the Engans is the Enga Pii language. Population densities are highest in Wabag with 58,9 persons/km^2, while the Kompiam-Ambum District has the lowest density of only 15,0 persons/km^2. More than half of the area of the province is unoccupied mountains.

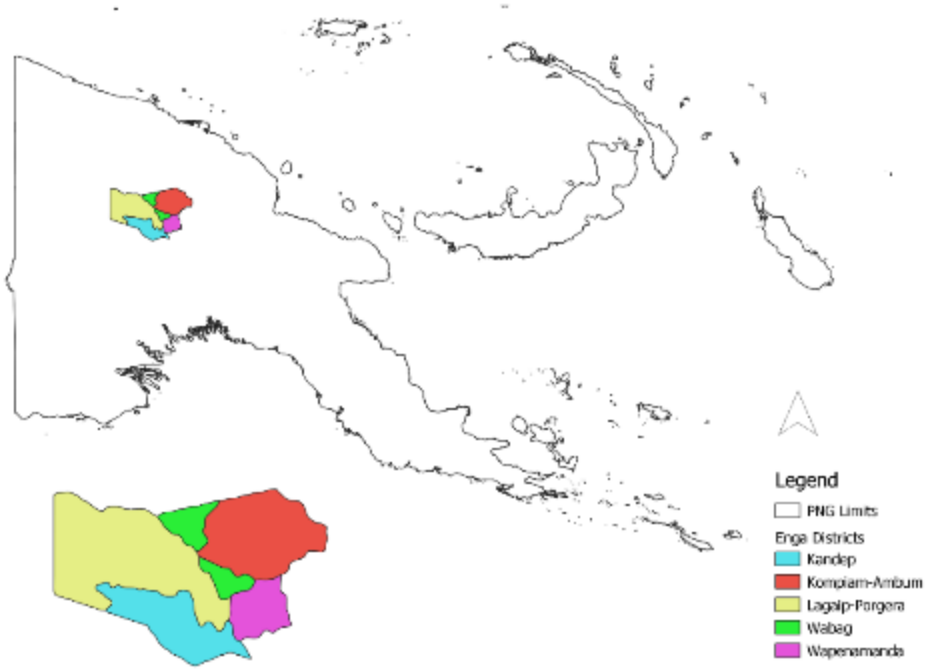

Figure 5. Districts in Enga Province

Despite having rich resources in Enga province, most people in Enga are still poor. People's incomes range between very low and moderate[2]. Agriculture provides only a low to the moderate source of income for the province, earned from the sale of coffee, food and firewood. Most of the coffee is grown around Wabag, Wapenamanda and Kompiam in areas below 2,100 meters, which is the upper altitudinal limit of Arabica coffee. People in the higher areas around Kandep and Laiagam sell small amounts of potatoes and firewood. People in the province's north are impoverished and have few cash-earning opportunities. Cultivated areas are prone to drought and frost, which can seriously affect food security. The Porgera gold mine provides royalties and wage employment. This income is very high but only benefits people living close to the mine.[3]

[2] Very low income (0–20 kina/person/year), Low income (21–40 kina/person/year), Moderate income (41–100 kina/person/year) (Hanson et. al 2001).
[3] Hanson L.W.J., et al. 2001.

Figure 6. Mixed-crop farmer in Birip, Enga (Source: FinnOC, 2022)

A branch of the Highlands Highway runs from Mt. Hagen up to Wapenamanda and Wabag and the Porgera Goldmine. Another road connects Kandep with Southern Highlands Province. Those living in the province's north are very remote and require more than a day's travel to reach a service centre. Around 62.5 per cent of the province's population lives within 5km of a national road. The overall literacy rate for the Enga province is 35.0 per cent, with a male literacy rate of 40.2 per cent and a female literacy rate of 29.5 per cent.

Figure 7. Kandep district station in Enga, PNG (Source: FinnOC, 2022)

Regarding the universal fundamental education indicators, the net admission rate is 14.8 per cent, gross enrolment rate 64.3 per cent and net enrolment rate 51.3 per cent in the province. The life expectancy at birth in Enga is 52.5 years. The under-five mortality rate in the Enga Province is 97

per 1,000. Under one-year infant mortality rate is 69 per 1,000. Furthermore, the child mortality rate is 28 between ages 1-4 per 1,000.[4]

1.2.2 Status of conservation and biodiversity in Enga province

New Guinea Island is considered one of the most biologically diverse regions globally since a large proportion of its fauna and flora is not found elsewhere (Richards 2017). PNG is rich and diverse not only in species but also in landscapes and ecosystems. For instance, forest cover in New Guinea constitutes the third-largest expanse of tropical rainforests on the planet, after the Amazon and the Congo Basin (CBD 2022).

Estimates for the number of vascular plant species for the entire island of New Guinea range from 11,000 to 25,000 species. Endemism probably exceeds 30% for Papua New Guinea and is well over 70% for Papuasia. PNG Guinea harbours an estimated 150,000 species of insects, 314 species of freshwater fishes (82 endemics), 641 species of amphibians and reptiles (328 endemics), 740 species of birds (77 endemics), and 276 species of mammals (69 endemics). The current status of species in Papua New Guinea includes one extinct, 36 critically endangered, 49 endangered, 365 vulnerable, and 288 near threatened (CBD 2022).

Enga province is located in PNG Highlands, mainly covered by lower and upper montane forests and alpine and subalpine grasslands (Takeuchi 2007). Recent floristic studies in Enga have found a checklist of 112 ferns and lycophytes, six gymnosperms, 69 monocots, and 305 dicots, from 262 genera (Takeuchi 2007). Similarly, a rapid biodiversity assessment of Kaijende Highlands in Enga found over 100 species of birds between 2000 and 3000 meters of elevation (Beehler & Sine 2007). Based on available information from the IUCN, it was possible to identify species in Enga province on the red list. Eight species (1 animal and seven plants) are critically endangered (CR), 26 (21 plants, three animals and two fungi) are endangered (EN), and 36 (23 plants and 13 animals) are vulnerable (VU).

There are currently no official protected areas designated within Enga province (**Figure 8**). Nevertheless, conservation initiatives exist in Enga during meetings with stakeholders, including Kazedi and Lembena conservation areas.

[4] Ibid.

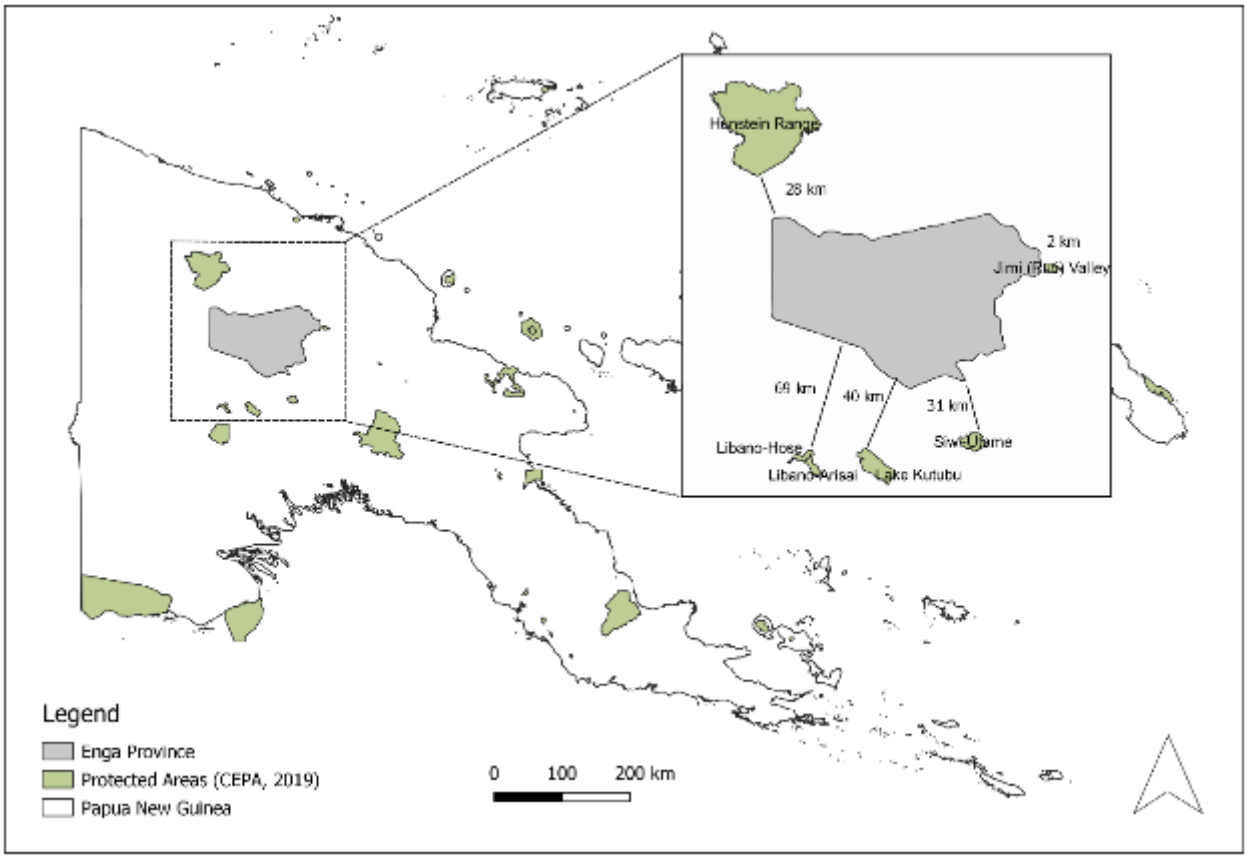

Figure 8. Protected areas near Enga Province (Source: UNEP-WCMC & IUCN 2022)

1.2.3 Deforestation and land-use drivers and barriers

From 2002 to 2020, PNG lost 777 000 hectares (ha) of humid primary forest, making up 51% of its total tree cover loss in the same period. The total area of humid primary forest in PNG decreased by 2.4% during this time. From 2001 to 2020, PNG lost 1.57 million ha (Mha) of tree cover, equivalent to a 3.7% decrease in tree cover since 2000 and 1.15Gt of CO_2e emissions. In PNG, from 2001 to 2019, 0.71% of tree cover loss occurred in areas where the dominant drivers of loss resulted in deforestation (GFW 2021)

Deforestation in PNG has been primarily driven by the conversion of forestland to cropland, accounting for 87% of deforestation. Of this, shifting agriculture is responsible for 63% of the land deforested and commercial agricultural developments, primarily in oil palm, are responsible for 30% of the deforested land. The trend in clearance for commercial agriculture has increased in the past decade following the rapid expansion of Special Agricultural Business Leases (SABLs), allocated over 5.1 million ha. While only a small number of these have initiated the development, and there has been an official moratorium and subsequent suspension, some logging and conversion have occurred. The figure below shows the primary drivers of deforestation and forest degradation in PNG.

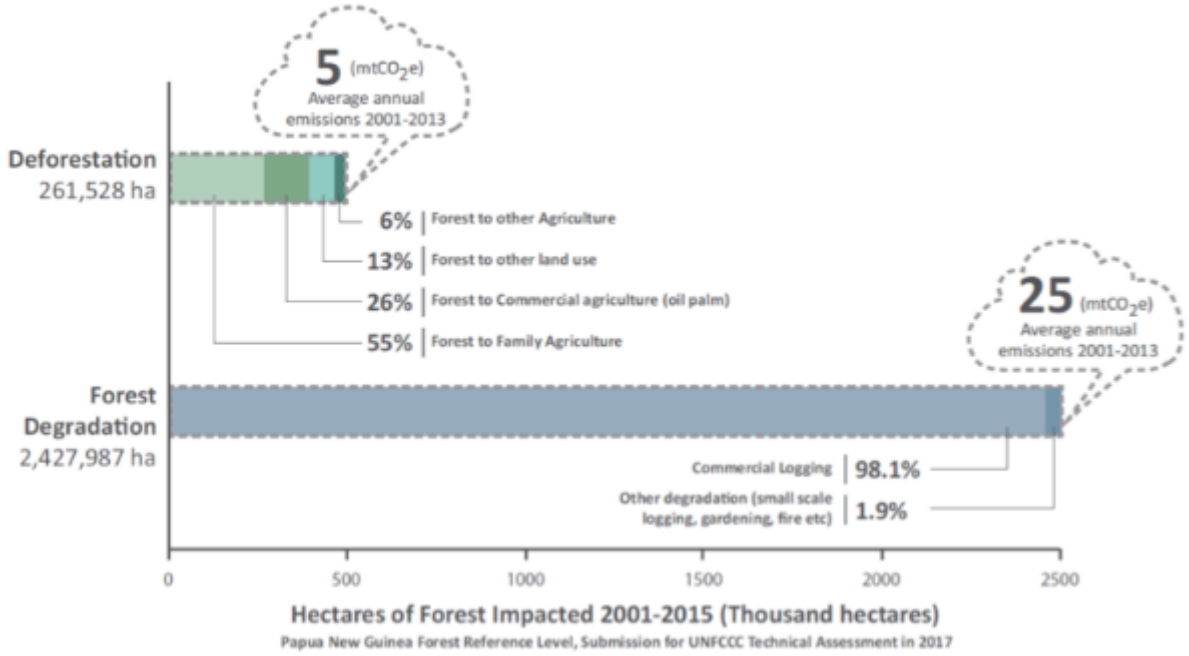

Figure 9. Primary drivers of forest cover change in Papua New Guinea (Government of Papua New Guinea 2017)

2 METHODOLOGY

2.1 Data collection on the ground

This section presents specific methods utilized for the baseline data collection/feasibility studies in Enga. The chapter discusses the survey tools, the data collection process, and the sampling issues. All survey tools are presented in **Annex 1**.

2.1.1 Survey tools

2.1.1.1 Focus group survey

Focus group discussions aimed at different groups such as farmers, coffee producers and women. The discussions aimed at revealing key information regarding climate change, food and nutrition, and biodiversity and conservation. The latter part included questions about deforestation and degradation processes, changes in vegetation and wildlife, and how climate change has affected their environment and economic activities. A photographic annex of the field survey is presented in **Annex 6**.

Figure 10. Farmers focus group held in Birib village (Source: FinnOC, 2022)

Figure 11. Women's focus group held in Pandai village (Source: FinnOC, 2022)

Figure 12. Coffee farmers participating to focus group survey in Mambisanda village (Source: FinnOC, 2022)

2.1.1.2 Household survey

The household (HH) surveys described the livelihoods of the households. The topics covered by the HH survey (Annex 1) included: (i) general information, (ii) household characteristics, (iii) agriculture, (iv) fishing, (v) food security, (vi) land-use change, forests and biodiversity and (vii) climate change. Regarding the land-use change, forests and biodiversity, the questionnaire aimed at revealing information regarding soil erosion and sedimentation, non-timber forest products and their uses, forest ownership, distance to forests, forest product markets, agroforestry, protected areas, land-use planning, deforestation and forest degradation, changes in vegetation cover and wildlife and more. Household surveys were conducted in each study village by interviewing both the male and female household members to gather gender data. The percentage of households selected for the study villages ranged between 10-40 per cent. A photographic annex of the field survey is presented in **Annex 6**.

Figure 13. A household survey was conducted in Pandai village (Source: FinnOC, 2022)

2.1.1.3 Provincial authorities' *discussion guideline*

The Consultant developed a discussion guideline to obtain information regarding the authority/ /organisations interviewed in Enga, including the type of work they do and the role related to study themes of climate change mitigation and adaptation, food and nutrition security and biodiversity and land/forest conservation; policies and strategies of the organisation and their relation to study themes, projects/interventions related to study themes, gender issues (organisations' gender focal point, constraints in reaching women and their empowerment, etc.). A photographic annex of the scoping mission is presented in **Annex 5**.

Figure 14. Interview with Environment/Climate Change Officer, Enga Provincial Government in Wabag (Source: FinnOC, 2022)

2.1.2 Sampling strategy

One team of Research Assistants (three females and two males), with the support of the Team, conducted the surveys in the field. The group surveyed two villages in every five districts. The selection of study villages was made together with the Client, advised by the Environment/Climate Change Officer of Enga Provincial Government.

The researchers conducted one focus group of smallholder farmers, one focus group of coffee producers, and one women's focus group in each surveyed village. Household surveys were conducted in each study village.

The team conducted the surveys from February 13 to March 6, 2022. The field work plan and schedule are presented in **Annex 2**. The list of people met during data collection is presented in **Annex 4**. Before the data collection, a village meeting/awareness of the upcoming survey was held in each surveyed village to explain the purpose of the survey to the village/community leaders and villagers in order to ensure smooth data collection. A photographic annexe of the field surveys is presented in **Annexes 5 and 6**, and a summary of the household characteristics is presented in **Annex 3**.

Figure 15. Community meeting held at Yakaedes village (Source: FinnOC, 2022)

The number of household surveys collected during the data collection trip totalled 456 households. There were ten women's focus groups, coffee farmers and farmers focus groups each, and six coffee farmers' focus group interviews.

Table 1. Sample sizes for study tools in Enga (Source: FinnOC, 2022)

Kandep	Luguteges	27	1	1	-
	Pindak	34	1	1	-
Kompiam	Pandai	38	1	1	1
	Par	64	1	1	1
Lagaip-Porgera	Naglum	36	1	1	-
	Tukusanda	43	1	1	-
Wabag	Birip	68	1	1	1
	Lukitap	43	1	1	1
Wapenamanda	Mambisanda	50	1	1	1
	Yaekadis	53	1	1	1
Grand Total		**456**	**10**	**10**	**6**

Coffee is not grown in the study villages of Luguteges, Pindak, Naglum and Tukusanda, and therefore the coffee farmers' surveys were not conducted in these villages

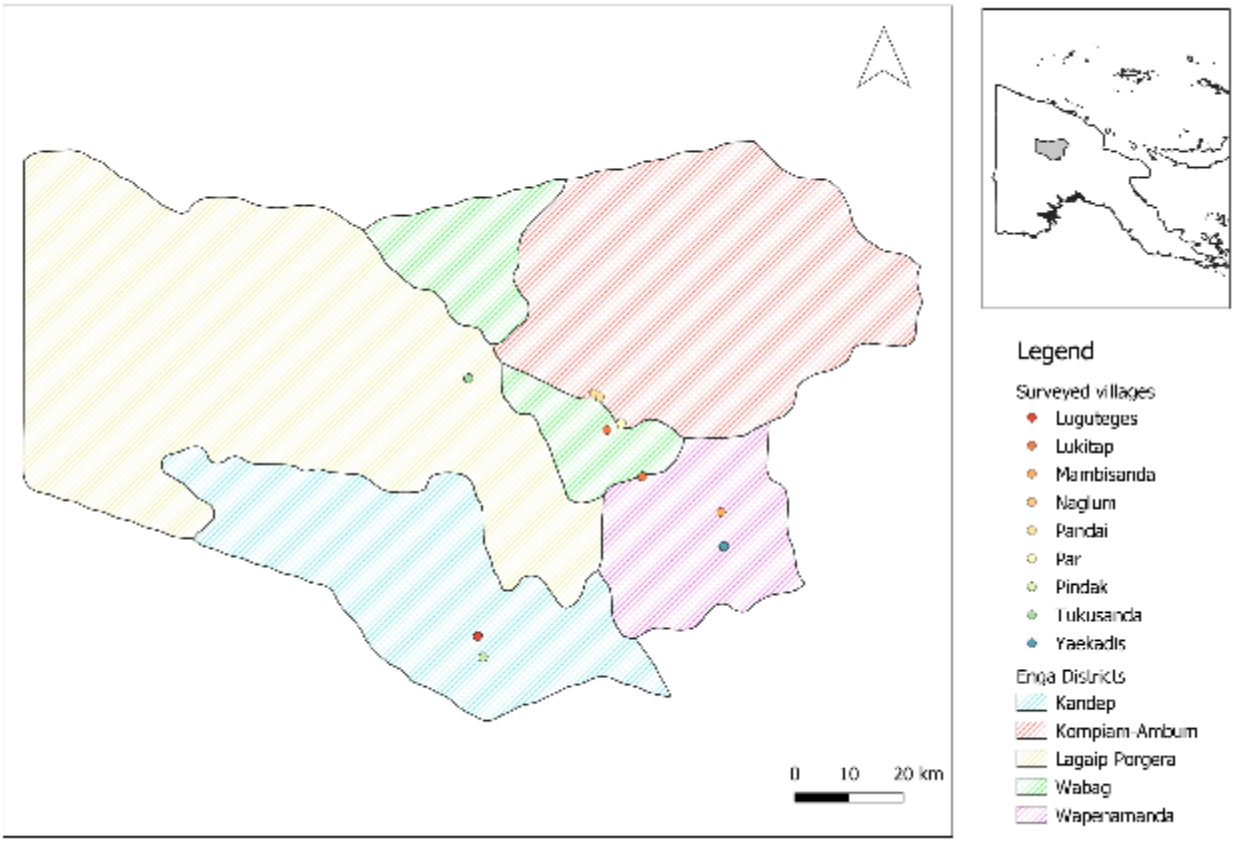

Figure 16. Location of the study villages in Enga Province (Source: FinnOC, 2022)

2.2 Scoping biodiversity, land use and forests in Enga province

The Consultant carried out a background literature review for the project. The team reviewed in detail all the available existing documentation generated by the client or by third parties, including background and preliminary studies carried out in Enga province. The documentation includes provincial development plans, national legislation, previous feasibility studies, alternatives analysis, social studies and any other related studies.

One of the products of major importance to be generated during this stage is the identification of information gaps (Gap Analysis), which will be directed to the search and identification of key aspects necessary for the development of the study. The present scope assumes that all necessary information that serves as input for the development of deliverables, other than the one that will be compiled in the field, and the one that is explicitly requested to be generated, will be delivered promptly by the client.

The Consultant carried out spatial analysis using available spatial information, which includes the identification of relevant environmental variables in Enga Province. **Table 2** summarizes some of the environmental variables used, which will serve as input for the spatial analyses and scoping. Some environmental layers are available at broad scales (e.g. regional scale), whereas others are finer

scales (e.g. landscape scale). **Figure 17** shows examples of some physical, biological and social variables in the study area.

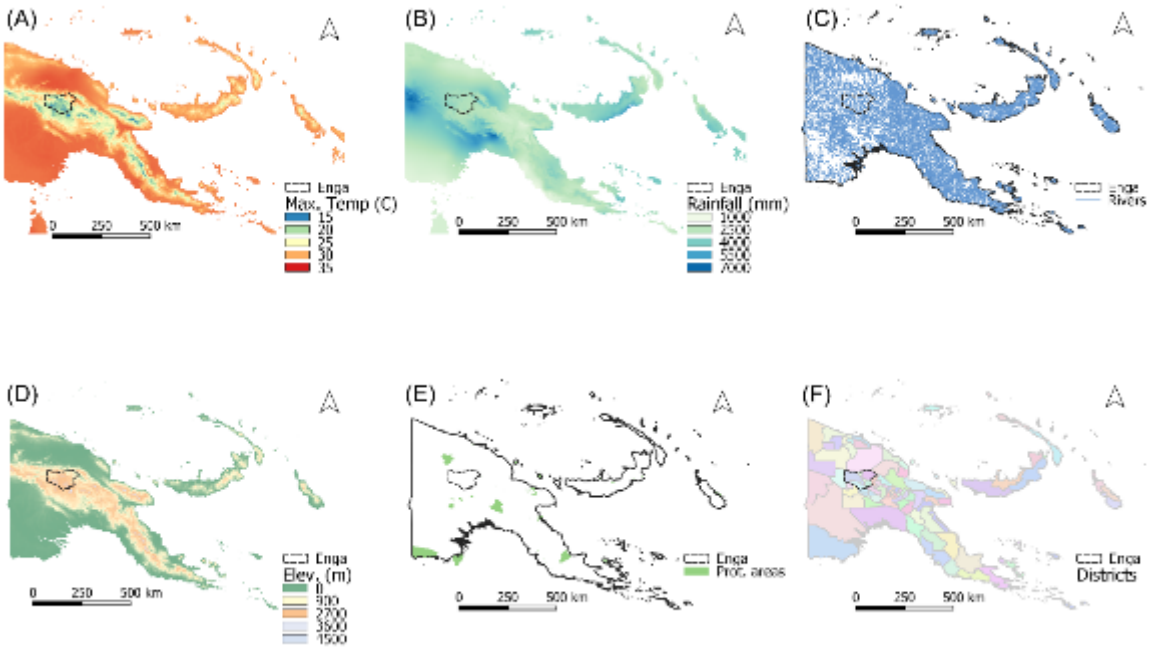

Figure 17. Examples of environmental conditions in Enga Province. (A) maximum temperature (°C), (B) annual rainfall (mm), (C) water bodies and river network, (D) elevation data from SRTM (Earth Resources Observation And Science (EROS) Center 2017), (E) protected areas, and (F) Administrative divisions. Climate data was downloaded from CHELSA-climate (Karger et al. 2017), elevation data from SRTM (Earth Resources Observation And Science (EROS) Center 2017), and water data from DCW (Digital Chart of the World, administrative divisions from GDAM.

Figure 18. FinnOC's local team with the UNDP Team in Wabag Town, Enga and the location of the Provincial Government Building Ipatas (Source: FinnOC, 2022)

Table 2. Geographical scale and type of environmental variables proposed for the environmental scoping and GIS analysis.

Scale	Group	Variable	Type
Regional-scale	Physical	Soils	Vector / Raster
		Elevation	Raster
		Monthly rainfall	Raster
		Monthly temperature	Raster
		Bioclimatic layers	Raster
	Biological	Vegetation cover	Raster
		Forest cover	Raster
		Conservation areas	Vector
	Social	Administrative areas	Vector
Landscape-scale	Physical	Digital elevation model	Raster
		Slope and hill-shade	Raster
		Soil chemical properties	Raster
		Soil physical properties	Raster
		Land cover classes	Raster
	Biological	Tree cover	Raster
		Species occurrence	Vector
	Social	Annual deforestation	Raster

3 REVIEW OF IMPROVED BIODIVERSITY AND LAND/FOREST ECOSYSTEMS CONSERVATION, RESTORATION AND SUSTAINABLE USE

3.1 Review of the forest sector in PNG

Three sectors in Papua New Guinea (PNG) make up the bulk of the economy, with agriculture comprising 18.4% of Gross Value Added (GVA), industry at 36.8%, and services contributing the largest share to GDP at 44.9% (UN 2021). Of these sectors, only agriculture represents almost 60% of the employment. In rural areas, agriculture, fishing, and community forestry are primary livelihood activities (World Bank 2021). The formal economy (15% of employment) in PNG is mainly dominated by large-scale extractive industries (mining and oil). In contrast, the informal economy (85% of the workforce) is dominated by semi-subsistence agriculture (Government of Papua New Guinea 2014b). Approximately 80% of the population of PNG lives in rural and remote coastal communities, making them highly vulnerable to the impacts of climate change (CFE-DM 2019). Even though PNG has around 36.1 million hectares (ha) of forested land (78% of the total land area), the forest sector barely contributes to PNG's economy.

PNG is prone to myriad natural hazards, and climate variability and change may increase their incidence. Some of these include landslides, soil erosion, deforestation, loss of biodiversity, as well an increased occurrence of recurrent floods and droughts (World Bank 2021). Climate change impacts already affect the main economic sectors in PNG, including agricultural production, infrastructure, water resources, public health, energy and availability of ecosystem goods and services (World Bank 2021). Adaptation strategies, therefore, have focused on agriculture and water resources management (Government of Papua New Guinea 2014b).

Forests cover around 78% of the PNG's land (**Figure 19**). Forests in PNG are defined as "land spanning more than 1 hectare, with trees higher than 3 meters and the canopy cover of more than 10 per cent (%)" (Climate Change and Development Authority 2017b). From 2002 to 2020, PNG lost 777kha of humid primary forest, making up 51% of its total tree cover loss in the same time period. The total area of humid primary forest in PNG decreased by 2.4% in this time period. From 2001 to 2020, PNG lost 1.57Mha of tree cover, equivalent to a 3.7% decrease in tree cover since 2000, and 1.15Gt of CO_2e emissions. In PNG, from 2001 to 2019, 0.71% of tree cover loss occurred in areas where the dominant drivers of loss resulted in deforestation (GFW 2021)

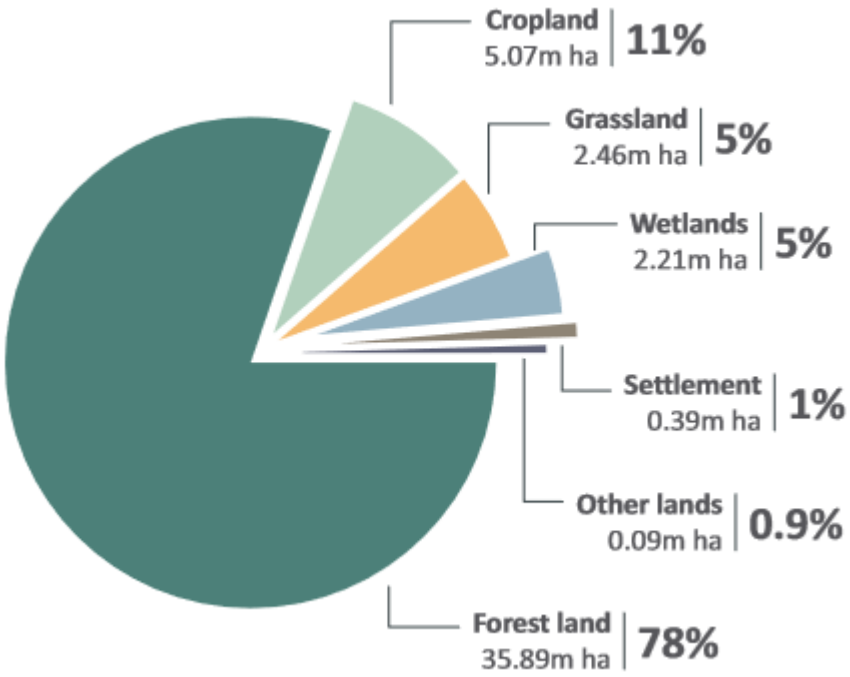

Figure 19. Land cover in PNG (Climate Change and Development Authority 2017b)

Deforestation in PNG has been primarily driven by the conversion of forestland to cropland, accounting for 87% of deforestation. Of this, shifting agriculture is responsible for 63% of the land deforested and commercial agricultural developments, primarily in the form of oil palm, are responsible for 30% of the deforested land. The trend in clearance for commercial agriculture has increased in the past decade following the rapid expansion of Special Agricultural Business Leases (SABLs), which were allocated over 5.1m ha. While only a small number of these have initiated the development, and there has been an official moratorium and subsequent suspension of them, some logging and conversion have occurred. The figure below shows the primary drivers of deforestation and forest degradation in PNG.

3.2 Importance of the forest sector in mitigation and adaptation strategies

In the Climate Compatible Development Strategy (CCDS) (Government of Papua New Guinea 2014a), it is recognized that climate change mitigation and adaptation must be coupled with economic development to ensure (i) promotion of economic development through low-carbon growth, (ii) mitigation through participation in the global REDD+ scheme, and (iii) adaptation to climate change-related hazards. Some priority abatement options that the forest sector can offer include: (a) Reduced impact logging (RIL), (b) Secondary forest management, (c) Afforestation/reforestation, (d) Community REDD+ schemes, (e) Land use planning and (f) Commercial plantation on non-forest land. The potential emission reduction adds up to around 107Tg

(or Mt) of CO_2 equivalent for the LULUCF-sector and an additional 25Tg for the other sectors for the year 2030. This would mean a 60-80% reduction compared to the business as usual (BAU) scenario.

PNG's commitment to adaptation for 2020-2030 will focus on four priority development sectors: agriculture, health, transport, and infrastructure. In contrast, mitigation actions will focus on the energy sector, land use, land-use change, and forestry sub-sector (LULUCF) (Climate Change and Development Authority 2020). Mitigation actions by 2030 in the LULUCF sub-sector will be based on: (i) a 25% reduction in annual deforestation, (ii) a 25% reduction in annual forest degradation and (iii) an increase in forest plantation and enhancement of ecosystem restoration (**Figure 20**).

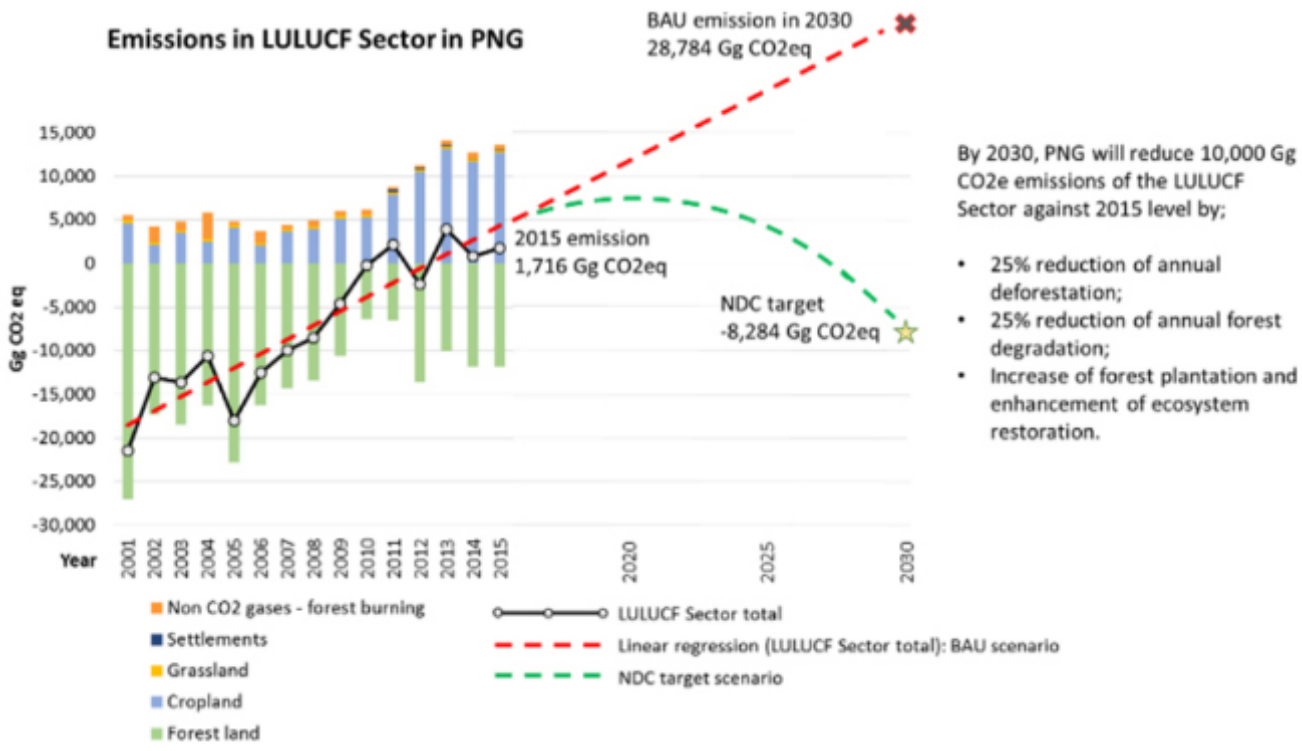

Figure 20. Emissions in the land use, land-use change and forestry sub-sector (Climate Change and Development Authority 2020)

Adaptation actions will be directed to nine priority areas: (i) Coastal Flooding and Sea Level Rise, (ii) Inland Flooding, (iii) Food Insecurity caused by crop failures due to droughts and inland frosts, (iv) Cities and Climate Change, (v) Climate-Induced Migration, (vi) Damage to Coral Reefs, (vii) Malaria and Vector-Borne Diseases, (viii) Water and Sanitation and (ix) Landslides (Climate Change and Development Authority 2020). Adaptation actions in the Enhanced NDC in PNG (Climate Change and Development Authority 2020) also include ecosystem and forest rehabilitation as well as forest plantations.

Mitigation and adaptation measures in the forest and biodiversity priority sectors in PNG include the conservation of intact forest landscapes, National Parks and Wildlife Management Areas. This is key to biodiversity conservation and serves to cope with climate change challenges as well (Government

of Papua New Guinea 2014b). Next to strengthening the protection of these areas, especially community participation in forest management should be enhanced.

Based on the Intended Nationally Determined Contribution (INDC) submitted Under the United Nations Framework Convention on Climate Change (UNFCCC) (Government of Papua New Guinea 2015a), mitigation opportunities can also be achieved through the Forest sector. PNG has extensive forest areas that present opportunities for mitigation, particularly through reducing emissions from deforestation and forest degradation (REDD). Besides reduction through REDD, other measures include supporting sustainable management, conservation and enhancement of forest carbon stocks. Similarly, different priorities related to climate change in Papua New Guinea were recently identified (Global Green Growth Institute 2019), including the forest sector. Conserving the country's extensive forests is a key priority in climate change due to their global significance for carbon storage, their role in sustainable agriculture, their provision of ecosystem services, and their economic potential.

In its Vision 2050 (Government of Papua New Guinea 2015b), the GoPNG developed seven Strategic Focus Areas (SFA): (i) human capital, development, gender, youth and people empowerment, (ii) wealth creation, natural resources and growth nodes, (iii) institutional development and service delivery, (iv) security and international relations, (v) climate change and environmental sustainability, (vi) spiritual, cultural and community development, and (vii) strategic planning, integration and control. The context of the project "*Consultancy Services to undertake feasibility studies on climate change, food and nutrition security, conservation and land-use in Enga Province of Papua New Guinea*" fall into the SFA-5: Environmental Sustainability and Climate Change. The following table summarizes the main objectives, outcomes, and key performance indicators (KPI) of SFA-5:

Table 3. Strategies for Strategic Focus Area Five: Environmental Sustainability and Climate Change (Government of Papua New Guinea 2015b)

Objective	Activity	Outcome	Indicator	Evaluation
Sustainable development measures developed in all sectors to increase resilience to the impacts of climate change and environmental changes	Develop appropriate adaptation and mitigation strategies for climate change and environmental changes	Sound policy and legal framework for the sustainable management of natural resources and mitigating climate change and hazards	(i) Less logging for exports, (ii) Communities' resilience is enhanced in villages, (iii) Sustainable development policies completed, (iv) Oceans and marine and terrestrial areas protected, (v) Forests are protected and sustained	(i) Legal cases and reports on the environment, (ii) Increased forests, and land-use areas designated for carbon opportunities, (iii) Large renewable energy projects developed
Conserve and use our natural resources and environment for the collective benefit and for future generations	Strengthen research and develop infrastructure, capacity and programs	World-class education, research, and sustainable management of natural resources and mitigating climate change	(i) 70% of PNG forests are conserved and managed for carbon trade purposes, (ii) Oceans and land resources are managed, (iii) Mitigation measures for all forms in industries, mining, energy and waste	(i) Community and stakeholder feedback on services, (ii) Policies implemented
Converse and wisely use our natural resources and environment, language and cultural diversity for the collective benefit of the present and future generation	Develop policies and organizational structures to address climate change and sustainable development. Develop enabling policies through legal instruments.	Sound institutional framework for sustainable management of natural resources and mitigating climate change. Develop an inventory of biodiversity, language and cultural diversity	(i) Professional competence and world standard research programs on environment and climate change, (ii) Increased tourism sector's contribution to GDP	(i) National and international environment and Management and research, (ii) BPNG Economic Bulletin Quarterly Reports

Effective partnership and cooperation with the international community on environmental sustainability and climate	Identify strategic partners and develop programs that strengthen partnership arrangements	Participate in and benefit from international environmental sustainability and climate change arrangements.	Adherence to international agreements	Reports from respective departments and institutions

3.3 The roles of the forest sector and conservation as mitigation and adaption measures in Enga province

All mitigation and adaptation measures are proposed at the national level (Government of Papua New Guinea 2010; Government of Papua New Guinea 2014b; Government of Papua New Guinea 2015b; Government of Papua New Guinea 2015b; Government of Papua New Guinea 2015a) are not necessarily applicable at the regional and provincial level (Global Green Growth Institute 2021). For instance, coastal flooding, sea-level rise, acidification, and cyclones are not relevant in Enga Province or the other Highlands provinces. Fortunately, recent studies have assessed climate change impacts in the highlands and particularly in Enga Province (Enga Provincial Disaster Committee 2015; National Disaster Centre 2015; Global Green Growth Institute 2021)

Table 4. Climate change impacts in Enga Province (Adapted from Enga Provincial Disaster Committee 2015; Global Green Growth Institute 2021)

Phenomenon	Confidence	Description
Rise in temperature	Very high	Decreased yield and quality of agricultural crops Increase in vector-borne and respiratory diseases Reduced habitat of montane bird species
Change in rainfall	High	Increase in flooding and damage to infrastructure Decrease in agricultural productivity Increase in vector and water-borne diseases
Occurrence of landslides	High	Decrease in agricultural productivity Reduced access to drinking water and reduced food security
Occurrence of drought events	Medium	Decrease in agricultural productivity Reduced access to drinking water and reduced food security
Occurrence of frost events	Medium	Decreased yield and quality of agricultural crops Reduced food security
The rise in sea level	Very high	Not relevant for Enga Province
Increase in ocean acidity	Very high	Not relevant for Enga Province
Occurrence of cyclones	Medium	Not relevant for Enga Province

The main climate change phenomena that will derive in impacts in Enga province are (i) rise in temperatures and (ii) changes in rainfall patterns. These changes will increase the occurrence of droughts, frost events, floods and landslides in a spatially differentiated manner throughout Enga province. Some mitigation and especially adaptation measures in the forestry sector and conservation at the provincial level in Enga are shown in the table below.

Table 5. Potential mitigation and adaption alternatives in Enga province

Measures type	Priority sectors/areas	Potential measures
Mitigation	Forestry / Biodiversity	- Conserve and protect local forests and shrublands - Implementation of sustainable forest management (SFM) and reduced impact logging (RIL) - Reduced Deforestation and Forest Degradation (REDD) schemes - Sustainable and participatory land-use planning - Increase forest areas through forest plantations - Reforest marginal agricultural land and degraded areas
Adaptation	Forestry / Biodiversity	- Construction of nature-based solutions such as flood defences using bamboo species or native tree species - Vegetation management on the side roads - Supporting water-conserving technologies and water harvesting initiatives by afforestation and reforestation initiatives in the higher watersheds. - Planting of trees to create shade.

4 ANALYSIS OF BIODIVERSITY, LAND-USE AND FOREST ECOSYSTEMS

4.1 Field surveys regarding biodiversity, land use and forests

The consultant collected data using different study tools (household surveys, focus groups and discussion guidelines) to uncover the issues related to biodiversity, forests and conservation in Enga Province. **Annex 1** presents each of the questionnaires used. A photographic annexe of the scoping mission is presented in **Annex 5**, and photos of the field survey in **Annex 6**. The field work plan and schedule are presented in **Annex 2**. The list of people met during data collection is presented in **Annex 4**.

4.1.1 Household survey results

Most of the respondents throughout Enga province (Kandep, Kompiam, Lagaip-Porgera, Wabag and Wapenamanda districts) practice agroforestry (**Figure 21**). Common trees used in agroforestry include casuarina trees (*Casuarina spp.*), yar (*Casuarina oligodon*), tanget (*Cordyline fruticosaguava*), avocado (*Persea spp.*), pandanus (*Pandanus sp.*), guava (*Psidium sp.*), gumtree and eucalyptus (*Eucalyptus spp.*) among others. Different cash crops and other crops are mixed with trees in Enga, including taro, coffee, banana, kaukau, beans, etc.

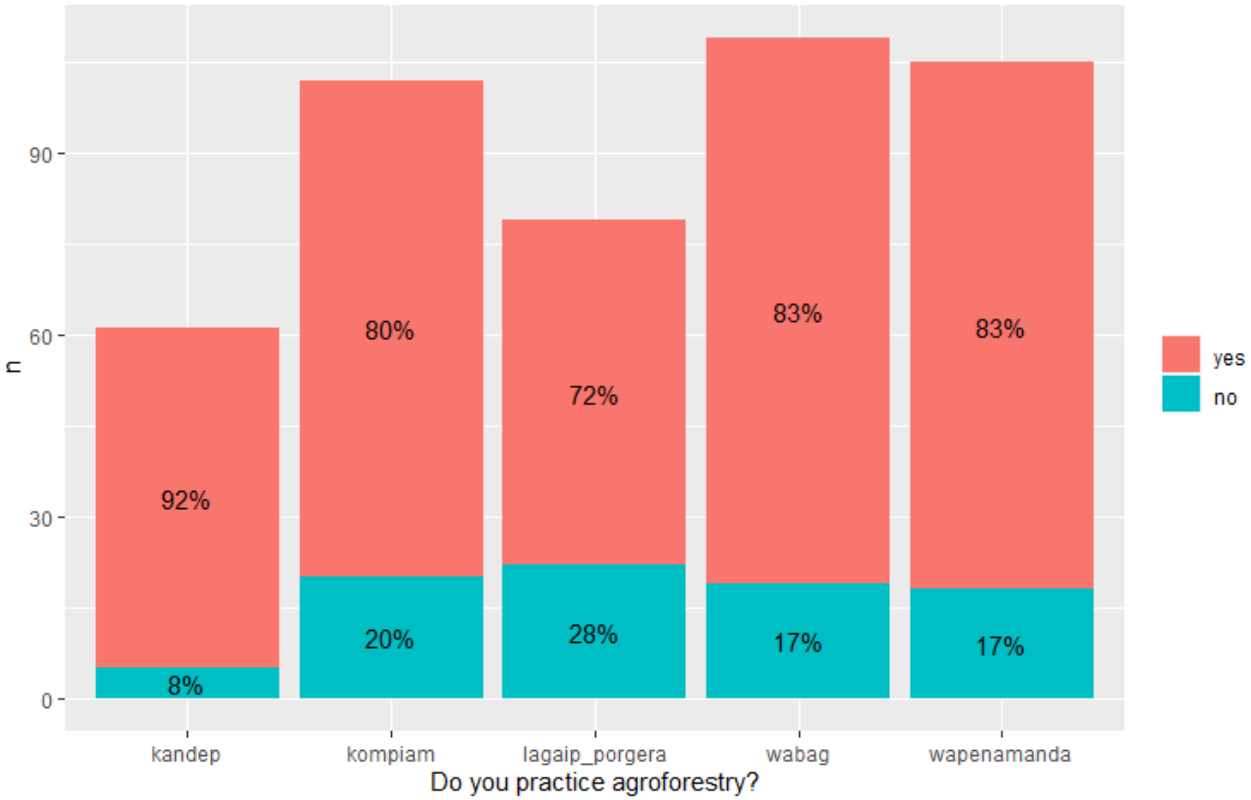

Figure 21. Agroforestry practices (Source: FinnOC, 2022)

In Kandep, Kompiam and Lagaip-Porgera districts, most of the respondents mentioned that there are protected areas near their villages (**Figure 22**), whereas, in Wabag and Wapenamanda, around 50% of the participants claimed to have protected areas near their villages. Even though there are no official protected areas in Enga, this shows the local people's perceptions on rather the status of the nearby forests. Nevertheless, an important proportion of the respondents state that there are not enough protected areas (**Figure 23**).

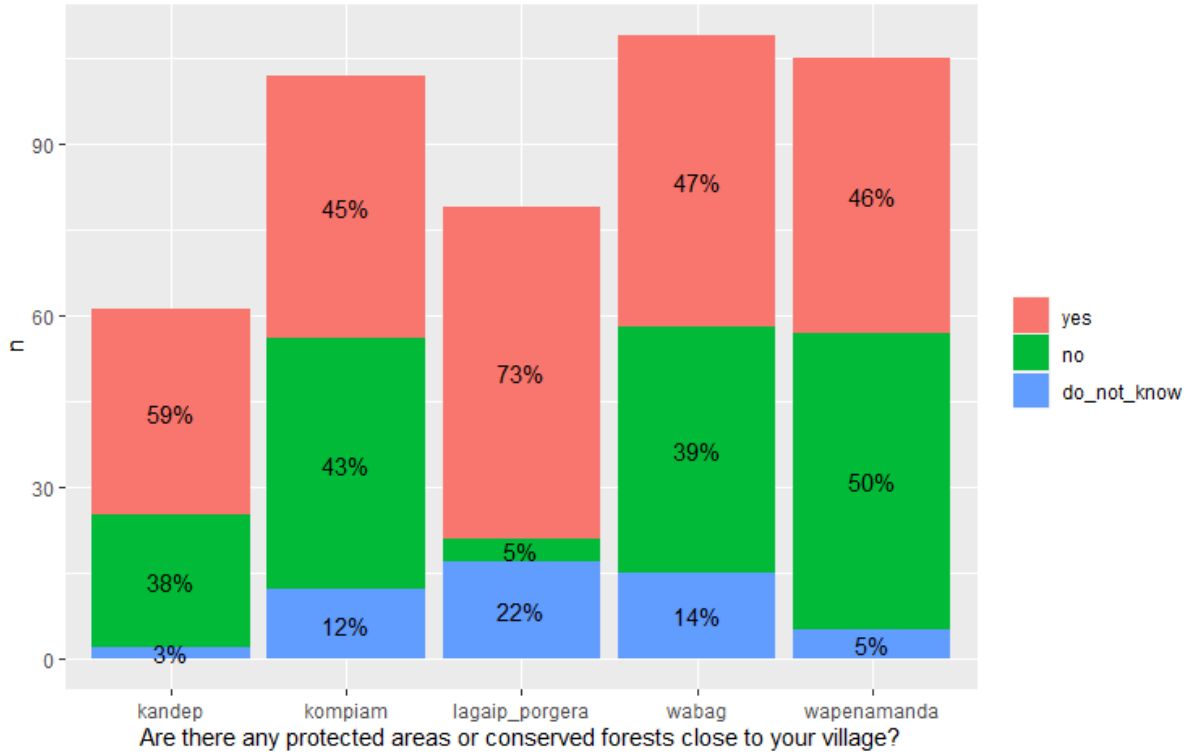

Figure 22. Perceptions of the presence of protected areas near the respondent's villages (Source: FinnOC, 2022).

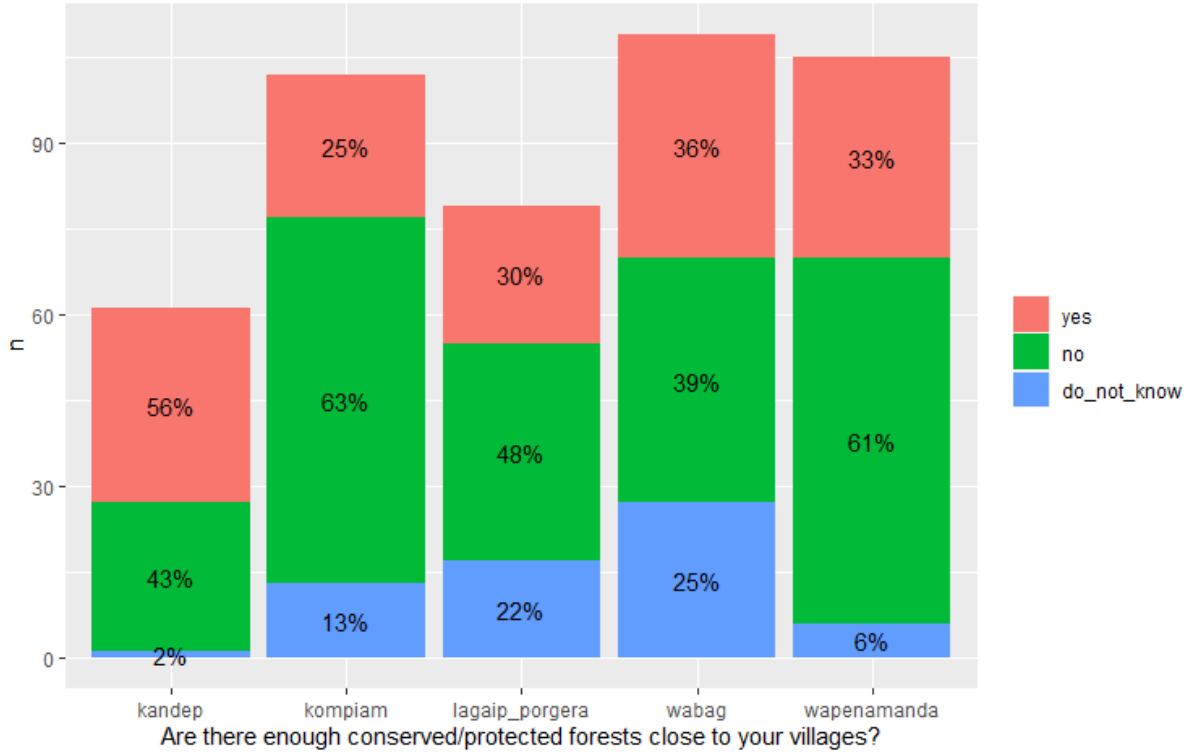

Figure 23. Sufficiency of protected areas (Source: FinnOC, 2022)

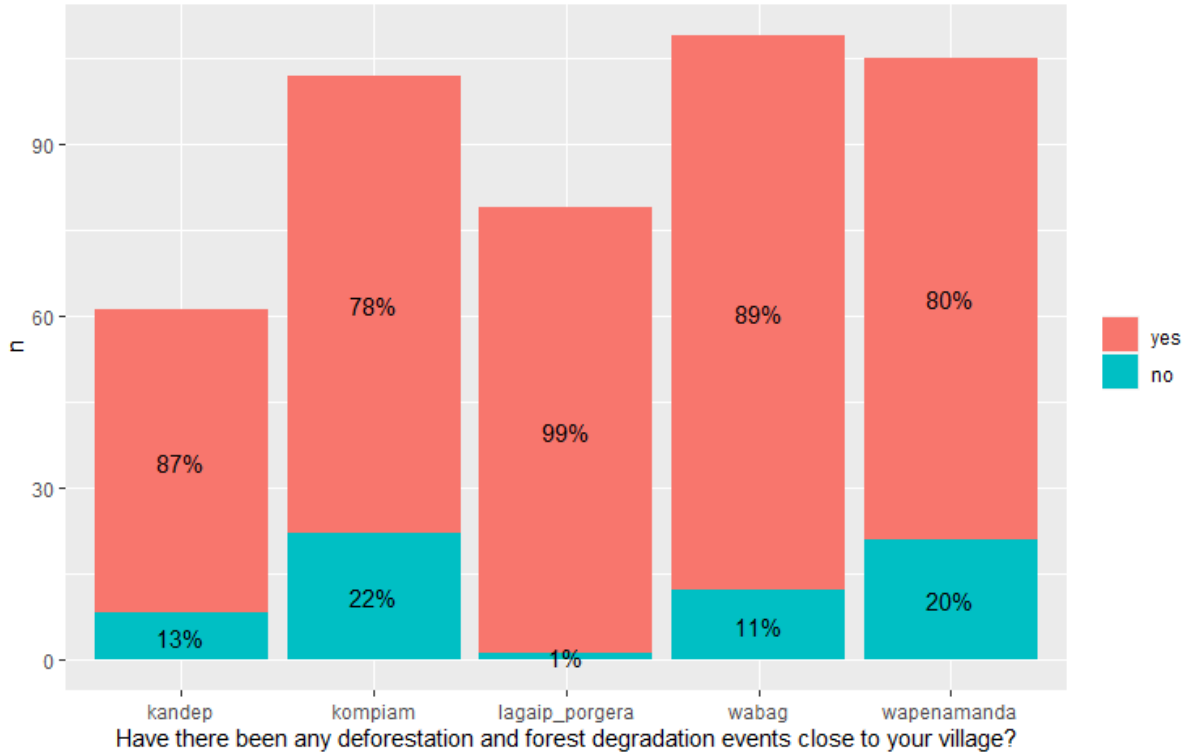

Figure 24. Perception of deforestation and degradation (Source: FinnOC, 2022)

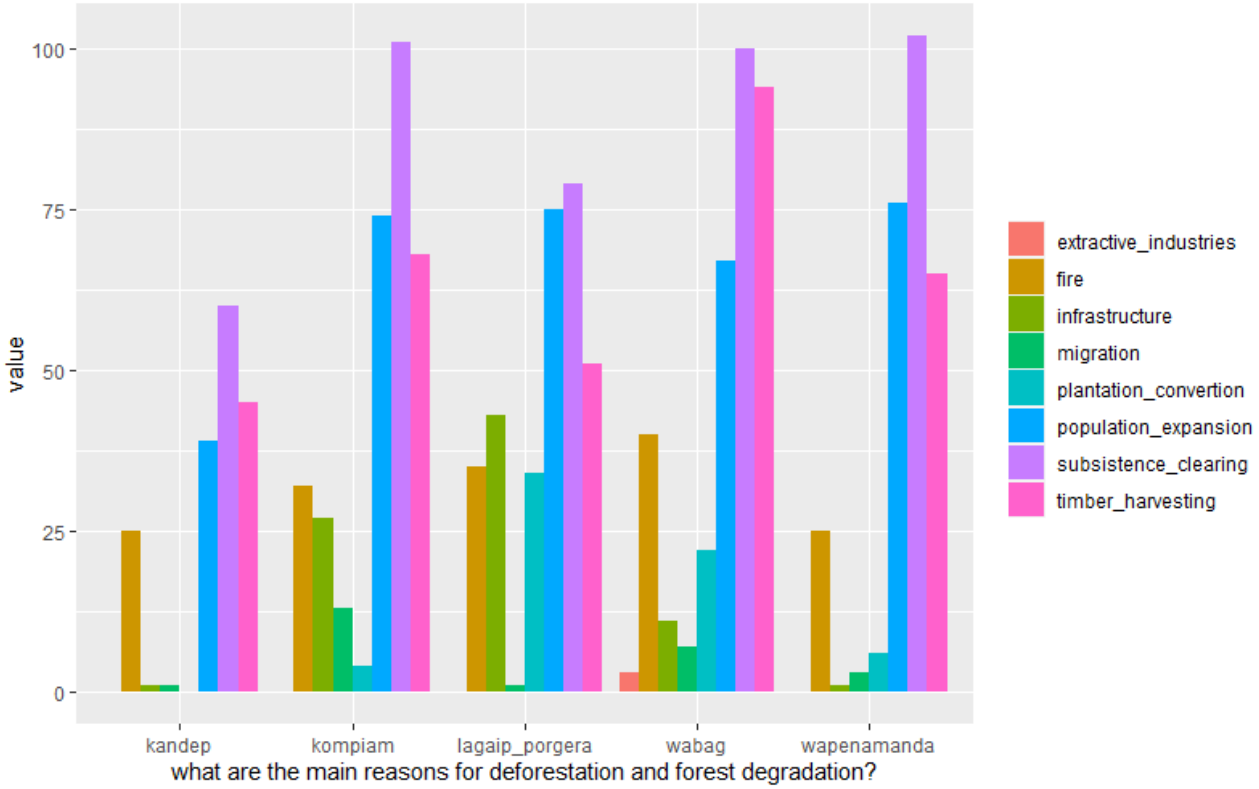

Figure 25. Reasons for deforestation and forest degradation (Source: FinnOC, 2022)

Based on the household interviews, it was clear that deforestation and forest degradation events are common in the five Enga districts (**Figure 24**). The main reasons for deforestation and forest degradation are subsistence clearing, population expansion and timber harvesting (**Figure 25**).

When enquired whether forest areas were near their villages, most of the participants in all districts mentioned that they were close, meaning reachable within hours, followed by "far" (less than one day to reach). In Wabag and Wapenamanda, an important proportion of the respondents also mentioned that forest areas were relatively close (less than an hour) to the villages (**Figure 26**).

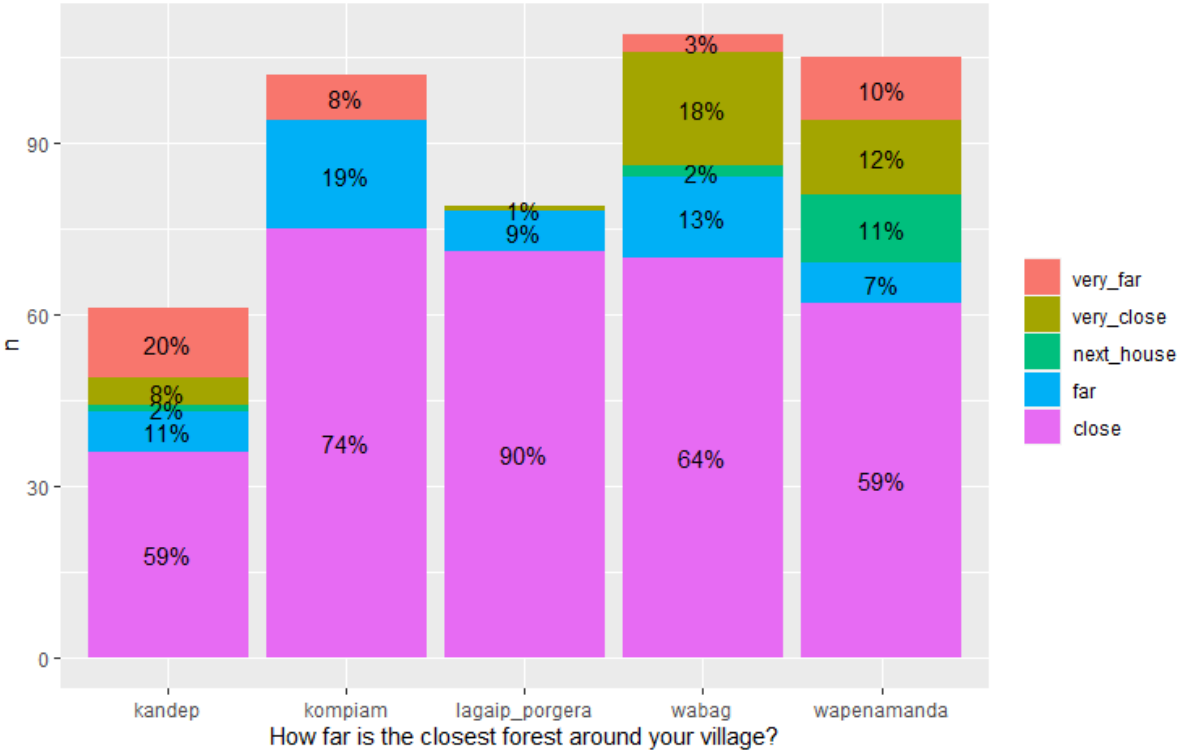

Figure 26. Distance to the nearest forest (Source: FinnOC, 2022)

Land-use planning seems to be a common practice in Kandep, Kompiam, Lagaip-Porgera and Wabag (**Figure 27**), but it is less practised in Wapenamanda. Community and family planning is part of the daily activities in Enga province. Common practices in the province include slash and burn (clearing forests) for creating new gardens, as well as mixed cultivation, crop rotation and drainage systems. Most of the native plants are used as building materials and food in all districts (**Figure 28**).

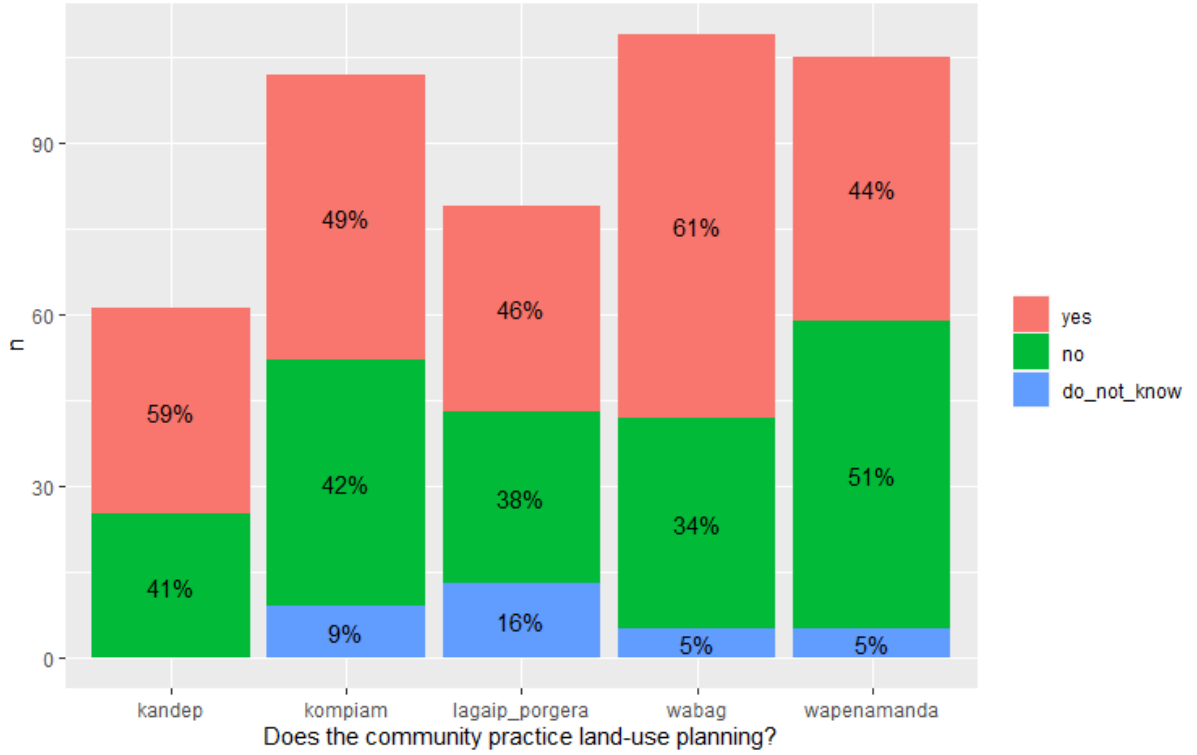

Figure 27. Land-use planning practice (Source: FinnOC, 2022)

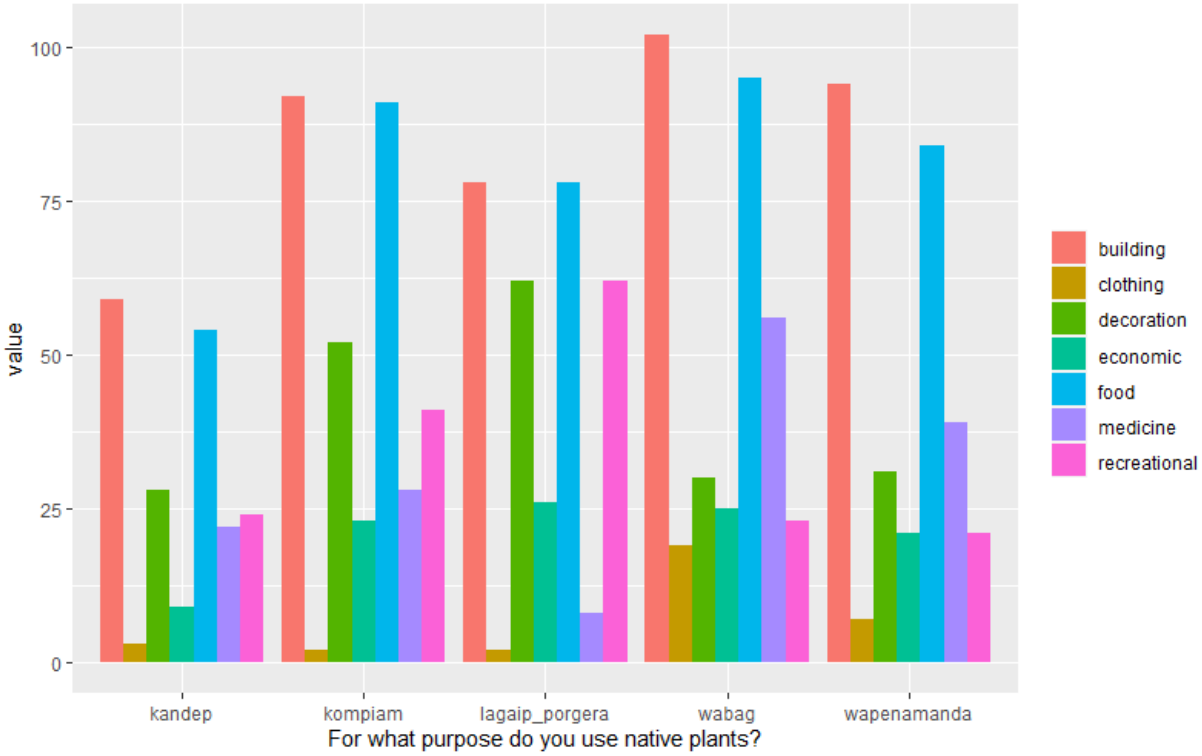

Figure 28. Use of native plants (Source: FinnOC, 2022)

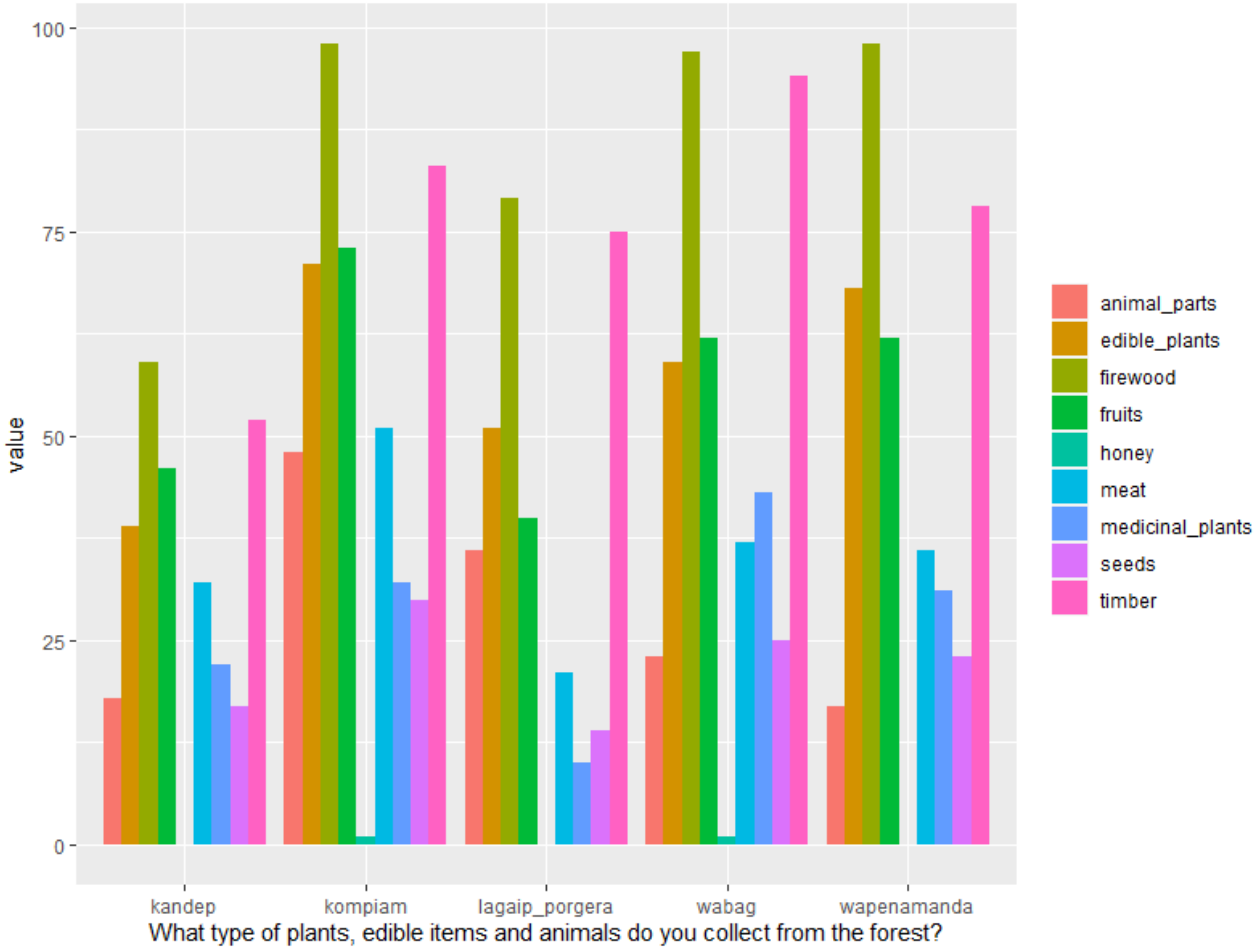

Figure 29. Forest products (Source: FinnOC, 2022)

A big proportion of forest resources are collected for firewood and timber, followed by edible plants and fruits (**Figure 29**). These products are mainly for self-sustaining families. Nevertheless, some of these (firewood, fruits, etc.) are also sold in markets, but seldomly throughout the year (**Figure 31**). In most of the provinces in Enga, forests are mainly owned by the community or families (**Figure 30**).

Most participants in Enga districts have experienced a reduction in vegetation cover (**Figure 32**) and wildlife (**Figure 33**). These patterns mainly increase due to the economic activities, including housing, farming and gardening.

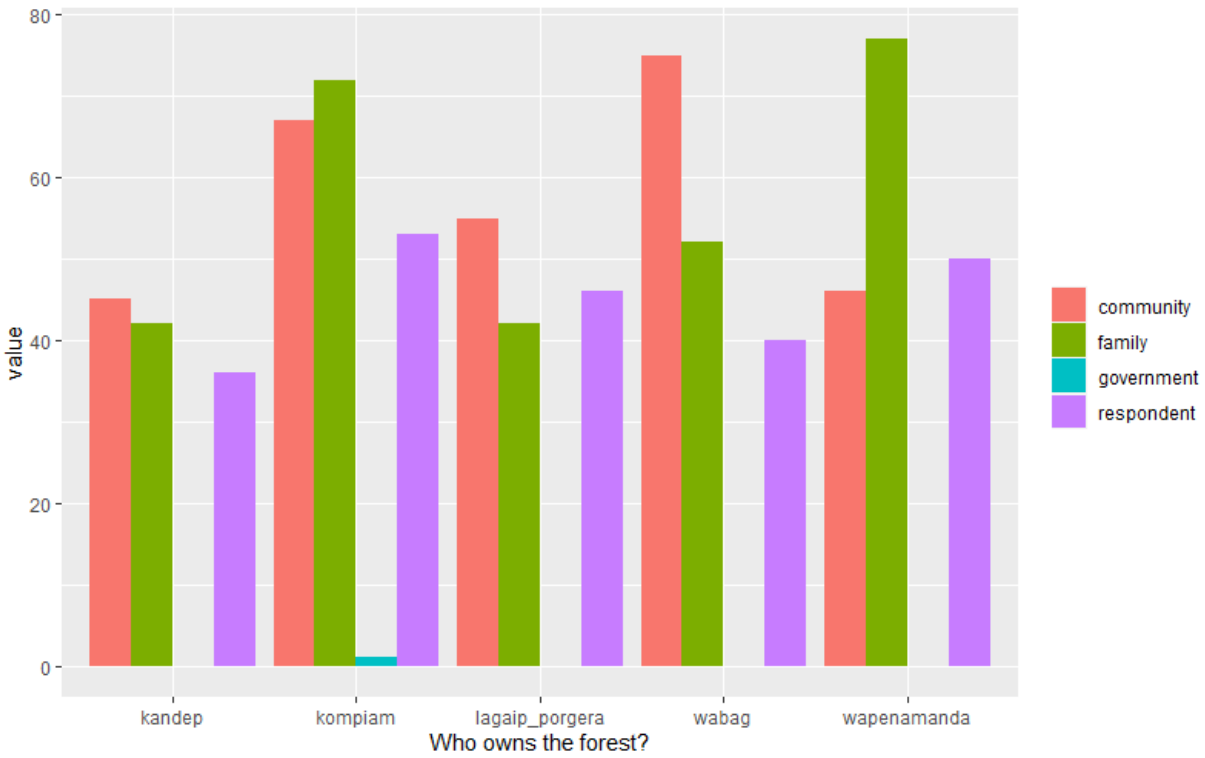

Figure 30. Forest ownership (Source: FinnOC, 2022)

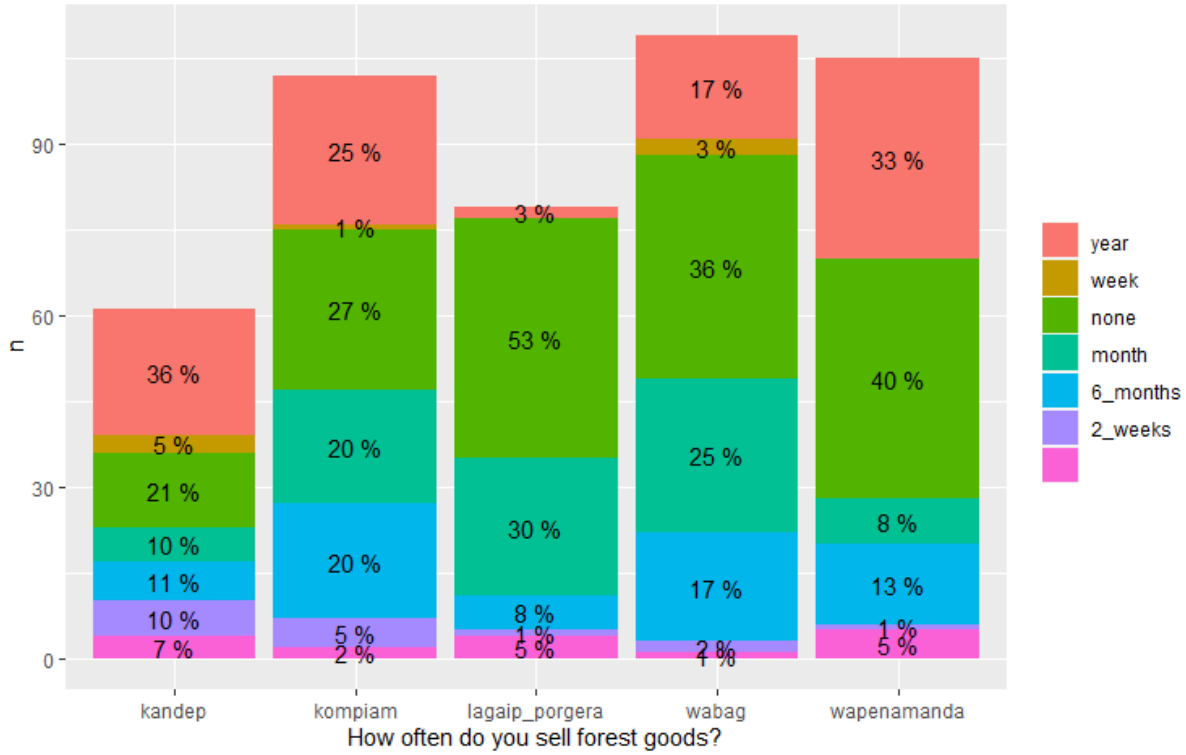

Figure 31. Forest product sales (Source: FinnOC, 2022)

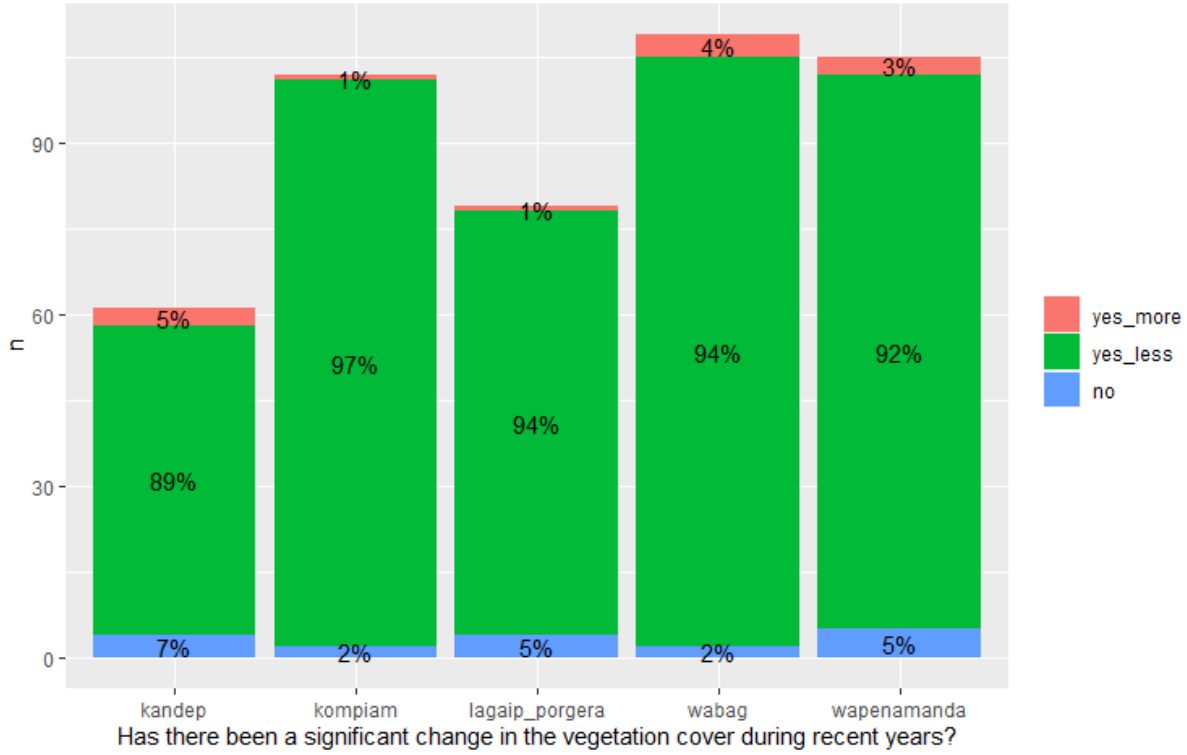

Figure 32. Changes in vegetation cover (Source: FinnOC, 2022)

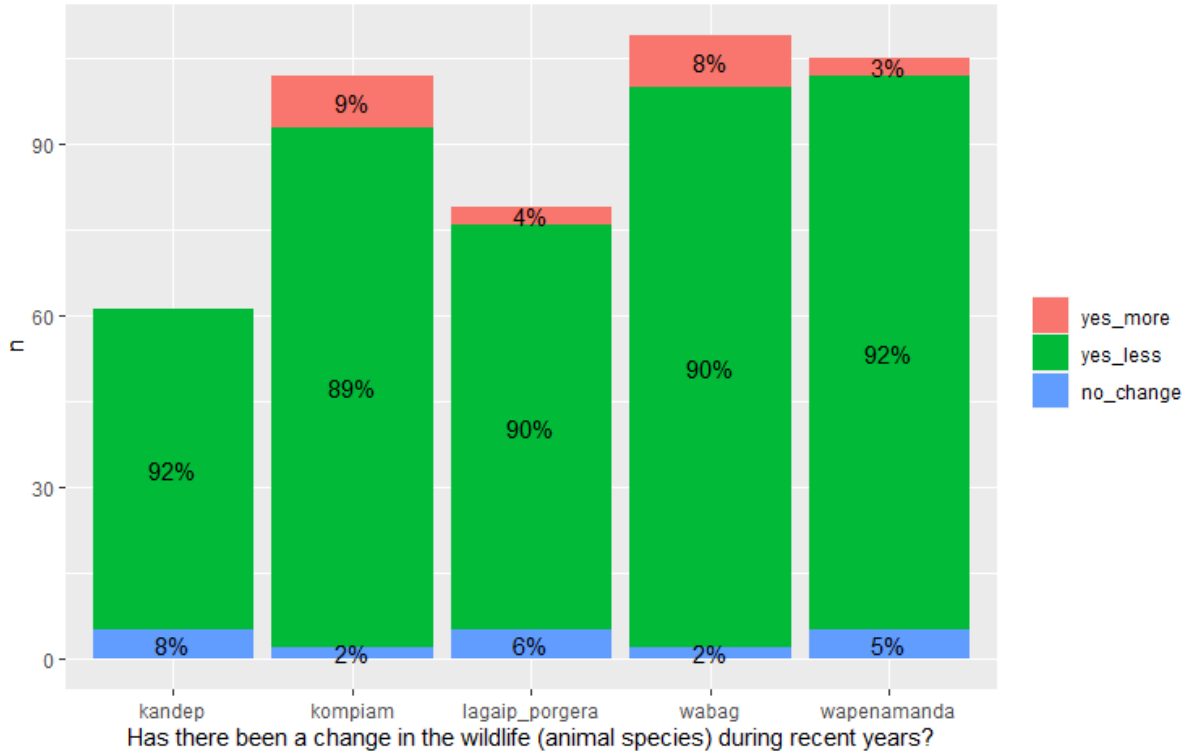

Figure 33. Changes in wildlife (Source: FinnOC, 2022)

4.1.2 Focus group results

During the focus group discussions (with farmers, coffee producers and women), the participants addressed climate change perceptions and their impact on agriculture, different adaptation and mitigation actions practices in each of the five districts visited, as well as the main struggles and needs for capacity building. **Table 6** shows the main results of the focus group discussions that took place in the ten villages throughout Enga districts.

Table 6. Results of the focus group discussions

Climate change perceptions	Climate change adaptation and mitigation actions	Main issues/struggles	Capacity building necessities
Variations in temperature and rainfall patterns were throughout the study villages More pests affecting crops (coffee, cash crops) Coffee quality is more variable nowadays and is overall reduced. Decrease in crop yields Fewer food supplies More soil erosion and waterlogging Road deterioration / transportation issues Difficulties in drying coffee beans and fibre preparation (bilums) under continuous heavy rainfall	No specific actions were stated since traditional farming is the main method they continue using Agroforestry is practised in many villages Construction of small drainage systems (during heave rainfall events) Stock food supplies to prepare for natural disasters (e.g., frost events) Mixed cropping and crop rotation People usually have multiple gardens as a storage strategy Food surplus stored and preserved New crops (e.g., carrot, broccoli)	More pests affecting coffee plants and crops Low prices in crop sales (e.g., coffee, potatoes) Lack of funds and incentives for improving sustainable practices Lack of competitive and proper markets Lack of agricultural training Lack of proper markets Lack of training and capacity building in coffee farming Lack of fertilizers Lack of agriculture/coffee extension activities Lack of resource centre	More agriculture training, especially for women Training in food security Training on climate change Training on agriculture Training on book-keeping and financial literacy Training on pest control Training on fertilizer management Training on sustainable farming and food security Training on climate change and environmental issues

Increased rainfall affects gardening activities More landslides when there is continuous rain		Land shortage for gardening activities	

4.1.3 Interviews during the scoping mission

The consultant conducted several interviews with key stakeholders in Enga during the scoping mission, such as provincial and district authorities, NGOs, and cooperative societies. The participants stated that Enga's natural disasters occur frequently, including flooding, landslides, frost, hail, and droughts.

Part of the Plans under the district DAL to mitigate climate change impacts on the land include tree planting (against strong winds and frost), crop rotation and integrated cropping and fallow (leaving the land unmanaged for some time). Under the agriculture crops divisions, the local authorities have practised a number of ways to sustain crops during climate change events (**Table 7**).

Table 7. Measures to sustain crops during climate conditions (Source: Interview with Mr Samson Fezamo – Scoping mission FinnOC 2022)

Village	Surveys
Frost	- Boil water until it simmers. Load the hot water into the pump and spray on food crops before the sun rise. Some potatoes are doing well with this approach. - Collect firewood and leaves and make smoke in the house to stop fros
Drought	- Cover all sweet potatoes with mulch. Water them in the mornings and afternoons to stop pest damage during the dry season.
Flooding/landslides	- Identify trees and plants like bamboo, which have widespread roots and are planted along the river side, land slops and garden areas to stop soil erosion and landslides. - Plant's like elephant grasses, wild pitpits, and canes to plant 3 meters on either side of the river in buffer zones
Landslide / Soil erosion	- Contour farming, sideways planting to stop soil erosion Awareness to people so they cover cropping with legumes or have plans for legume planting to put back nitrogen into the soil and to stop soil erosion.

During the interviews, the participants made different suggestions on improving climate change mitigation and adaptation. Some of these consolidated suggestions are stated below:

- Improve, upgrade and connect roads.
- Improve and create local markets.
- Increase awareness and capacity in terms of climate change and agriculture.
- Provide access to safe drinking water.
- Improve farming sustainable farming practices.
- Minimize loss of seedlings by preserving seedlings in a storage centre.
- Increase funding for extension and capacity building.
- Increase capacity building regarding forestry, biodiversity and climate change issues.

Similarly, during the scoping mission, provincial authorities mentioned that they are seeking approval for five conservation areas in Enga province from the National Executive Council (NEC).

4.2 Scoping analysis

4.2.1 Protected Areas (Pas) and Key biodiversity areas (KBAs)

The following protected areas were found within 100 km of the area of interest (**Table 8**). The closest PA is Jimi (Ruti) Valley National Park which is located around 2 km from Enga Province (**Figure 34**). No officially designed protected areas were found within Enga Province, even though, based on discussions with the provincial authority, there are some existing conservation initiatives in the province, such as Lembena and Kumul conservation projects.

Table 8. Protected Areas (PAs) within a 100k buffer from Enga (UNEP-WCMC & IUCN 2022)

Protected Area	Province	Type	Area (km2)	Designation year	Ownership type	Distance to Enga
Jimi (Ruti) Valley	Western Highlands	National Park	42,27	1991	Communal	2 km
Siwi-Utame	Southern Highlands	Wildlife Management Area	121,81	1977	Communal	31 km
Lake Kutubu	Southern Highlands	Wildlife Management Area / Ramsar Site / Wetland of International Importance	236,51	1992	Communal	40 km
Libano-Arisai	Southern Highlands	Wildlife Management Area	49,29	2008	Communal	69 km
Libano-Hose	Southern Highlands	Wildlife Management Area	46,19	2008	Communal	69 km
Hunstein Range	East Sepik	Wildlife Management Area	2286,81	1997	Communal	28 km
Sulamesi	Southern Highlands	Wildlife Management Area	684,84	2007	Communal	90 km
Mt. Wilhelm	Chimbu	National Park	8,14	1990	Communal	100 km

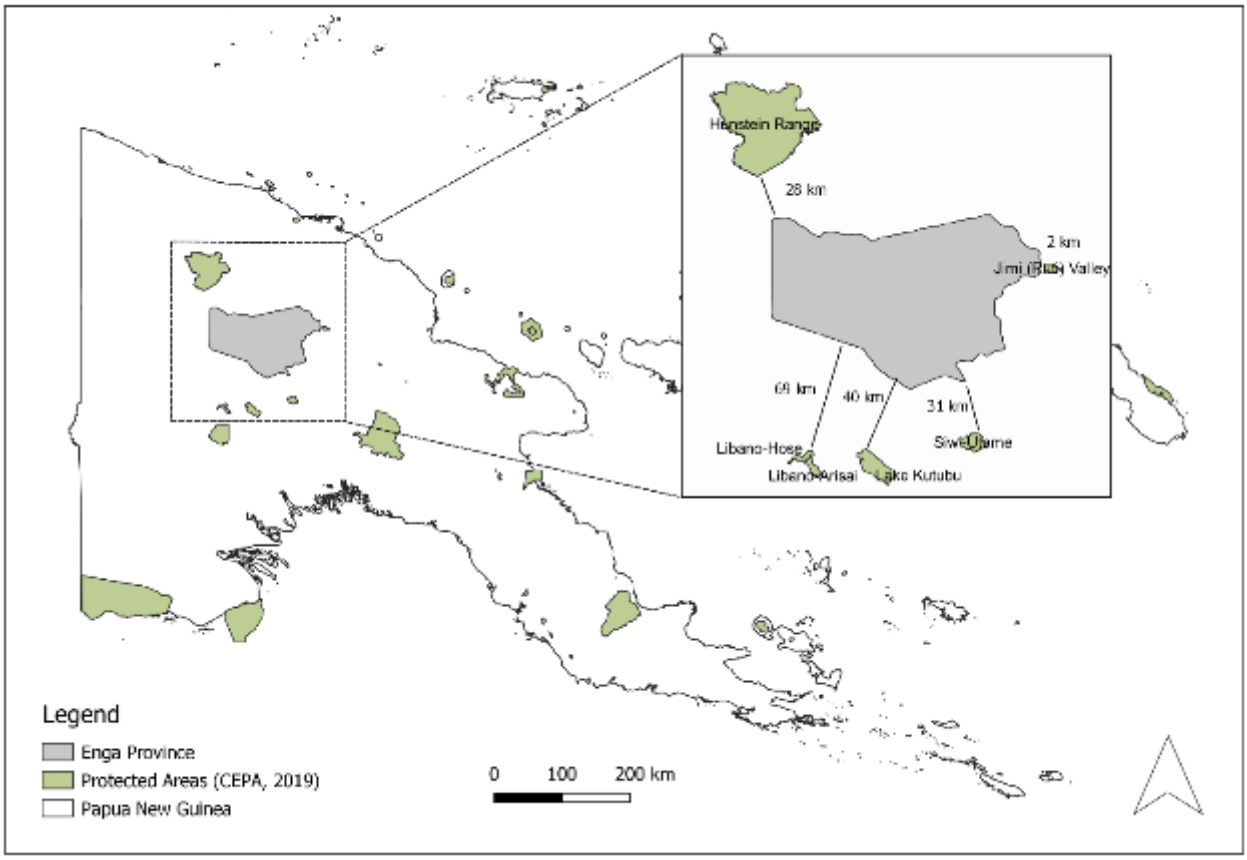

Figure 34. Protected areas near Enga Province (Source: UNEP-WCMC & IUCN 2022)

The following key biodiversity areas are found within 10 km of Enga Province (**Table 9**). Three KBAs are found within a 1 km buffer of Enga Province (Hagen-Giluwe, Porgera and Salir River Jimi Valley) and eight within a 50 km buffer (**Figure 35**). None of these KBAs is important to bird areas (IBAs) nor alliance for zero extinction (AZE). The global and regional status of Hagen-Giluwe, Porgera and Sali River Jimi Valley KBAs needs to be determined and reassessed (Key Biodiversity Areas Partnership 2022b; Key Biodiversity Areas Partnership 2022a; Key Biodiversity Areas Partnership 2022c).

Table 9. Key biodiversity areas (KBAs) within a 50k buffer from Enga (IBAT 2021)

Key Biodiversity Area	Province	Distance	Important Bird Area (IBA)	Alliance for Zero Extinction (AZE)
Hagen-Giluwe	Southern Highlands / Enga	1 km	No	No
Porgera	Enga	1 km	No	No
Sali River Jimi Valley	Western Highlands	1 km	No	No
Golowa	Western	50 km	No	No
Hunstein Range	East Sepik	50 km	No	No
Kubor Range	Chimbu	50 km	No	No
Lake Kutubu	Southern Highlands	50 km	No	No
Mount Sisa	Hela	50 km	No	No
NeTaRi Waranubu	Hela	50 km	No	No
Schrader Mountains	Madang	50 km	No	No
Tamide	Hela	50 km	No	No

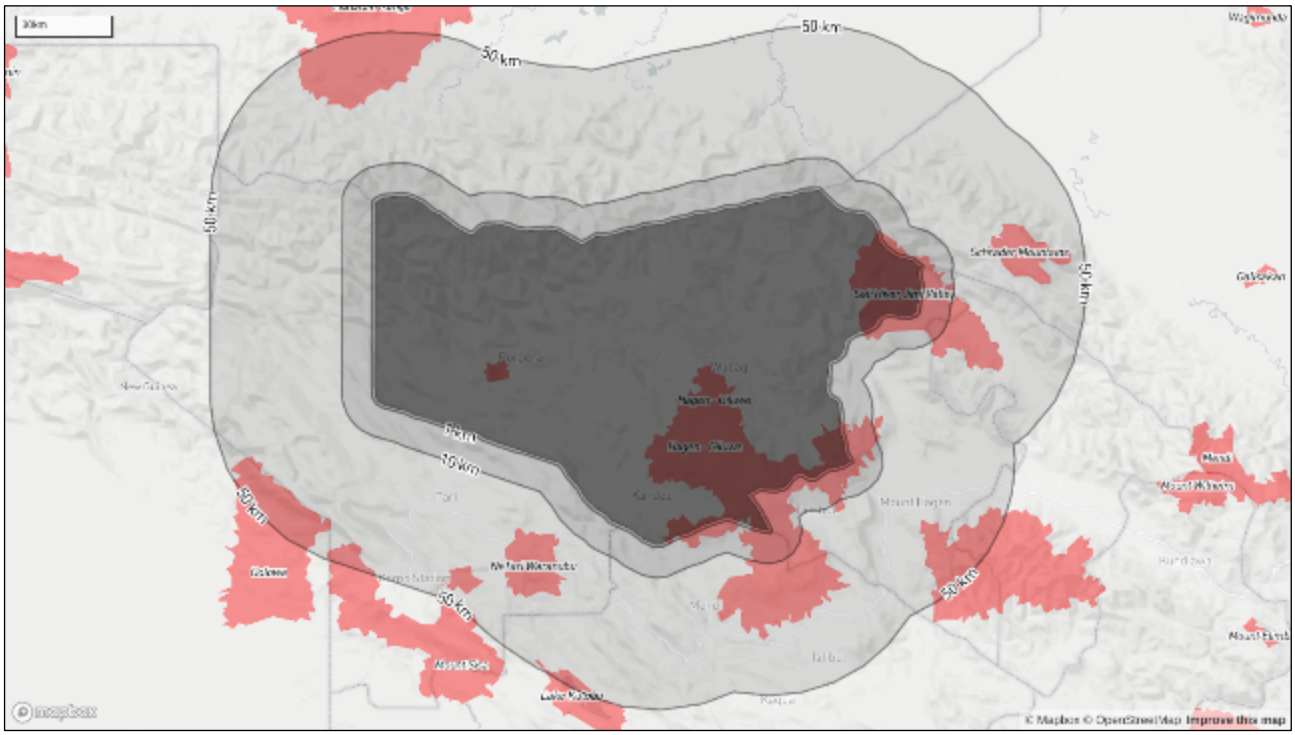

Figure 35. Key biodiversity areas near Enga Province (Source: IBAT 2021)

After consulting the PNG Climate Change and Forest Monitoring Web-Portal, the consultant team found seven areas need conservation assessment (**Figure 36**) and six priority conservation areas (**Figure 37**).

Figure 36. Areas that need conservation assessment in Enga Province (Climate Change and Development Authority 2017a)

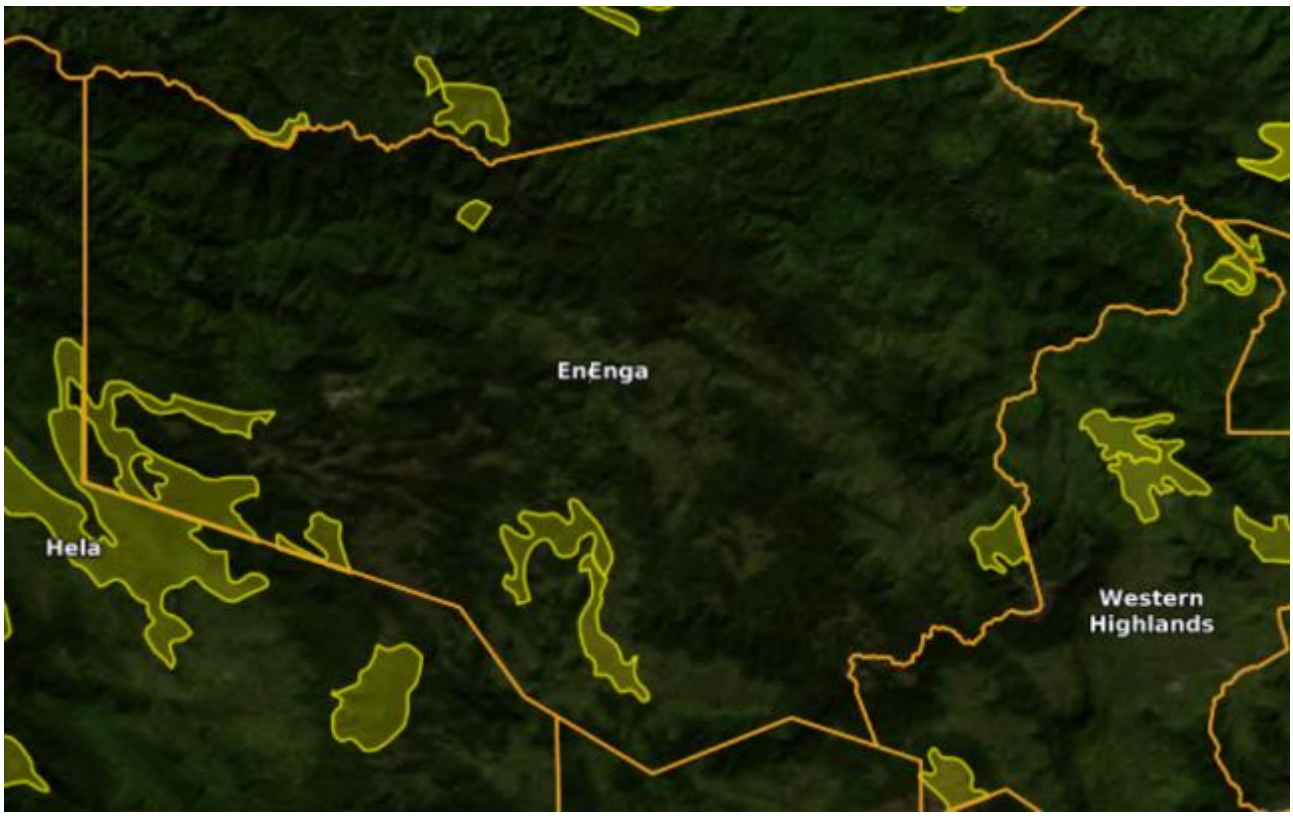

Figure 37. Biodiversity priority areas in Enga Province (Climate Change and Development Authority 2017a)

4.2.2 Red list species

The following table shows the total assessed species in the red list with the potential to occur within 50 km of Enga province. Seventy (70) of these species are under threat categories, meaning in the CR, EN, and VU categories (**Table 11**). Eight species are critically endangered (CR), 26 are endangered (EN) and 36 vulnerable (VU). We searched the occurrence of all those 70 species in the Global Biodiversity Information Facility (GBIF). We downloaded the occurrence records and displayed the number of available records within Papua New Guinea in **Table 11**.

Table 10. Red list species with potential to occur within Enga province (CR = critically endangered, EN = endangered, VU = vulnerable, NT = nearly threatened, LC = least concern and DD = data deficient)

Taxonomic Group	Total assessed species	Total (CR, EN & VU)	CR	EN	VU	NT	LC	DD
MAMMALIA	138	7	1	3	3	3	122	6
MAGNOLIOPSIDA	487	50	7	20	23	15	403	19
LECANOROMYCETES	2	1	0	1	0	0	1	0
LILIOPSIDA	28	1	0	1	0	0	26	1
AGARICOMYCETES	1	1	0	1	0	0	0	0
REPTILIA	54	2	0	0	2	0	49	3
AVES	450	4	0	0	4	13	431	2
AMPHIBIA	108	1	0	0	1	1	100	6
INSECTA	109	3	0	0	3	1	83	22
GASTROPODA	1	0	0	0	0	0	1	0
POLYPODIOPSIDA	2	0	0	0	0	0	2	0
JUNGERMANNIOPSIDA	1	0	0	0	0	0	1	0
ARACHNIDA	4	0	0	0	0	0	4	0

Table 11. Species under threat categories within 50 km of Enga province (IBAT 2021; IUCN 2021)

Class	Family	Species	Red List Category	Number of occurrences from GBIF
MAMMALIA	PHALANGERIDAE	*Spilocuscus rufoniger*	CR	1
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya alticola*	CR	4
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya flavisperma*	CR	0
MAGNOLIOPSIDA	PENTAPHYLACACEAE	*Eurya fragilis*	CR	2
MAGNOLIOPSIDA	PHYLLANTHACEAE	*Glochidion kopiaginis*	CR	5
MAGNOLIOPSIDA	RUTACEAE	*Acronychia richards-beehleri*	CR	3
MAGNOLIOPSIDA	CORNACEAE	*Alangium glabrum*	CR	1
MAGNOLIOPSIDA	CORNACEAE	*Alangium ledermannii*	CR	3
MAMMALIA	MACROPODIDAE	*Dendrolagus goodfellowi*	EN	10
MAMMALIA	MACROPODIDAE	*Thylogale calabyi*	EN	0
MAMMALIA	MACROPODIDAE	*Dendrolagus notatus*	EN	1
LECANOROMYCETES	PARMELIACEAE	*Cetreliopsis papuae*	EN	5
LILIOPSIDA	POACEAE	*Oryza schlechteri*	EN	7
AGARICOMYCETES	CALOSTOMATACEAE	*Calostoma insigne*	EN	0
MAGNOLIOPSIDA	ERICACEAE	*Rhododendron multinervium*	EN	24
MAGNOLIOPSIDA	RUTACEAE	*Acronychia wabagensis*	EN	3
MAGNOLIOPSIDA	LAURACEAE	*Beilschmiedia podagrica*	EN	6
MAGNOLIOPSIDA	SALICACEAE	*Casearia monticola*	EN	5
MAGNOLIOPSIDA	EUPHORBIACEAE	*Croton pilophorus*	EN	6
MAGNOLIOPSIDA	FABACEAE	*Crudia katikii*	EN	5
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya bullata*	EN	2
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya elongata*	EN	1
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya filicifolia*	EN	6
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya forbesii*	EN	7
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya splendens*	EN	4
MAGNOLIOPSIDA	LAURACEAE	*Endiandra spathulata*	EN	1
MAGNOLIOPSIDA	MORACEAE	*Ficus eustephana*	EN	4
MAGNOLIOPSIDA	CLUSIACEAE	*Garcinia jaweri*	EN	5
MAGNOLIOPSIDA	PHYLLANTHACEAE	*Glochidion galorii*	EN	9
MAGNOLIOPSIDA	EUPHORBIACEAE	*Macaranga intonsa*	EN	13
MAGNOLIOPSIDA	RUBIACEAE	*Psychotria marafungaensis*	EN	5
MAGNOLIOPSIDA	MALVACEAE	*Sterculia peekelii*	EN	2
MAGNOLIOPSIDA	LAURACEAE	*Litsea complanata*	EN	2

MAGNOLIOPSIDA	LAURACEAE	*Endiandra inaequitepala*	EN	0
MAMMALIA	MACROPODIDAE	*Dendrolagus spadix*	VU	0
MAMMALIA	MACROPODIDAE	*Thylogale browni*	VU	7
MAGNOLIOPSIDA	PROTEACEAE	*Helicia acutifolia*	VU	5
MAGNOLIOPSIDA	MALVACEAE	*Pterocymbium beccarii*	VU	27
MAGNOLIOPSIDA	SAPINDACEAE	*Cupaniopsis euneura*	VU	4
MAMMALIA	TACHYGLOSSIDAE	*Zaglossus bartoni*	VU	11
REPTILIA	TRIONYCHIDAE	*Pelochelys signifera*	VU	0
AVES	PSITTACIDAE	*Psittrichas fulgidus*	VU	581
AVES	ACCIPITRIDAE	*Harpyopsis novaeguineae*	VU	236
AVES	MELIPHAGIDAE	*Melionyx princeps*	VU	0
REPTILIA	PYTHONIDAE	*Leiopython fredparkeri*	VU	12
AVES	COLUMBIDAE	*Goura scheepmakeri*	VU	9
MAGNOLIOPSIDA	MYRTACEAE	*Eucalyptus deglupta*	VU	147
MAGNOLIOPSIDA	CTENOLOPHONACEAE	*Ctenolophon parvifolius*	VU	21
MAGNOLIOPSIDA	FAGACEAE	*Lithocarpus vinkii*	VU	52
AMPHIBIA	MICROHYLIDAE	*Choerophryne alpestris*	VU	4
INSECTA	LIBELLULIDAE	*Lanthanusa cochlear*	VU	0
INSECTA	PLATYCNEMIDIDAE	*Palaiargia traunae*	VU	0
MAGNOLIOPSIDA	LAMIACEAE	*Gmelina sessilis*	VU	15
MAGNOLIOPSIDA	SAPOTACEAE	*Planchonella orkor*	VU	9
MAGNOLIOPSIDA	RUTACEAE	*Acronychia foveata*	VU	9
MAGNOLIOPSIDA	LAURACEAE	*Cinnamomum kami*	VU	12
MAGNOLIOPSIDA	EUPHORBIACEAE	*Claoxylon paucinerve*	VU	20
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya caloneura*	VU	19
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya longepetiolata*	VU	16
MAGNOLIOPSIDA	ELAEOCARPACEAE	*Elaeocarpus millarii*	VU	19
MAGNOLIOPSIDA	LAURACEAE	*Endiandra bullata*	VU	5
MAGNOLIOPSIDA	EUPHORBIACEAE	*Euphorbia brassii*	VU	20
MAGNOLIOPSIDA	AQUIFOLIACEAE	*Ilex stenura*	VU	3
MAGNOLIOPSIDA	ARALIACEAE	*Heptapleurum koresii*	VU	0
MAGNOLIOPSIDA	MELASTOMATACEAE	*Astronidium morobiense*	VU	14
INSECTA	SYNTHEMISTIDAE	*Palaeosynthemis nigrostigma*	VU	1
MAGNOLIOPSIDA	LAURACEAE	*Litsea alveolata*	VU	5
MAGNOLIOPSIDA	LAURACEAE	*Litsea habbemensis*	VU	3
MAGNOLIOPSIDA	LAURACEAE	*Cryptocarya ledermannii*	VU	13
MAGNOLIOPSIDA	RUBIACEAE	*Timonius oblongus*	VU	2

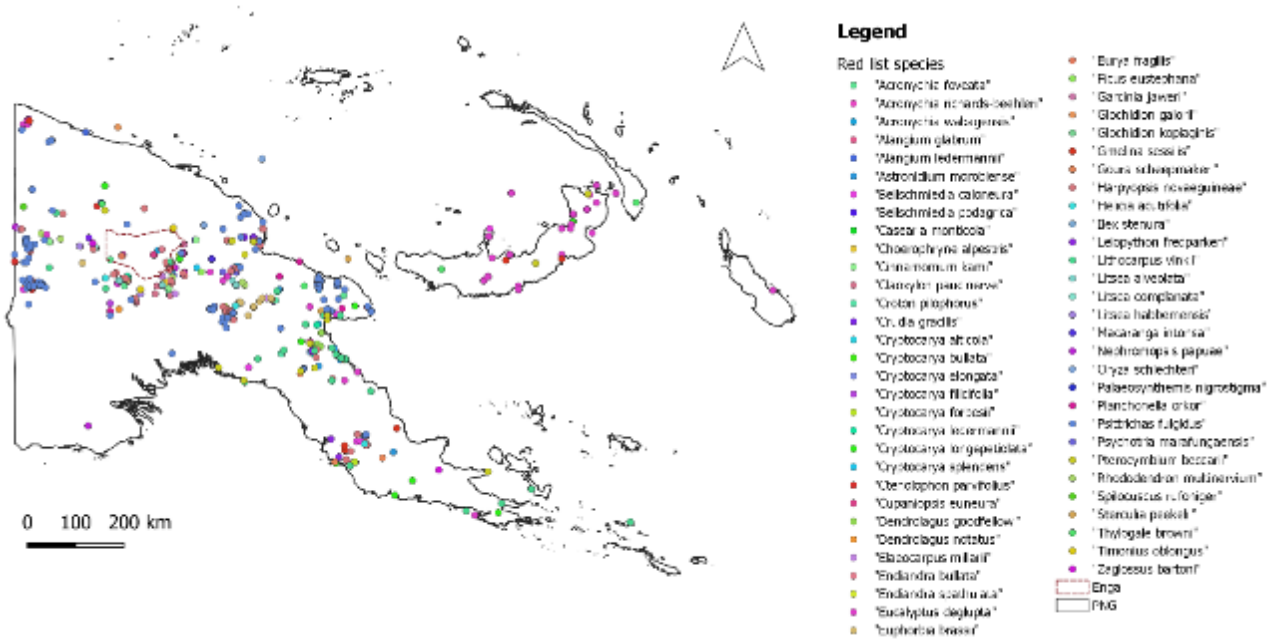

Figure 38. Occurrence of red list species with potential to occur in Enga Province (GBIF 2022n; GBIF 2022p; GBIF 2022ah; GBIF 2022i; GBIF 2022a; GBIF 2022b; GBIF 2022c; GBIF 2022ac; GBIF 2022o; GBIF 2022d; GBIF 2022ad; GBIF 2022z; GBIF 2022t; GBIF 2022e; GBIF 2022f; GBIF 2022g; GBIF 2022h; GBIF 2022q; GBIF 2022ag; GBIF 2022j; GBIF 2022k; GBIF 2022l; GBIF 2022aa; GBIF 2022u; GBIF 2022r; GBIF 2022ai; GBIF 2022v; GBIF 2022w; GBIF 2022ae; GBIF 2022x; GBIF 2022y; GBIF 2022m; GBIF 2022af; GBIF 2022s; GBIF 2022ab; GBIF 2022aj; GBIF 2022ak; GBIF 2022am; GBIF 2022al; GBIF 2022an; GBIF 2022ao; GBIF 2022ap; GBIF 2022aq; GBIF 2022ar; GBIF 2022as; GBIF 2022at; GBIF 2022au)

4.2.3 Species distribution modelling and species richness

4.2.3.1 Species distribution modelling (SDM)

Species distribution models (SDM) characterize the environmental conditions that are suitable for a species and then identify where those suitable environmental conditions are distributed geographically (Guisan & Zimmermann 2000; Guisan & Thuiller 2005; Franklin 2010; Peterson et al. 2011; Guisan et al. 2017). SDMs are used to deliver predictive maps of the species distributions, meaning predicting the likelihood of finding a species even in areas where field data are still unavailable (Franklin 2010). SDMs have been widely used for different practical applications such as reserve design and conservation planning (Boitani et al. 2008; Rodríguez-Soto et al. 2011; Franklin 2013; Guisan et al. 2013; Freeman et al. 2019), natural resources management (Chaves et al. 2018), invasive species assessments (Barbet-Massin et al. 2018; Chapman et al. 2019), as well as environmental impact assessments (Franklin 2010).

After identifying the species under threat in Enga Province, records of their location (occurrence data) were accessed and downloaded from the Global Biodiversity Information Facility (GBIF), as seen in **Figure 38**. Of the 70 species under threat identified, only 59 had sufficient occurrence records (**Table 11**) to model their distribution. Relevant environmental layers were also accessed and downloaded, including bioclimatic variables (Fick & Hijmans 2017; Karger et al. 2017) and soil variables (Hengl et al. 2015; Hengl et al. 2017), digital elevation models (Earth Resources Observation And Science (EROS) Center 2017). Both occurrence and environmental data (bioclimatic variables) were used to model the distribution of all species with occurrence data with MaxEnt algorithm. **Figure 39** depicts a methodological framework for modelling species distribution within the study area.

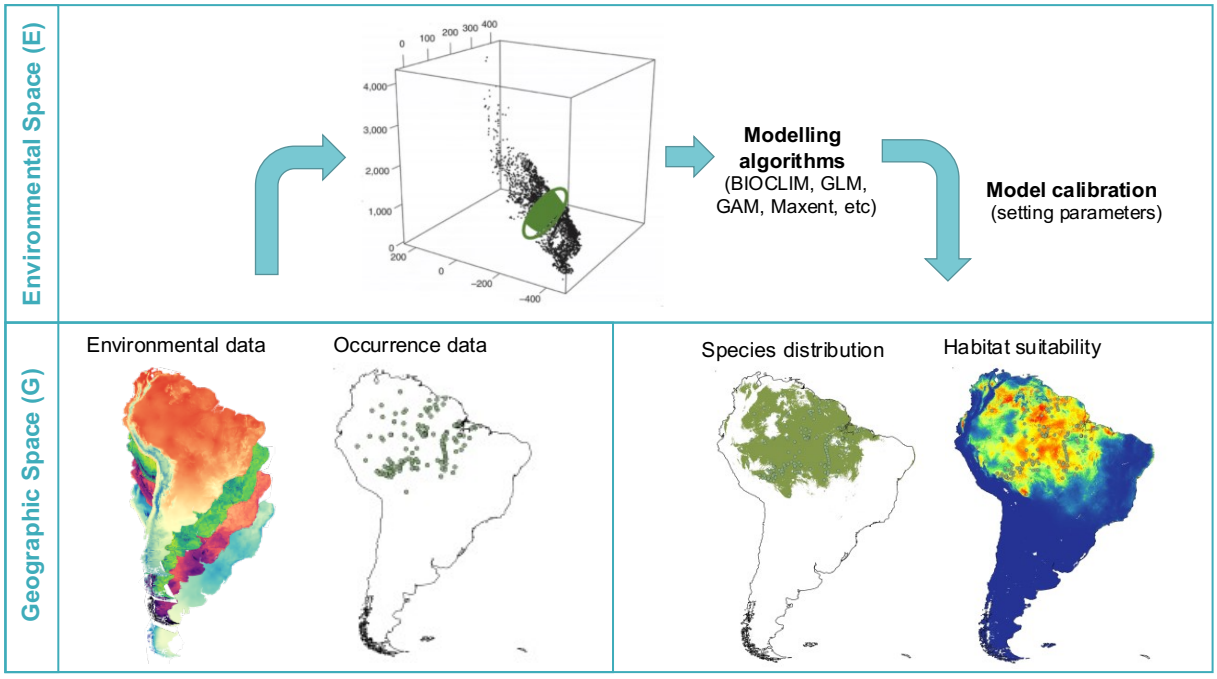

Figure 39. Example of a methodological framework for modelling the distribution of species.

Table 12. Description of the bioclimatic variables

Layer	Description
BIO01	Annual Mean Temperature
BIO02	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO03	Isothermality (BIO2/BIO7) (×100)
BIO04	Temperature Seasonality (standard deviation ×100)
BIO05	Max Temperature of Warmest Month
BIO06	Min Temperature of Coldest Month
BIO07	Temperature Annual Range (BIO5-BIO6)
BIO08	Mean Temperature of Wettest Quarter
BIO09	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

Bioclimatic variables (**Table 12**) were used as the main environmental layers to model the distribution of species in Enga province. **Figure 40** shows some of the bioclimatic variables used in the modelling process.

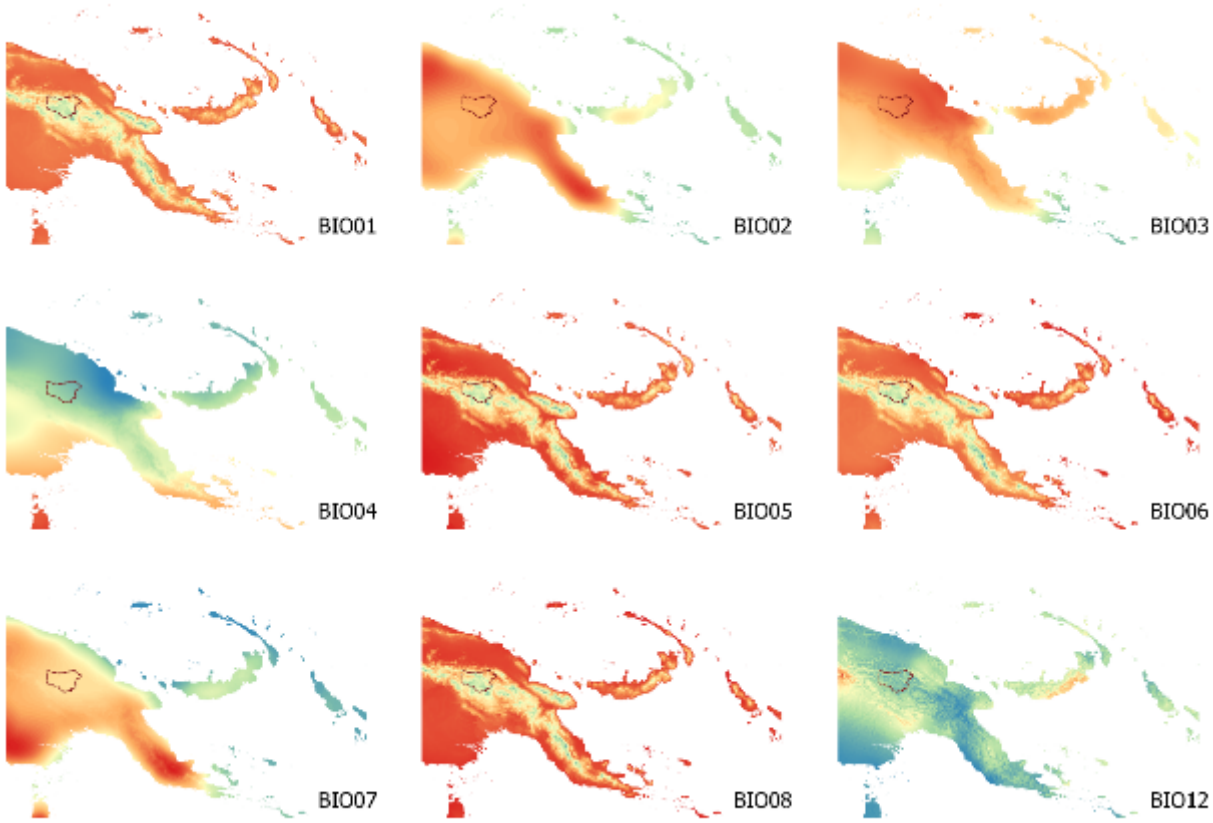

Figure 40. Bioclimatic variables in Papua New Guinea

Maxent algorithm (Phillips et al. 2017) was used as the main approach for modelling the distribution of species in the study area. MaxEnt is a machine learning algorithm that combines Bayesian methods, maximum entropy theory and statistical methods to model the distribution of species based on the presence of individuals and environmental background data. Maxent allows estimating the probability of the presence of certain species through a linkage function between the probability density of the variables obtained from the presence records and the environment data (Figure 7). Maxent has performed equally well or better than other modelling algorithms (Elith* et al. 2006; Hernandez et al. 2006; Phillips et al. 2006; Wisz et al. 2008; Merckx et al. 2011), deriving consistent predictions (Giovanelli et al. 2010) and being less sensitive to parametrization (Hallgren et al. 2019).

We estimated the abiotically suitable distribution of 59 species under threat (CR, EN and VU) with the potential to occur in Enga province. **Figure 41** shows the distribution of four species: *Psittrichas fulgidus* ("Pesquet's parrot"), *Harpyopsis novaguineae* ("Papuan eagle"), *Dendrolagus goodfellowi* ("Goodfellow's tree-kangaroo") and *Glochidion kopiaginis* ("Airy Shaw"). In those figures, red colours represent suitable areas (higher likelihood or probability of finding the species given the environmental layers) for the species to occur, whereas blue colours unsuitable locations.

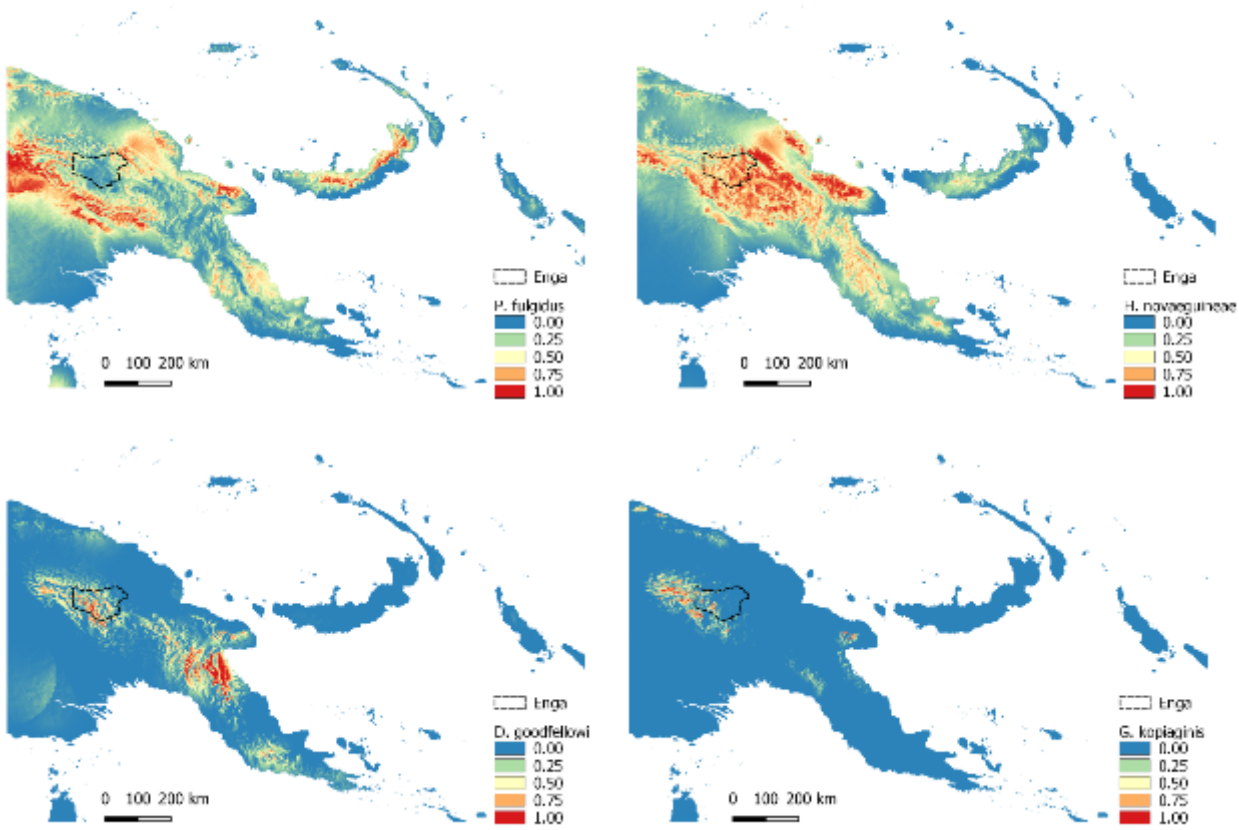

Figure 41. Habitat suitability or abiotically suitable distribution of *Psittrichas fulgidus* ("Pesquet's parrot"), *Harpyopsis novaguineae* ("Papuan eagle"), *Dendrolagus goodfellowi* ("Goodfellow's tree-kangaroo") and *Glochidion kopiaginis* ("Airy Shaw")

	
Pesquet's parrot (Source: ebird.org)	Papuan eagle (Source: ebird.org)
	
Goodfellow's tree-kangaroo (Source: biolib.cz)	Airy Shaw (Source: kew.org)

Figure 42. Photographs of *Psittrichas fulgidus* ("Pesquet's parrot"), *Harpyopsis novaguineae* ("Papuan eagle"), *Dendrolagus goodfellowi* ("Goodfellow's tree-kangaroo") and *Glochidion kopiaginis* ("Airy Shaw")

4.2.3.2 Species richness

After modelling the distribution of species under threat in Enga province, we transformed the habitat suitability maps (**Figure 41**), from numerical or continuous layers (that go because 0-low suitability to 1, high suitability), to binary maps (0, species is absent, and 1, species is present). We used the "maximum training sensitivity plus specificity threshold" method since it derives consistent results under different data and methods (Liu et al. 2016). **Figure 43** shows presence/absence maps of the same species from **Figure 41**.

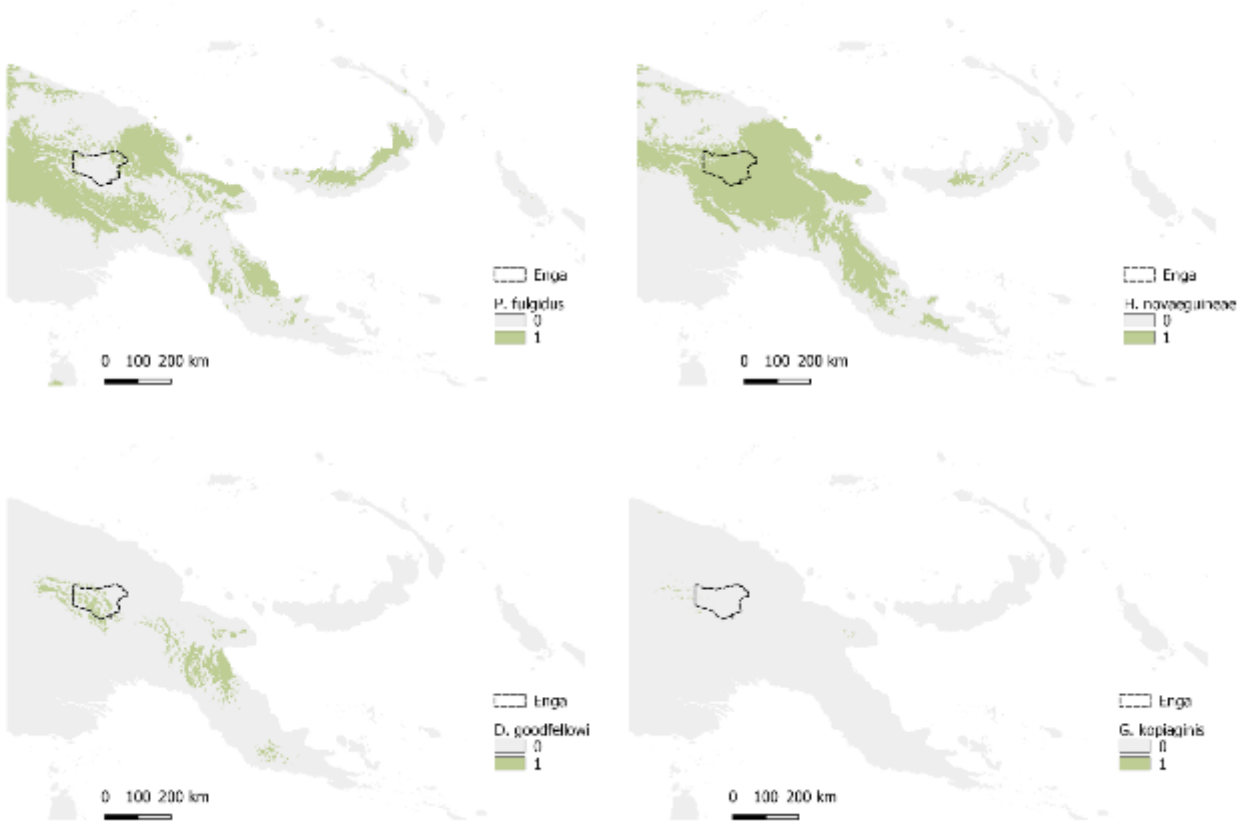

Figure 43. Presence/absence maps of *Psittrichas fulgidus* ("Pesquet's parrot"), *Harpyopsis novaguineae* ("Papuan eagle"), *Dendrolagus goodfellowi* ("Goodfellow's tree-kangaroo") and *Glochidion kopiaginis* ("Airy Shaw"). Green colours (1) represent areas where the species are present and grey colours (0), areas where the species is absent.

After deriving presence/absence maps for all species, the 59 layers were aggregated and summed as a single layer, depicting the number of threatened species (or species richness) with the potential to occur in Enga province. **Figure 44** shows the number of threatened species potentially occurring in Enga province. Locations with a higher number of species are areas with high conservation value (HCV).

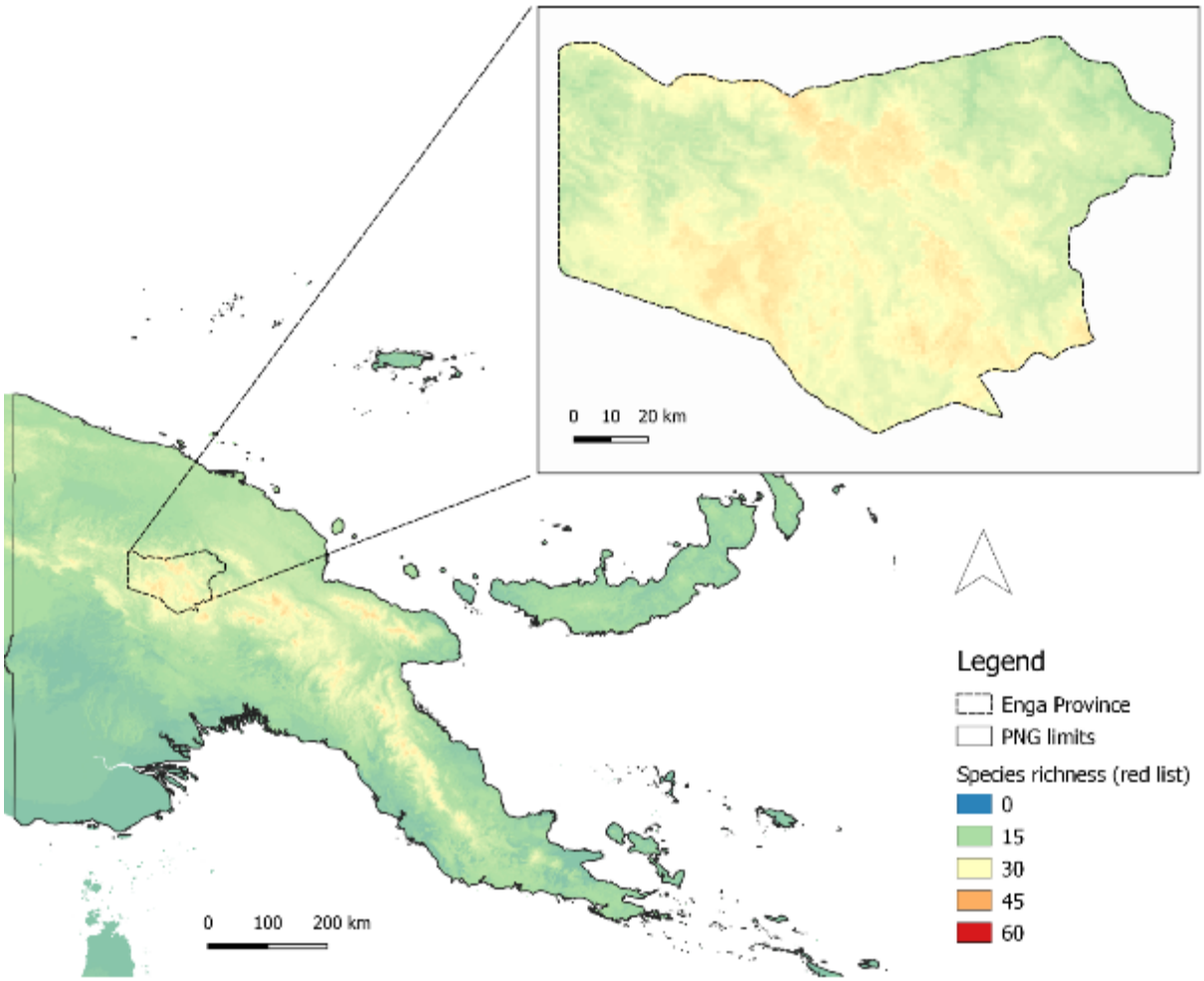

Figure 44. Number of threatened species (species richness) with potential to occur in Enga Province

The National Forest Inventory (NFI) has established several permanent plots throughout PNG; nevertheless, none of them is in Enga Province.

Figure 45. Permanent plots of the National Forest Inventory

4.2.4 Identification of degraded areas

Three indicators were used to preliminary identify degraded areas within Enga Province: (i) soil organic carbon stock change (Hengl et al. 2015; Hengl et al. 2017; Wheeler & Hengl 2018; Hengl et al. 2020), (ii) forest cover loss (Hansen et al. 2013) and (iii) land cover change layers (Marcel Buchhorn et al. 2020c; Marcel Buchhorn et al. 2020a; Marcel Buchhorn et al. 2021). The indicator layers were accessed, downloaded and cropped to the study area. The table below shows that the layers were available at different spatial and temporal resolutions.

Table 13. Land degradation indicators and spatial resolution

N	Land degradation indicator	Temporal resolution	Spatial Resolution (m)
1	Soil organic carbon stock change	2005-2015	250
2	Forest cover loss	2001-2020	30
3	Land cover change	2015-2019	100

4.2.4.1 *Soil organic carbon stock (SOC) change*

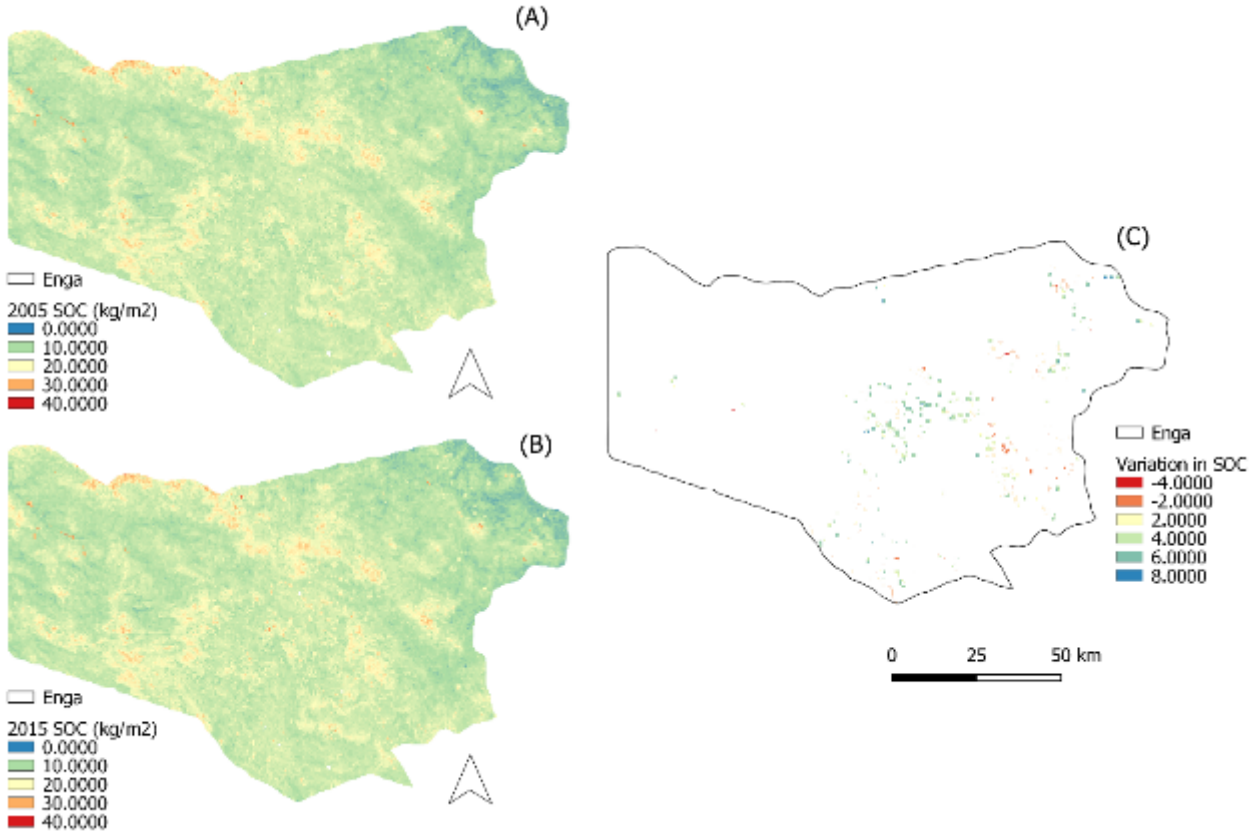

Figure 46. Soil organic carbon (SOC) stock (kg/m2) in Enga Province in (A) 2005, (B) 2015 and (C) its variation. Source (Wheeler & Hengl 2018)

Yearly layers of soil organic carbon (SOC) stock (kg/m^2) exist globally from the period 2005-to 2015. We downloaded and cropped the 2005 and 2015 layers to Enga Province. The SOC stocks are shown in **Figure 46** for both periods, as well as the variation in SOC stock in the time period. In **Figure 46**, red colours show locations where there has been a decrease in the soil organic carbon stock.

Figure 47 shows areas that: (i) have experienced an increase in soil organic carbon (SOC) stock (represented in green), (ii) have lost soil organic carbon stock (represented in red) and areas that remained unchanged (represented in light grey). Between 2005 and 2015, approximately 3025 and 1735 ha have experienced loss and gain of SOC respectively in Enga Province.

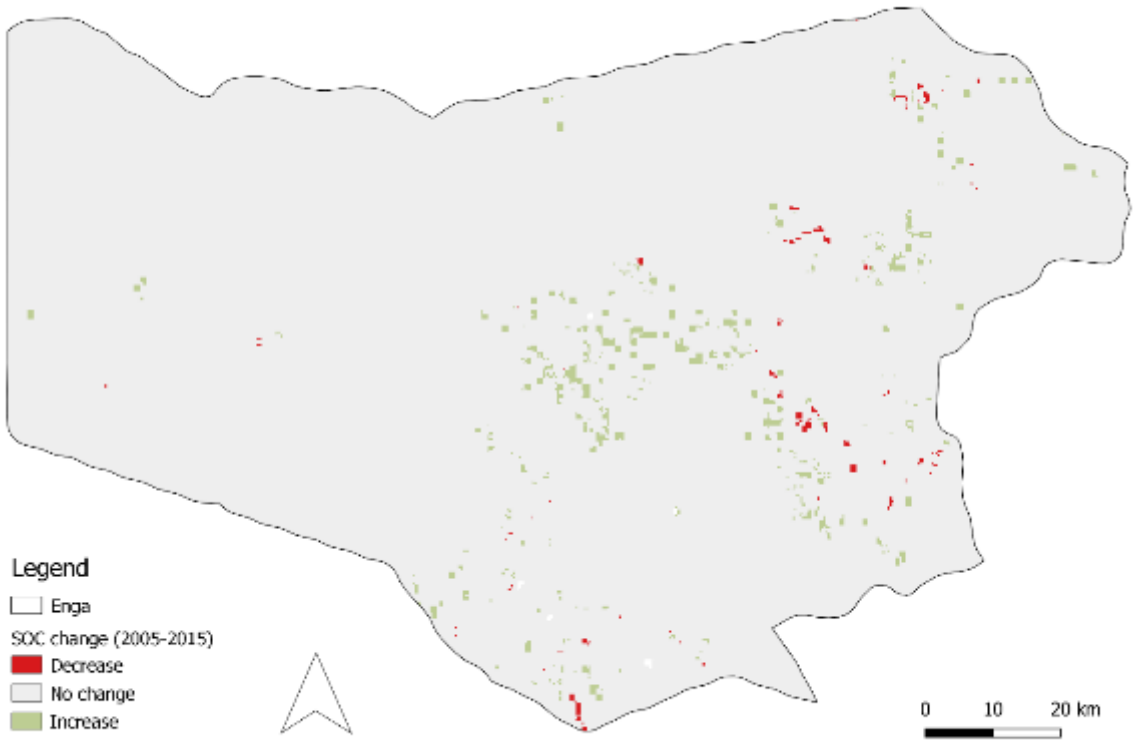

Figure 47. Soil organic carbon (SOC) change in Dodoma Urban District between 2005-2015 in Source (Wheeler & Hengl 2018)

4.2.4.2 Forest loss

Results from a time-series analysis of Landsat images in characterizing global forest extent and change from 2000 through 2020 were accessed and downloaded (Hansen et al. 2013). Forest loss during the period 2000–2020 is defined here as a stand-replacement disturbance or a change from a forest to a non-forest state. The accessed layers are encoded as either 0 (no loss) or else a value in the range 1–20, representing loss detected primarily in the year 2001–2020, respectively. In **Figure 48**, red colours show areas where forests have been recently lost, whereas blue colours areas that have been deforested in the 2000s.

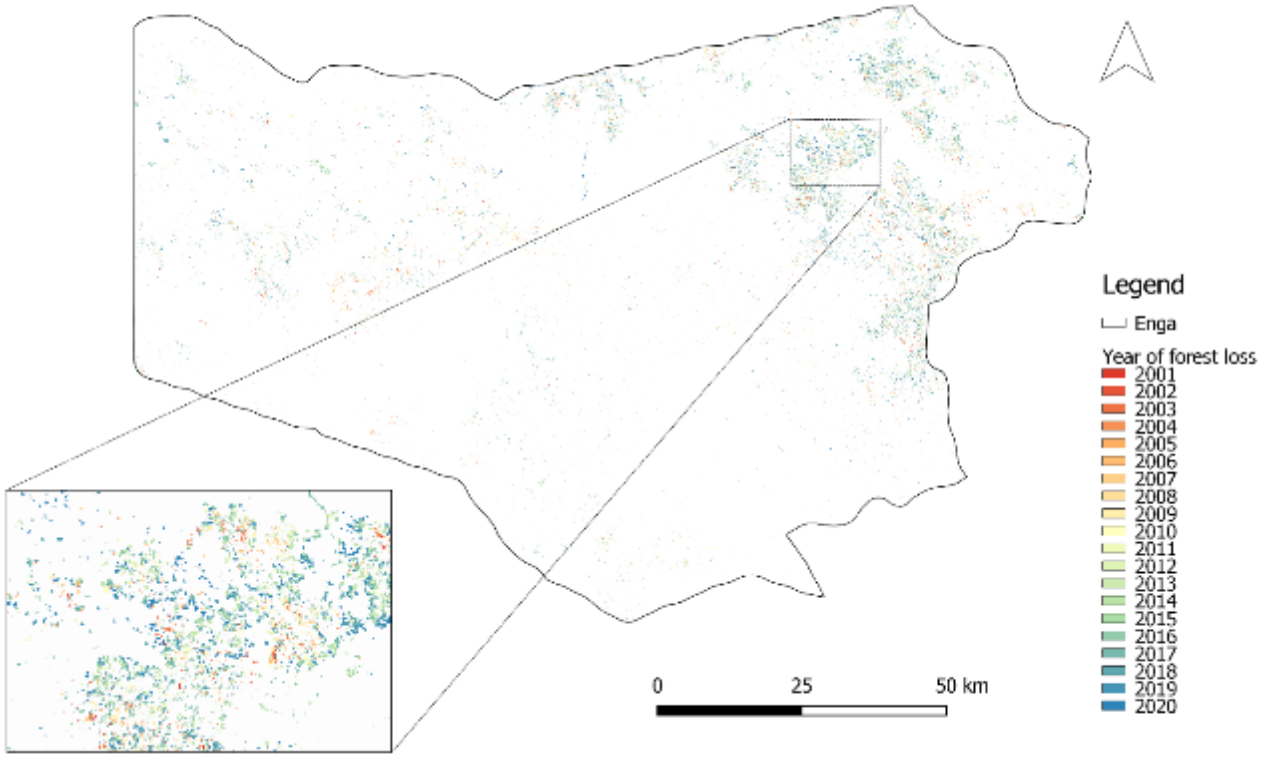

Figure 48. Location of forest loss detected between 2001-2020 in Enga Province. Source (Hansen et al. 2013)

Yearly forest loss between 2001-2020 in Enga Province ranged between 345 ha reported in 2001 and 3485 reported in 2016 (**Figure 49**). The mean yearly loss in that period in Enga Province was approximately 1568 ha. A total of 31353 ha were deforested in Enga Province between 2001-2020.

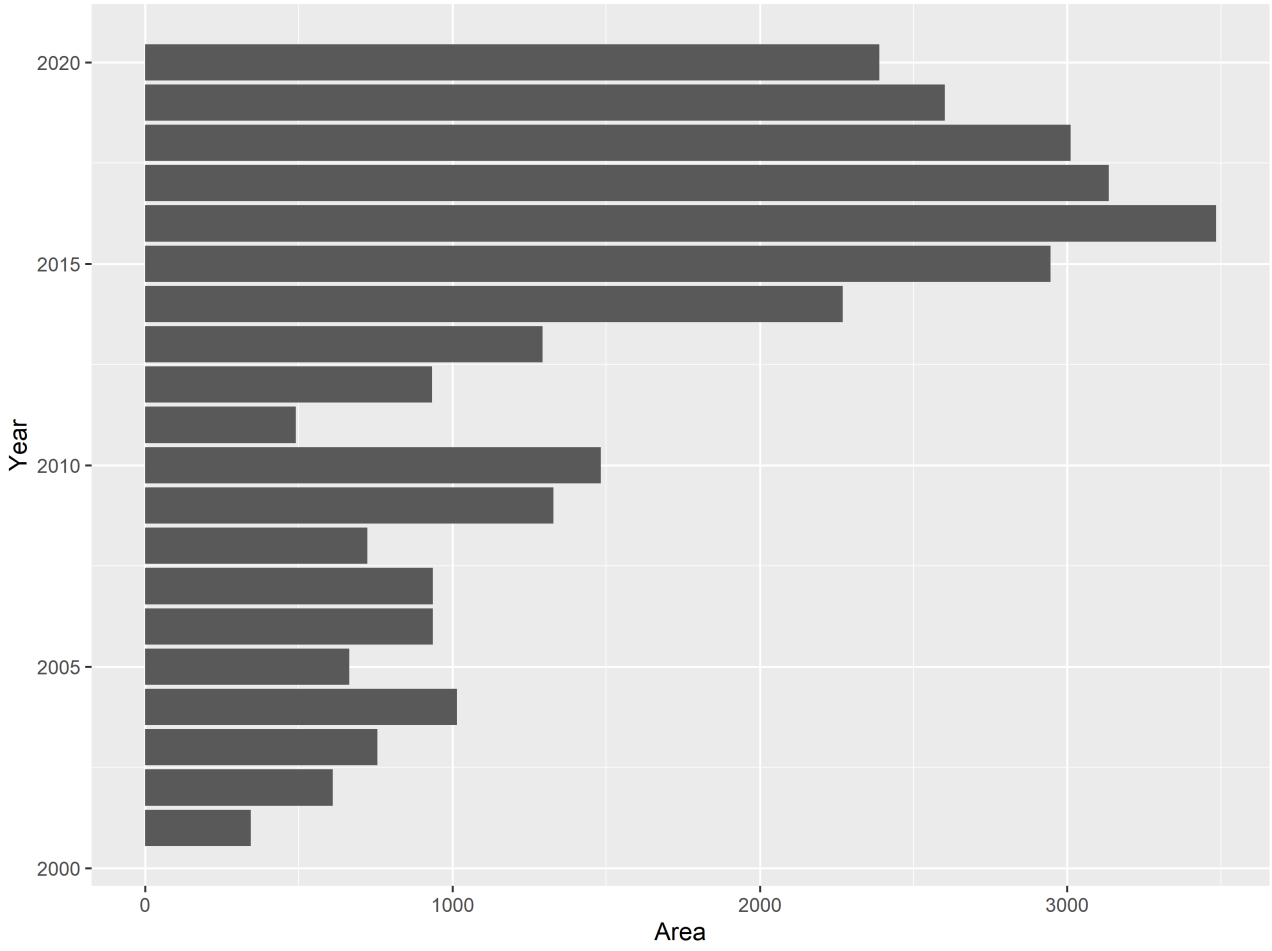

Figure 49. Yearly forest loss in hectares (ha) was detected between 2001-2020 in Enga Province. Source (Hansen et al. 2013)

4.2.4.3 Land cover and land cover change

The land cover maps of the Copernicus Moderate Dynamic Land Cover project (Marcel Buchhorn et al. 2021) were accessed and extracted for Enga Province for the years 2015 and 2019 (**Figure 50**). In the 5 years (2015-2019), forested areas decreased in Enga Province. This offers a unique opportunity of developing conservation initiatives in those rather intact forests, especially since there are no conservation areas and protected units in Enga Province and deforestation is increasing.

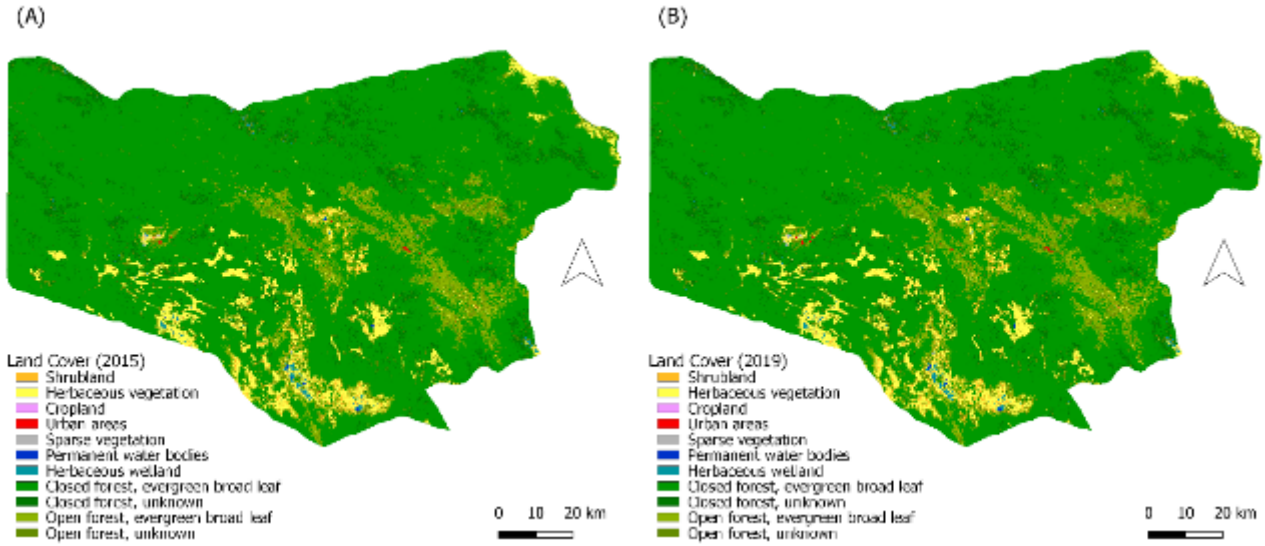

Figure 50. Land cover maps (Marcel Buchhorn et al. 2021) for Enga Province in (A) 2015 (Marcel Buchhorn et al. 2020b) and in (B) 2019 (Marcel Buchhorn et al. 2020d)

Table 14. Land cover definitions.

Land Cover Class	Definition
Shrubland	These are woody perennial plants with persistent and woody stems and no defined main stem being less than 5 m tall. The shrub foliage can be either evergreen or deciduous
Herbaceous vegetation	Plants without persistent stem or shoots above ground and lacking definite firm structure. Tree and shrub cover is less than 10 %.
Cultivated and managed vegetation/agriculture (cropland)	Lands are covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Perennial woody crops will be classified as the appropriate forest or shrubland cover type.
Urban areas	Land covered by buildings and other man-made structures
Sparse vegetation	Lands with exposed soil, sand, or rocks and never has more than 10 % vegetated cover during any time of the year
Water bodies	lakes, reservoirs, and rivers. They can be either fresh or salt-water bodies.
Herbaceous wetland	Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or freshwater
Closed forest, evergreen, broadleaf	tree canopy >70 %, almost all broadleaf trees remain green year-round. Canopy is never without green foliage.
Closed forest, unknown	Closed forest, not matching any of the other definitions
Open forest, evergreen, broadleaf	top layer- trees 15-70 % and second layer-mixed of shrubs and grassland, almost all broadleaf trees remain green year-round. Canopy is never without green foliage
Open forest, unknown	Open forest, not matching any of the other definitions

Table 15. Land cover dynamics in Enga province between 2015 and 2019.

Land cover class	Abb.	Area (ha)		
		2015	2019	Delta
Shrubland	Shr	6369	6141	-228
Herbaceous vegetation	Her	46734	46038	-696
Cropland	Cro	83	81	-2
Urban areas	Urb	299	304	5
Sparse vegetation	Spa	23	209	-21
Permanent water bodies	Wat	289	320	31
Herbaceous wetland	Wet	3033	5307	2274
Closed forest, evergreen broad leaf	Cfd	761434	761212	-222
Closed forest, unknown	Cfu	51274	50543	-731
Open forest, evergreen broadleaf	Ofd	60153	60196	43
Open forest, unknown	Ofu	42800	42347	-453

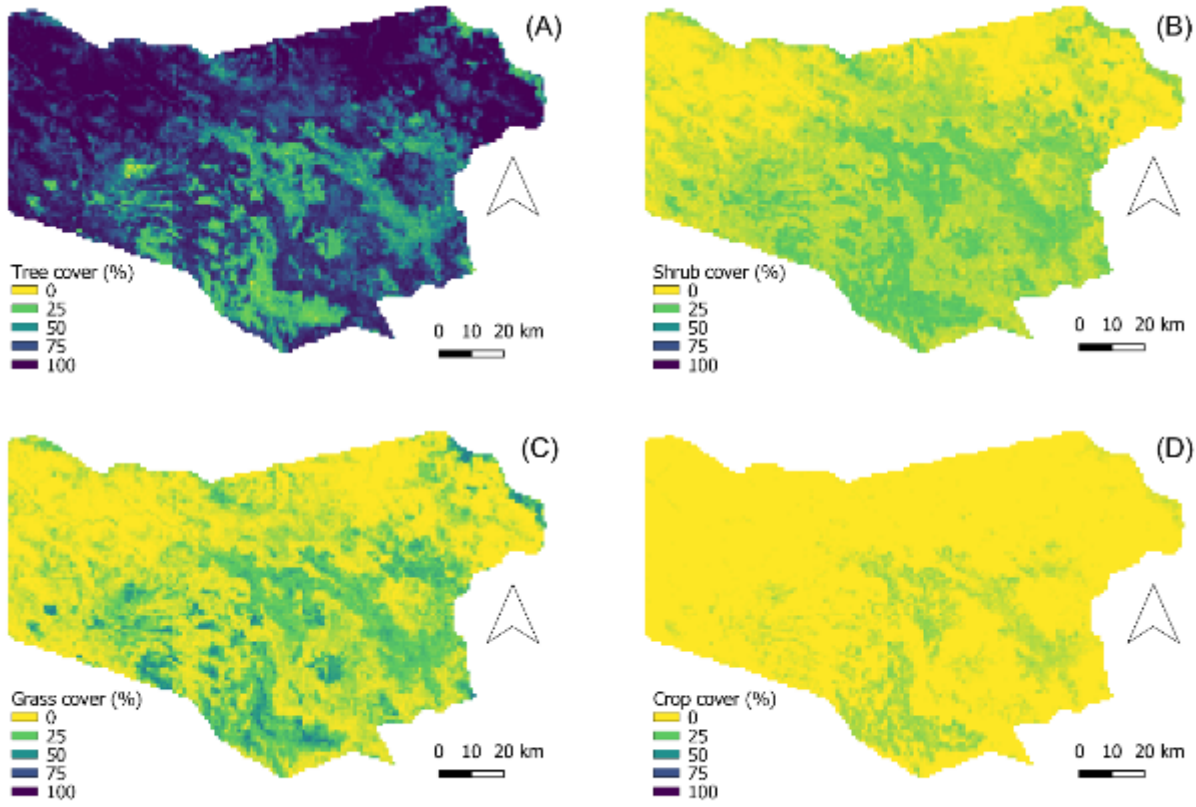

Figure 51. Vegetation cover in Enga Province. (A) tree cover, (B) shrub cover, (C) grass cover and (D) crop cover.

The transition between land cover classes between 2015-2019 is presented following the transition matrix method (Alamanos & Linnane 2021). In **Table 16**, the potential land degradation areas are shown in red, whereas green colours show improvement and light yellow colours show stable areas in terms of land-use change.

Table 16. Potential land degradation and land cover dynamics in Enga Province between 2015 and 2019

LULC in 2015	LULC in 2019 (ha)										
	Shr	Her	Cro	Urb	Spa	Wat	Wet	Cfd	Cfu	Ofd	Ofu
Shrubs (Shr)	6132	13	0	0	0	0	215	0	2	2	5
Herbaceous vegetation (Her)	9	45886	0	2	0	0	648	0	1	34	154
Cropland (Cro)	0	0	80	0	0	0	3	0	0	0	0
Urban areas (Urb)	0	0	0	299	0	0	0	0	0	0	0
Bare / sparce vegetation (Spa)	0	0	0	0	209	6	15	0	0	0	0
Permanent water bodies (Wat)	0	0	0	0	0	271	18	0	0	0	0
Herbaceous wetland (Wet)	0	4	0	0	0	36	2993	0	0	0	0
Closed forest, evergreen broad leaf (Cfd)	0	0	0	0	0	0	167	761185	50	3	29
Closed forest, unknown (Cfu)	0	7	0	0	0	0	604	13	50486	4	160
Open forest, evergreen broad leaf (Ofd)	0	7	0	1	0	0	5	7	0	60126	7
Open forest, unknown (Ofu)	0	121	1	2	0	7	639	7	4	27	41992

* LULC refers to Land Use / Land Cover Change

4.2.5 Landscape fragmentation and connectivity

Landscape ecology provides a theoretical framework for local landscape study. The landscape is understood as an area of heterogeneous terrain composed of a set of interacting ecosystems that are similarly repeated (Forman et al. 1986). Landscape dynamics depend on the relationships between societies and their environment, creating changing structures in space and time. The resulting Spatio-temporal heterogeneity controls numerous movements and flows of organisms, matter and energy. Therefore, to understand the mechanisms for the maintenance of species and the permanence of water flow or nutrients, it is essential to consider the determinants of heterogeneity origin in the environment. In this sense, landscape ecology integrates the object of study (landscape), its determinants (the environment and society) and its effects on ecological processes (Burel & Baudry 2003)

Habitat fragmentation can be defined as the process by which habitat loss results in large and continuous division into smaller, isolated remnants (Didham 2010). The following figure shows an example of how fragmentation modifies the geometric configuration of landscapes. Fragmented landscapes differ in the size and shape of the patches, spatial configuration and the floristic composition that they harbour. Most landscape fragmentation studies have been carried out at the level of fragments, where they individually are the unit of study (Bennett & Saunders 2010).

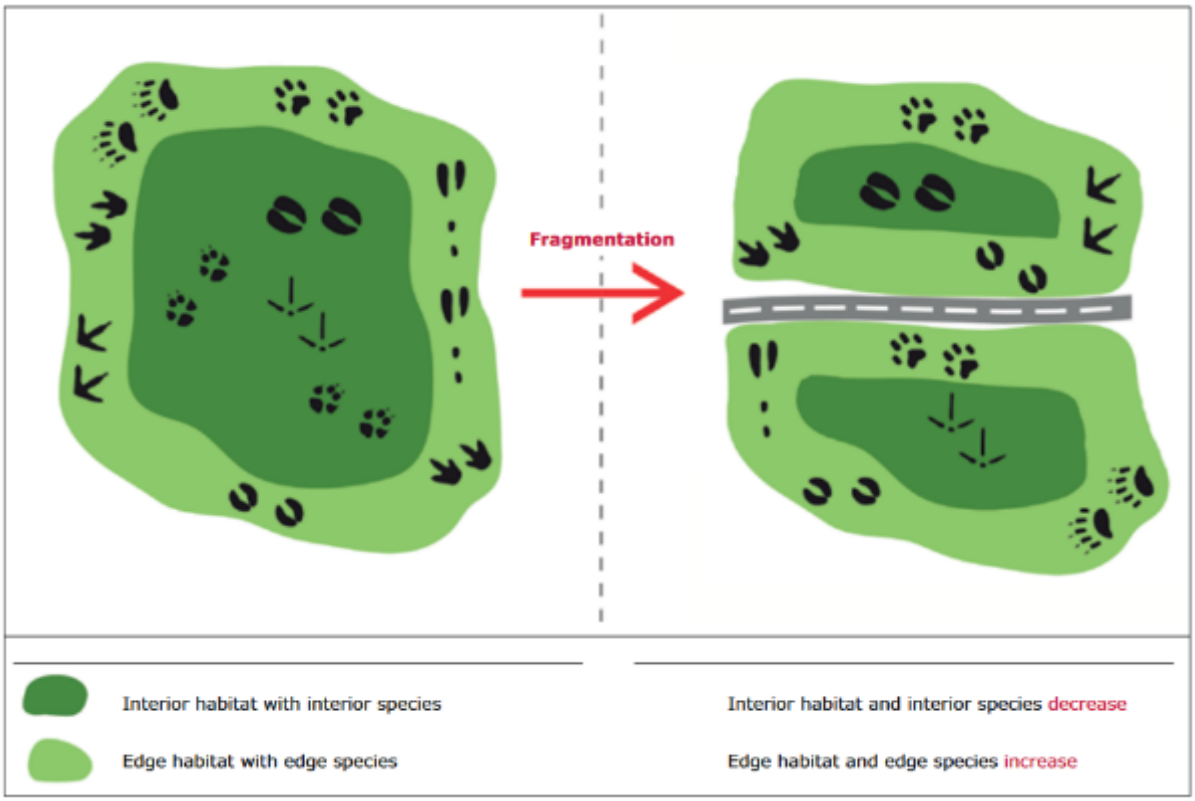

Figure 52. Illustration of the loss of core habitat (or interior habitat) caused by road construction cutting through a patch of habitat (European Environment Agency & Swiss Federal Office for the Environment (FOEN) 2011).

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The landscape components can be articulated in the space in very different forms, giving rise to very diverse configurations or spatial structures (Forman et al. 1986). The landscape has the following types of elements or spatial configurations:

- Patches: non-linear surfaces that are distinguished by their appearance from what surrounds them. The set of patches or patches forms a mosaic.
- Corridors: narrow, elongated terrain surfaces that differ in appearance from what surrounds them. The set of corridors forms a network.
- Matrix: corresponds to the landscape elements that occupy a greater surface and have a greater connection with the other spots, generally playing the dominant role in the operation of the landscape. The establishment of the matrix will be determined in the analysis of landscape diversity.

Landscape ecology and fragmentation analysis in the study area were assessed using open-source software and tools:

- Spatial Pattern Analysis Program for Categorical Maps (FRAGSTATS) is a spatial analysis program that allows quantifying the landscape's structure. The user defines the landscape subject to the analysis and can represent any spatial phenomenon. FRAGSTATS quantifies the spatial heterogeneity of the landscape as represented on a categorical map (McGarigal et al., 2012)
- Landscape Ecology Statistics (LecoS) is a plugin for QGIS software that allows delivering calculations of fragmentation, connectivity and landscape ecology (Jung 2016)

The following table summarizes the main parameters and indexes that were used to assess landscape ecology, fragmentation and connectivity parameters in Enga Province.

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Table 17. Landscape ecology metrics

Metric	Description
Land cover	Returns the total number of cells for each class in a classified land cover grid.
Landscape proportion	Defined as the class cell proportion of the number of total cells in a classified land cover grid.
Number of patches	Conducts a connected component labelling and returns all identified patches per class.
Patch density	Conducts a connected component labelling and calculates the identified area size per class.
Mean patch area	Returns the mean identified patch size multiplied with the exponentiated cell size value.
Patch cohesion index	Measures the cohesion of a focal class. Approaches 0 as the landscape becomes increasingly subdivided and less physically connected. The patch cohesion index measures the physical connectedness of the corresponding patch type.
Landscape division index	It is calculated as one minus the sum of individual patch area divided by total landscape area, summed across all corresponding landcover class type patches. Returns the probability that two random landscape cells are not in the same landcover class patch.
Splitting index	Equals the total landscape area squared and divided by the sum of patch areas squared, summed across all patches in the landscape.

Table 18. Land cover and proportion in Enga province between 2015-2019

Land cover class	Abb.	Area (ha)			Proportion		
		2015	2019	Delta	2015	2019	Delta
Shrubland	Shr	6369	6141	-228	0.655	0.631	-0.023
Herbaceous vegetation	Her	46734	46038	-696	4.805	4.733	-0.072
Cropland	Cro	83	81	-2	0.009	0.008	0.000
Urban areas	Urb	299	304	5	0.031	0.031	0.001
Sparse vegetation	Spa	23	209	-21	0.024	0.021	-0.002
Permanent water bodies	Wat	289	320	31	0.030	0.033	0.003
Herbaceous wetland	Wet	3033	5307	2274	0.312	0.546	0.234
Closed forest, evergreen broad leaf	Cfd	761434	761212	-222	78.281	78.258	-0.023

Closed forest, unknown	Cfu	51274	50543	-731	5.271	5.196	-0.075
Open forest, evergreen broad leaf	Ofd	60153	60196	43	6.184	6.189	0.004
Open forest, unknown	Ofu	42800	42347	-453	4.400	4.354	-0.047

In the 5-year period (2015-2019), forest areas, shrublands, and herbaceous vegetation decreased in Enga Province, whereas herbaceous wetlands increased (**Table 19**). These changes in land cover areas are derived from differences in the number of patches and patch density per class. The number of patches increased considerably in most of the land cover classes between 2015-2019, especially in forest ecosystems and herbaceous wetlands. The more patches, the more fragmented an area is. Similarly, the more patch density a class has, the higher fragmentation or lower connectivity it has. The only classes that experimented with a reduction in patch density were cropland, urban areas, sparse vegetation and herbaceous wetland. All the best (shrublands, forests, etc.) experimented with an increase in patch density, hence, more fragmented **Table 19**.

As the patch cohesion index decreases, then fragmentation increases in a certain area. As seen in **Table 19**, the path cohesion index decreased between 2015-2019 in shrublands, grasslands and forests. As the landscape division index and the splitting index increase, so does fragmentation. Both landscape division and splitting index increased between 2015-2019 in shrublands, grasslands and forests in Enga province. Our results suggest that connectivity has decreased in the forests, shrublands and grasslands in Enga Province.

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Table 19. Landscape ecology metrics' results from Enga Province

Land cover class	Abb.	Area (ha)			Number of patches			Patch density (N/km2)		
		2015	2019	Delta	2015	2019	Delta	2015	2019	Delta
Shrubland	Shr	6369	6141	-228	1620	1578	-42	25.436	25.696	0.260
Herbaceous vegetation	Her	46734	46038	-696	1720	1734	14	3.680	3.766	0.086
Cropland	Cro	83	81	-2	68	66	-2	81.928	81.481	-0.446
Urban areas	Urb	299	304	5	37	37	0	12.375	12.171	-0.204
Sparse vegetation	Spa	23	209	-21	21	16	-5	9.130	7.656	-1.475
Permanent water bodies	Wat	289	320	31	24	35	11	8.304	10.938	2.633
Herbaceous wetland	Wet	3033	5307	2274	422	733	311	13.914	13.812	-0.102
Closed forest, evergreen broadleaf	Cfd	761434	761212	-222	1631	1646	15	0.214	0.216	0.002
Closed forest, unknown	Cfu	51274	50543	-731	6496	6555	59	12.669	12.969	0.300
Open forest, evergreen broad leaf	Ofd	60153	60196	43	4286	4295	9	7.125	7.135	0.010
Open forest, unknown	Ofu	42800	42347	-453	6833	6843	10	15.965	16.159	0.194

Table 20. Landscape ecology indicator in Enga Province

Land cover class	Abb.	Patch Cohesion Index			Landscape Division			Splitting Index		
		2015	2019	Delta	2015	2019	Delta	2015	2019	Delta
Shrubland	Shr	7.8791	7.8625	-0.0167	0.999999865	0.999999871	6.0E-09	7404166.367	7769458.922	365292.555
Herbaceous vegetation	Her	9.6960	9.6614	-0.0346	0.999926701	0.999944579	1.8E-05	13642.73724	18043.80525	4401.06801
Cropland	Cro	6.3896	6.3896	0.0000	1	1	0	5059579675	5114277834	54698159
Urban areas	Urb	8.4519	8.4564	0.0044	0.999999987	0.999999987	0	76554850.65	75090587.24	-1464263.41
Sparse vegetation	Spa	8.6460	8.6043	-0.0417	0.999999987	0.999999989	2.0E-09	76215675.79	88300643.88	12084968.09
Permanent water bodies	Wat	8.5817	8.6028	0.0212	0.999999986	0.999999984	-2.0E-09	69096720.89	63219390.57	-5877330.32
Herbaceous wetland	Wet	8.9146	9.0115	0.0970	0.999999735	0.999999416	-3.2E-07	3770554.217	1713456.226	-2057097.991
Closed forest, evergreen broad leaf	Cfd	9.9801	9.9801	0.0000	0.408674569	0.40905398	3.8E-04	1.691116174	1.692201938	0.001085764
Closed forest, unknown	Cfu	9.3065	9.2949	-0.0116	0.999985727	0.999986299	5.7E-07	70061.04909	72986.93576	2925.88667
Open forest, evergreen broad leaf	Ofd	9.7650	9.7648	-0.0002	0.999810615	0.999810773	1.6E-07	5280.239795	5284.653639	4.413844
Open forest, unknown	Ofu	8.6034	8.5927	-0.0107	0.999997348	0.999997412	6.4E-08	377065.9405	386436.1572	9370.2167

4.2.6 Climate change modelling

Climate change scenarios were retrieved and analysed at different spatial and temporal resolutions. Monthly climate data (rainfall, maximum and minimum temperature) were retrieved from the WorldClim dataset (Hijmans et al. 2005; Fick & Hijmans 2017), which are available at a different spatial resolutions up to 1 km. For both datasets, current and future climate conditions were retrieved and analysed.

Table 21. Available climate information for climate change assessment

Dataset	Conditions	Res.		Period	Description
		Spatial	Temporal		
WorldClim	Current	1 km	Monthly	1970-2000	Max. temperature (ºC)
					Min. temperature (ºC)
					Rainfall (mm)
	Future	1 km	Monthly	2050 & 2070	Max. temperature (ºC)
					Min. temperature (ºC)
					Rainfall (mm)

Future conditions include the Intergovernmental Panel on Climate Change Sixth Assessment (IPPC6) climate projections from global climate models (GCMs) for different shared socio-economic pathways (SSPs). Different climate scenarios were used according to the data availability of IPPC6.

Table 22 summarizes different available global climate models (GCM), shared socio-economic pathways (SSP) and the climatic data availability, such as monthly average minimum temperature (tn), monthly average maximum temperate (tx) and monthly total precipitation (pr).

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Table 22. Availability of climate projections using different global climate models (GLM) and shared socio-economic pathways (SSP)

Global Climate Models (GCM)	SSP126	SSP245	SSP370	SSP585
BCC-CSM2-MR	tn, tx, prc	tn, tx, pr	tn, tx, pr	tn, tx, pr
CNRM-CM6-1	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
CNRM-ESM2-1	tn, tx, pr,	tn, tx, pr	tn, tx, pr	tn, tx, pr
CanESM5	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
GFDL-ESM4	tn, tx, pr	--, --, --, --	tn, tx, pr	-, -, pr, -
IPSL-CM6A-LR	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MIROC-ES2L	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MIROC6	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr
MRI-ESM2-0	tn, tx, pr	tn, tx, pr	tn, tx, pr	tn, tx, pr

Shared socio-economic pathways (SSP) are four different greenhouse gas trajectories adopted by IPPC6. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come.

Two of the four available scenarios were used to assess climate change in Enga Province: SSP370 (intermediate emission scenario) and SSP585 (high emission scenario). Climate model selection might lead to different climate predictions in a certain area; hence it is recommended to select a minimum of 5 rather distant models to represent a decent amount of uncertainty in climate model projections (Sanderson et al., 2015). Here we used all the available Global Climate Models described in **Table 22** and derived a median ensemble model to tackle uncertainty in the future climate projections.

Climate change assessments were done spatially throughout Enga Province. The following figures show current and future climatic conditions (rainfall, minimum and maximum temperature) using SSP370 and SSP585 scenarios, as well as the variation in those climatic parameters between current and future conditions. The future scenarios were based on a median ensemble model of the global climate models shown in **Table 22**.

In the following figures, the first row shows current (1950-2006) monthly climate conditions (minimum and maximum temperature and precipitation); the second row shows future monthly climate predictions projected to 2050, and the last row shows the difference between current and future climate conditions. This enables identifying locations where climate conditions will vary the most in the future, and hence it will allow identifying hotspots for the development projects and making recommendations regarding climate resilience for the project implementation.

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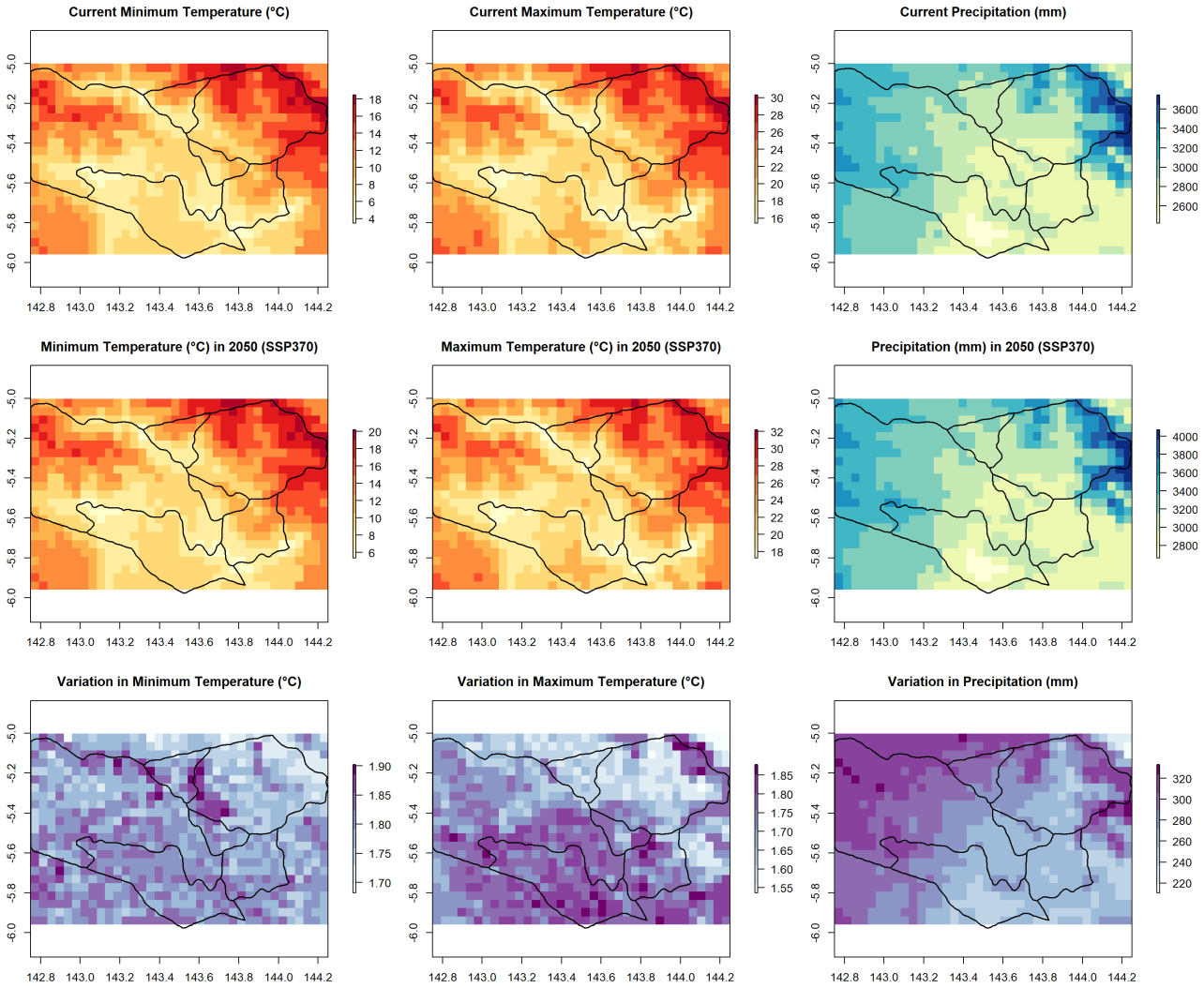

Figure 53. Spatial climate change assessment in Enga Province using SSP370. The first row shows current (1950 – 2006) climate conditions (minimum and maximum temperature and precipitation). The second row shows climate projections to 2050 using an ensemble model of 8 global climate models (GCMs). The last row shows the difference between current and future climate conditions. The climate layers have a spatial resolution of approximately 17.5 km.

Minimum and maximum monthly temperatures in the project area will increase on average by 1.8 °C, whereas variation in total rainfall will be low based on an intermediate emission scenario (SSP370) by 2050. In a higher emission scenario (SSP585), minimum and maximum monthly temperatures in the project area will increase on average by 2 °C, and total rainfall will slightly increase.

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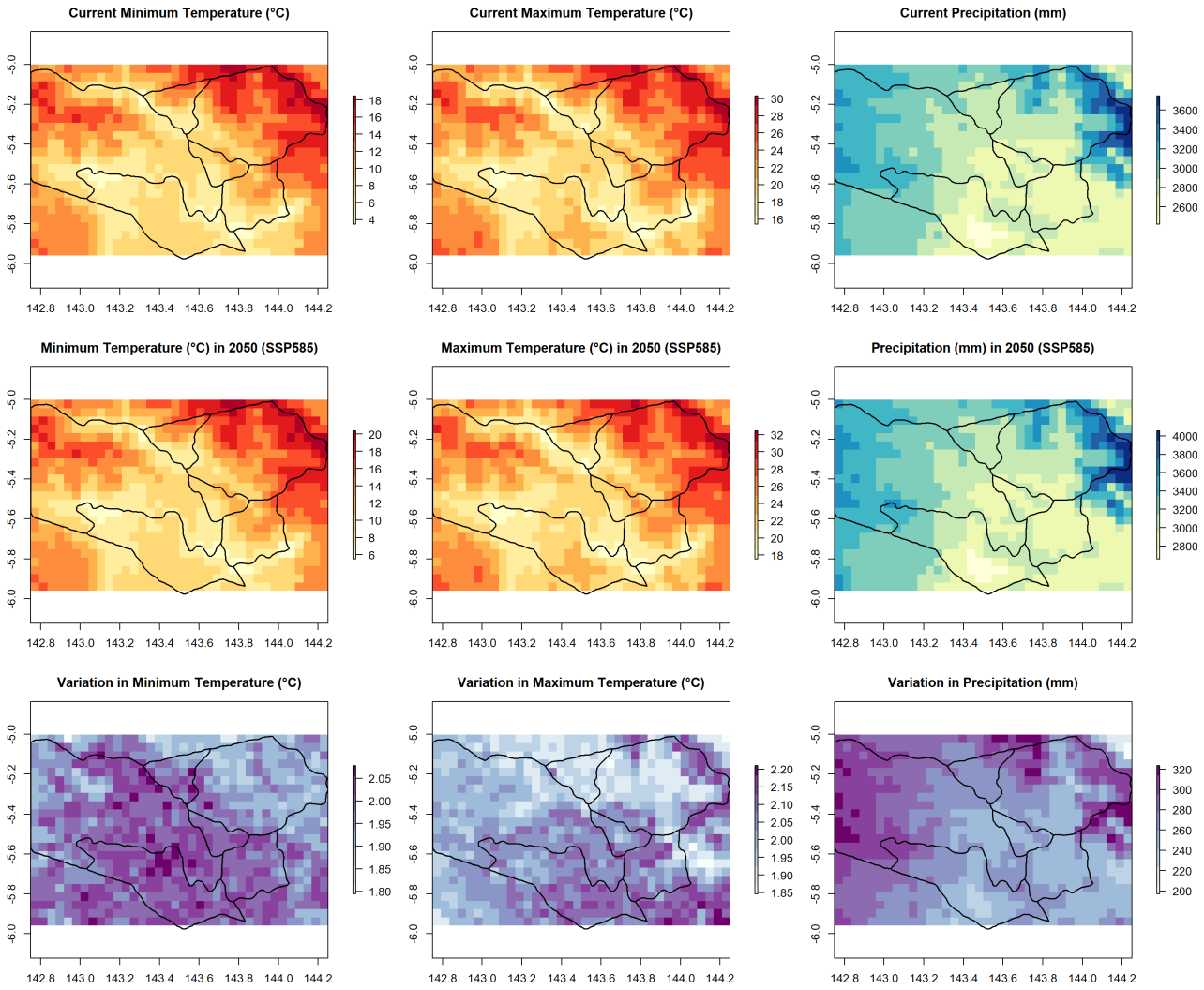

Figure 54. Spatial climate change assessment in Enga Province using SSP585. The first row shows current (1950 – 2006) climate conditions (minimum and maximum temperature and precipitation). The second row shows climate projections to 2050 using an ensemble model of 8 global climate models (GCMs). The last row shows the difference between current and future climate conditions. The climate layers have a spatial resolution of approximately 17.5 km.

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4.3 Multi-criteria analysis (MCA) for conservation areas

In general, terms, evaluating alternatives means comparing them by analysing the performance of each of them in relation to a series of very different criteria for selecting the best one. The evaluation will be multi-criteria and includes the following phases (1) formalizing an array of data for evaluation and (2) applying a decision model to the matrix and deciding on the basis of the results. The characteristics of the evaluation criteria are described below:

- Weighting coefficients of the criteria: the weights of the criteria will be adjusted to a scale that varies between 1 and 10.
- Scoring of alternatives: values will be standardized between 1 and 10, where 1 represents a poor performance with respect to the criterion, while 10 indicates a highly satisfactory behaviour.
- Matrix management: this method operates by obtaining the value of each alternative by weighted average (multiplying the assigned scores of each of them for each criterion by the weight of the criteria, then adding and dividing the result by the total weight sum). The alternative that obtains the highest value is chosen if the difference is significant, or discard the least value (Gómez, D. 2010).

$$Vai = \frac{\sum V_{ij} \times P_j}{\sum P_j}$$

Where:
Vai: Weighted average of the value obtained by alternative i
Vij: Standardized value attributed to alternative i for criterion j
Pj: Weight attributed to criterion j

Table 23. Analysis of alternatives matrix

Criteria	Weighting	Proposed alternatives (conservations areas)					
		A_1	**A_2**	**...**	**A_j**	**...**	**A_n**
C_1	P_1						
C_2							
...	...						
C_j	P_i				V_{ij}		

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…	…						
C_n	P_n						V_{nn}

The following tables present preliminary criteria for prioritizing potential conservation areas in Enga Province. It is important to mention that the final criteria and weights will be identified during the project implementation. If further stages are beyond the current feasibility studies, they can be used for the multi-criteria analysis in the following stages:

Table 24. Analysis of alternatives matrix

Criteria	Description	Range	Preliminary weights*
C1	Conservation needs assessment areas	Binary map: 100 to areas that require conservation assessment, 0 to the rest. This is based on the CEPA layers (see **Figure 36**)	10%
C2	Biodiversity priority areas	Binary map: 100 to biodiversity priority areas, 0 to the rest. This is based on the CEPA layers (see **Figure 37**)	10%
C3	Species richness (red list)	The red list species richness map (see **Figure 44**) will be reclassified between 0 (no species) and 100 (maximum number of threatened species with potential to occur in Enga province)	50%
C4	Tree cover	Tree cover, expressed in percentage (%). Forest habitats provide more habitats, shelter and food resources to a wide range of species.	10%
C5	Climate change – Variation in temperature	Species ranges are likely to shift due to changes in maximum temperature patterns. Variations in temperature layers (see **Figure 54**) will be reclassified (100 areas that maintain maximum temperatures and 0 areas where the maximum temperature will vary more than 3 degrees Celsius)	10%
C6	Climate change – Variation in temperature	Species ranges are also likely to shift due to changes in annual rainfall. Variations in rainfall layers (see **Figure 54**) will be reclassified (100 areas that maintain rainfall patterns and 0 areas where the maximum temperature will vary over 400 mm/year)	10%

Total	**100**

* to be discussed with stakeholders during the project implementation

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4.4 Mitigation alternatives

4.4.1 Land-use change emissions in Enga province

The land cover maps of the Copernicus Moderate Dynamic Land Cover project (Marcel Buchhorn et al. 2021) were accessed and extracted for Enga Province for the years 2015 and 2019 (**Figure 50**). The land cover maps were produced by the global component of the Copernicus Land Service, derived from PROBA-V satellite observations and ancillary datasets. The 100-m spatial resolution layers include a main discrete classification with 23 classes aligned with UN-FAO's Land Cover Classification System, as well as quality layers on input data density and on the confidence of the detected land cover change. For more details, the following links provide more information about the methodological framework of the land cover classification as well as the quality assessment for the years 2015 and 2019, respectively (https://doi.org/10.5281/zenodo.3939050 and https://doi.org/10.5281/zenodo.3939038)

In the PNG Climate Change and Forest Monitoring Web-Portal (Climate Change and Development Authority 2017a), it was possible to visualize a PNG Land-use map for the year 2015, which has a lower spatial resolution than the previously presented maps. Similarly, not only the spatial resolution is lower but also the radiometric and temporal resolution. This means that the number of land-use classes is lower in the PNG 2015 land-cover map compared to land cover maps of the Copernicus Moderate Dynamic Land Cover project. Finally, in order to estimate land-use change and emissions, a temporal frame is needed for comparison. The PNG Land cover map was only available for the year 2015. Therefore, we used the Copernicus Moderate Dynamic Land Cover project since it has higher spatial (100-m), radiometric (more land-use classes) and temporal (from 2015 to 2019) resolution.

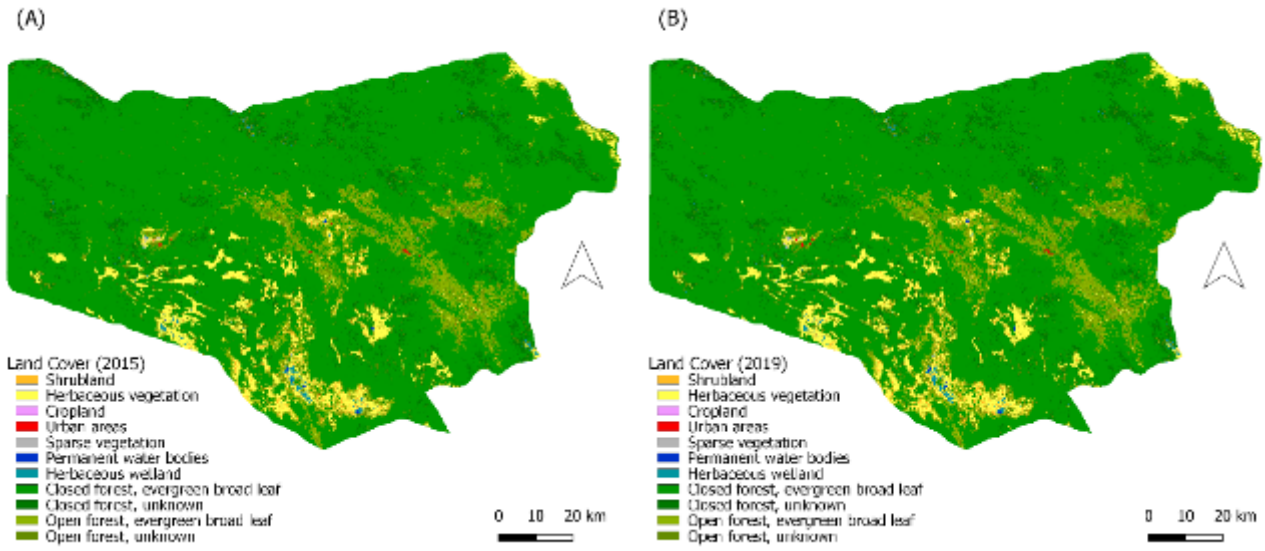

Figure 55. Land cover maps (Marcel Buchhorn et al. 2021) for Enga Province in (A) 2015 (Marcel Buchhorn et al. 2020b) and in (B) 2019 (Marcel Buchhorn et al. 2020d)

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Table 25. Land cover definitions.

Land Cover Class	Definition
Shrubland	These are woody perennial plants with persistent and woody stems and without any defined main stem being less than 5 m tall. The shrub foliage can be either evergreen or deciduous
Herbaceous vegetation	Plants without persistent stem or shoots above ground and lacking definite firm structure. Tree and shrub cover is less than 10 %.
Cultivated and managed vegetation/agriculture (cropland)	Lands are covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.
Urban areas	Land covered by buildings and other man-made structures
Sparse vegetation	Lands with exposed soil, sand, or rocks and never has more than 10 % vegetated cover during any time of the year
Water bodies	lakes, reservoirs, and rivers. Can be either fresh or salt-water bodies.
Herbaceous wetland	Lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water
Closed forest, evergreen, broad leaf	tree canopy >70 %, almost all broadleaf trees remain green year-round. Canopy is never without green foliage.
Closed forest, unknown	Closed forest, not matching any of the other definitions
Open forest, evergreen, broad leaf	top layer- trees 15-70 % and second layer-mixed of shrubs and grassland, almost all broadleaf trees remain green year-round. Canopy is never without green foliage
Open forest, unknown	Open forest, not matching any of the other definitions

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In the 5-year period (2015-2019), most of the land cover classes decreased (especially forests, grasslands and shrublands) except herbaceous wetlands (**Table 26**)

Table 26. Land cover dynamics in Enga province between 2015 and 2019.

Land cover class	Abb.	Area (ha)		
		2015	2019	Delta
Shrubland	Shr	6369	6141	-228
Herbaceous vegetation	Her	46734	46038	-696
Cropland	Cro	83	81	-2
Urban areas	Urb	299	304	5
Sparse vegetation	Spa	23	209	-21
Permanent water bodies	Wat	289	320	31
Herbaceous wetland	Wet	3033	5307	2274
Closed forest, evergreen broad leaf	Cfd	761434	761212	-222
Closed forest, unknown	Cfu	51274	50543	-731
Open forest, evergreen broad leaf	Ofd	60153	60196	43
Open forest, unknown	Ofu	42800	42347	-453

The land cover classes and carbon stocks provided by Cauya et al. (2019) were assigned to the Copernicus Land cover classes. The following table shows the difference in area between 2015 and 2019 in Enga Province per land cover class and the assigned carbon stock value assigned per each. Between 2015 and 2019, there was a negative carbon balance of approximately 95000 tC due to land cover dynamics, which represent approximately 351,500 tCO_2 emitted. We acknowledge that accurate carbon reference data should be provided in order to properly estimate the carbon balance due to land use chance (Vincent et al. 2015). GoPNG has advanced significantly in estimating carbon reference levels for forest ecosystems (Government of Papua New Guinea 2017) but not for all land cover or vegetation classes.

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Table 27. Land cover dynamics and carbon stocks in Enga Province between 2015 and 2019.

Land cover	Total carbon (t C ha^{-1})*	Area difference (ha)	Carbon balance (t C)
Shrubland	13.5	-228	-3078
Herbaceous vegetation	3.4	-696	-2366.4
Cropland	4.13	-2	-8.26
Urban areas	0	5	0
Sparse vegetation	3.7	-21	-77.7
Permanent water bodies	7.9	31	244.9
Herbaceous wetland	3.7	2274	8413.8
Closed forest, evergreen broad leaf	82.4	-222	-18292.8
Closed forest, unknown	82.4	-731	-60234.4
Open forest, evergreen broad leaf	47.8	43	2055.4
Open forest, unknown	47.8	-453	-21653.4
Total			**-94996.86**

* Estimate values from (Mauya et al. 2019)

4.4.2 Capturing CO_2 through forest plantations

Tree plantations in the Pacific region have reported varied biomass and carbon sequestration rates. For instance, tree plantations can produce 10-40 m^3 biomass per hectare per year. If we assume a conservative scenario of 10 m^3 ha^{-1} $year^{-1}$ and the use of a medium-density tree species (density of 500 kg m^{-3}), it would be possible to capture five tones (t) of biomass ha^{-1} $year^{-1}$ representing approximately 2.25 tC ha^{-1} $year^{-1}$ or 8.325 tCO_2 captured ha^{-1} $year^{-1}$(1tCO2 is equivalent to approximately 3.7 tC). Even though it could be possible to have more productive forest plantations in Enga Province due to the suitable climatic conditions, no specific studies have been found. Therefore, in a conservative scenario (depending on the purpose of the forest plantations), we are assuming biomass rates of 10 m^3 ha^{-1} $year^{-1}$.

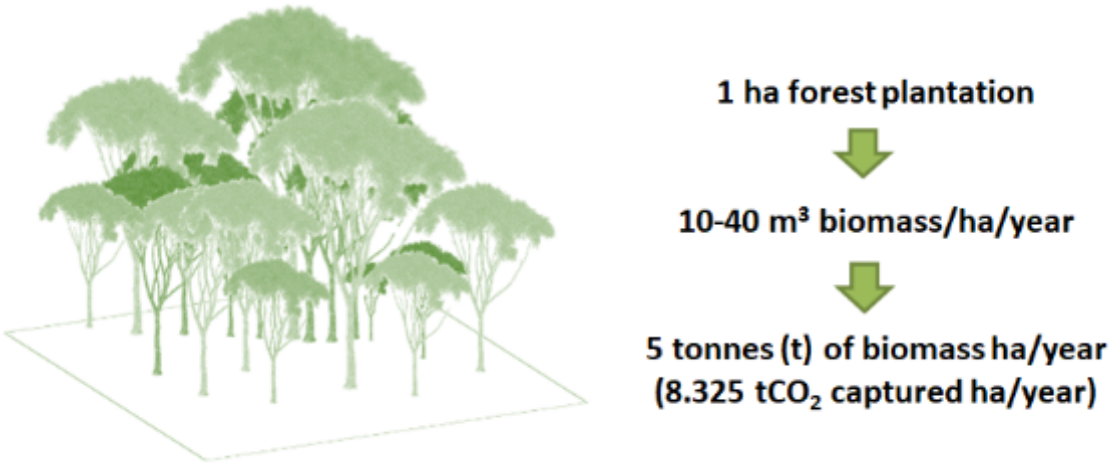

Figure 56. Scheme of CO2 capture through forest plantations

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4.5 Deforestation and forest degradation indicators

4.5.1 Existing products for forest monitoring

The Global Forest Watch (GFW) has different forest monitoring products, including a time-series analysis of Landsat images for characterizing global forest extent and change from 2000 through 2020 (Hansen et al., 2013). Forest loss during the period 2000–2020 is defined here as a stand-replacement disturbance or a change from a forest to a non-forest state. These layers are encoded as either 0 (no loss) or else a value in the range 1–20, representing loss detected primarily in the year 2001–2020, respectively. These layers can be used to monitor changes in forest cover throughout the years. Even though currently there is data availability until 2020, these data are updated continuously. As an example, in the figure below, blue colours show areas where forests have been recently lost, whereas red colours areas that have been deforested in the 2000s.

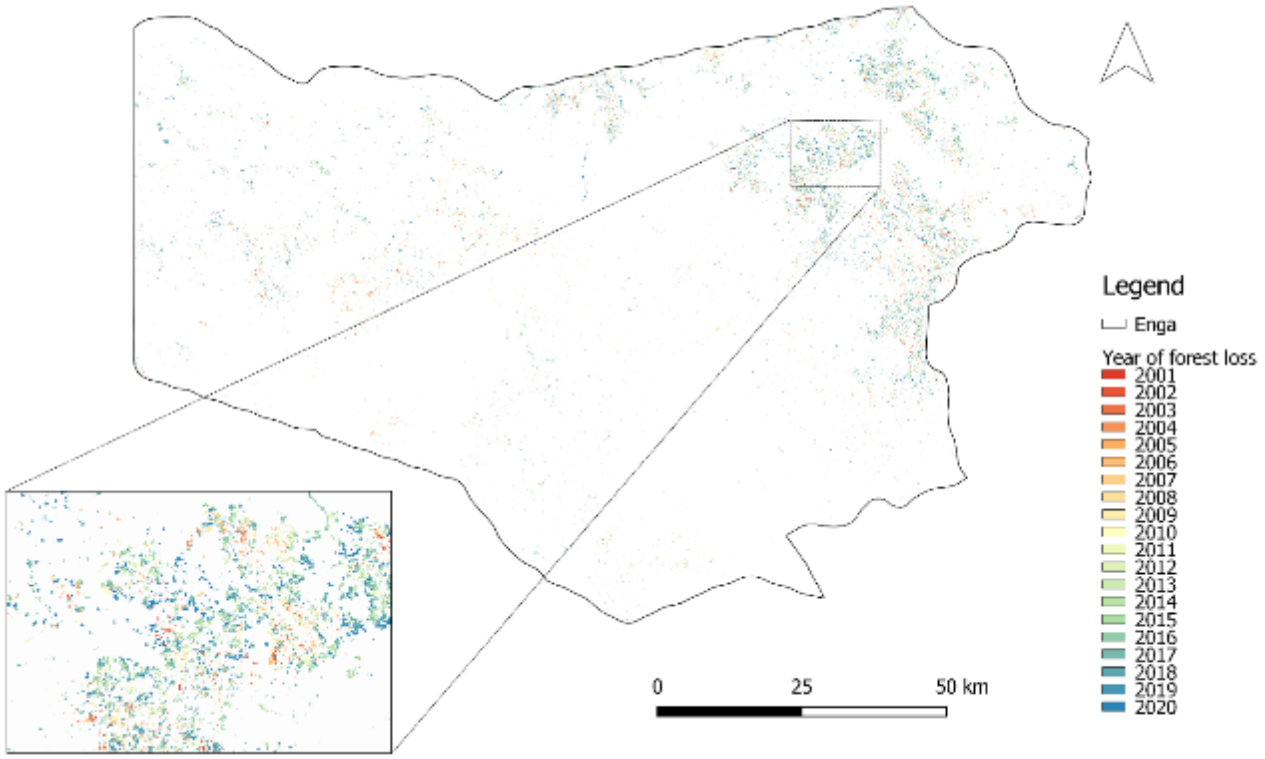

Figure 57. Location of forest loss detected between 2001-2020 in Enga Province. Source (Hansen et al. 2013)

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4.5.2 Landsat time-series analysis

Landsat satellite images have a spatial resolution of 30 meters, which allows for the detection of changes in land cover within the study area. Different objects, such as vegetation, water or soils, reflect the sun's radiation in a different way, and satellites capture this spectral information in images. For instance, vegetation absorbs a large proportion of incident radiation in the visible spectral range and relatively lower radiation in the infrared, which is not shown on other surfaces, such as soils and water (Jones & Vaughan 2010). This spectral variability makes it possible to characterize different objects, also making use of different indicators such as the Normalized Difference Vegetation Index (NDVI) derived from the red (Landsat band 3) and infrared spectrum (Landsat band 4), which allows estimating the vigour and density of vegetation or also differentiating between degraded and healthy vegetation (Jones & Vaughan 2010).

Annual layers of the Normalized Difference Vegetation Index (NDVI) can be calculated from Landsat satellite imagery over a 15-year period (2006-2022). Landsat data is freely available from the United States Geological Survey (USGS) Earth Explorer service. Time series analysis uses different metrics such as NDVI to analyse patterns over time at a particular location. Trend series analysis (Hermosilla et al. 2015) can be used to identify abrupt changes in land cover in Enga Province by detecting steady and recovery states due to disturbance events. In this way, it will be possible to identify locations within the study area that have experienced significant negative and positive changes in vegetation cover and identify when the change happened. This information can serve as evidence for identifying changes in land cover in Enga Province. The following figure shows an example of how it is possible to detect abrupt changes in vegetation through a time series analysis of NDVI from 1980 until 2010.

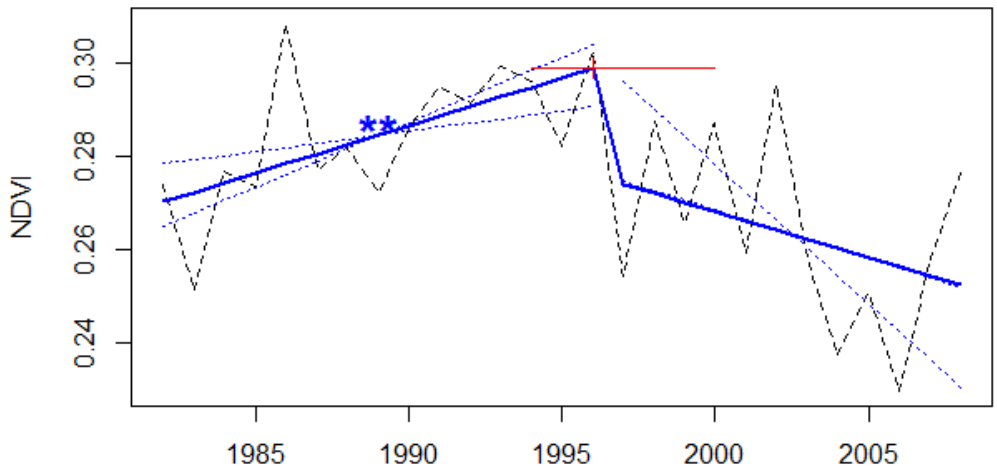

Figure 58. Example of trend analysis in mean annual NDVI for a single grid cell location.

The following images show different existing approaches to detect land cover changes and identify the period when a disturbance event has happened. In the previous image, the main disturbance event happened in the year 1996, but this is for a single grid location. The same analyses can be

done of every single grid or pixel within a targeted study area (such as Enga Province). In the figures below, each colour represents the year in which that location experienced a significant disturbance (e.g. deforestation event). Breakpoints in the time-series analysis can be calculated by a linear, simple "top-down" approach, a moving window neighbour average approach or using the additive season and trend (BFAST) function. The "top-down" approach is computationally more efficient compared to the "window" or "bfast" approaches. Nevertheless, they all identify temporal disturbance based on time-series analysis.

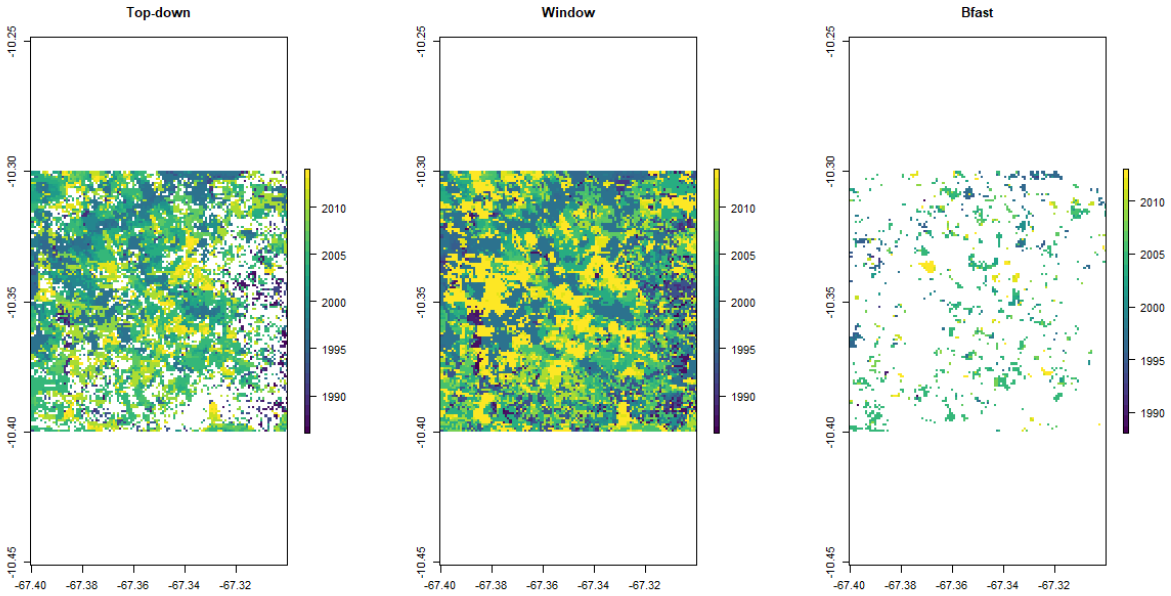

Figure 59. Examples of different approaches to identify areas that have been disturbed and the period when the event happened.

Annual NDVI values can be hence derived from Landsat satellite images in any given monitoring period based on the methodology of (Pironkova et al. 2018) in order to identify trends and cut-off points in the time series analysis. All these analyses can be done by freely available software such as R software (R Core Team 2020) using the packages "raster" (Hijmans et al. 2020), "greenbrown" (Forkel & Wutzler 2015) and "bfast" (Verbesselt et al. 2019).

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5 REVIEW OF DEVELOPMENT PLANS, INSTITUTIONAL AND STAKEHOLDERS

5.1 Institutional stakeholders in Enga province

There are different institutions directly or indirectly involved in climate change adaptation and mitigation issues in Enga province. The list below presents some of the most relevant institutions for the current climate change feasibility study in Enga:

Enga ***Provincial Authority (PA)*** is the main institution that decentralized government decisions in Enga, including agriculture, fishing, trade and industry, land and land development, forestry and natural resources. Provincial governments also have certain limited powers to raise revenue, including the right, subject to certain conditions, to impose sales and services tax.

The ***Papua New Guinea Forest Authority (PNGFA)***, part of the ***Department of Forestry***, is the government body responsible for monitoring and controlling the wood and forest-based industries and the management of PNG's forest resources. There are three key arms of the forestry administration of PNG: (i) the National Forest Board, (ii) Provincial Forest Management Committees and (iii) the National Forest Service.

The ***Conservation and Environment Protection Agency (CEPA)*** aims at ensuring that natural and physical resources are managed to sustain environmental quality and human well-being. The roles of CEPA include Environment management policy development, Biodiversity protection policy development, Pollution control and the regulation of hazardous substances, Management of Water Resources, Environmental Impact Assessments, Biodiversity assessment and data management, Hydrological investigation, data collection and analysis, Coordination of donor-funded programs and Education & Awareness.

The ***Climate Change and Development Authority (CCDA)*** is the main institution that coordinates the Climate Change efforts of the Government of Papua New Guinea. CCDA has four divisions: (i) Corporate Services, (ii) Adaptation and Projects, (iii) REDD+ and Mitigation, and (iv) Measurement, Reporting and Verification (MRV) and National Communication.

The ***National Disaster Centre (NDC)*** is part of the Department of Provincial & Local Level Government Affairs and provides the necessary and appropriate disaster management services to the people of Papua New Guinea. There are two divisions at NDC: Risk Management (RM) and Community Government Liaison (CGL). The Risk Management Division deals with pro-active matters through research, analysis, awareness, education and training, whilst the Community Government Liaison handles rapid response and operations. Similarly, NDC has Provincial Disaster Centres, including Enga. Under emergencies, the Provincial Disaster Relief Committee (PDRC) might also be part of conducting disaster situational assessments.

The ***National Research Institute (NRI)*** aims at providing quality research which contributes to evidence-based public policies and decision-making processes that improve service delivery, leading

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to a better quality of life for all Papua New Guineans. NRI has eight research programs: (i) Building Safer Communities Program, (ii) Development Indicators Program, (iii) Economics Policy Program, (iv) Gender in PNG Program, (v) Governance Program, (vi) Informal Economy Program, (vii) Sustainable Land Development Research Program and (viii) Education Research Program.

The ***Department of Agriculture and Livestock (DAL)*** is the lead government agency responsible for the management of the agriculture sector in Papua New Guinea. It is divided into three deputy secretary sections: (i) Provincial Agriculture Technical Services, (ii) Corporate Services and (iii) Policy. Under the Deputy Secretary of Provincial Agriculture Technical Services, there are 4 (Southern Region, Highlands Region, Island Region, Northern Region) Provincial and Industry Support Services (P&ISS)

The ***Department of Lands and Physical Planning (DLPP)*** provides physical planning, lease information, and land information services. The Department has four (4) main functions: (i) the ROT (Register of Titles), which takes responsibility for all Land Titles in the Country, and (ii) the Deputy Secretary for Customary Land, that is the section responsible for Land Acquisition, (iii) the Deputy Secretary for Land Services, where all Survey Information is kept, including the office of the Surveyor-General, the Valuer General, the Chief Physical Planner, the Alienated Land section and (iv) the Deputy Secretary for Corporate Affairs office, which deals with the welfare of the staff of the department.

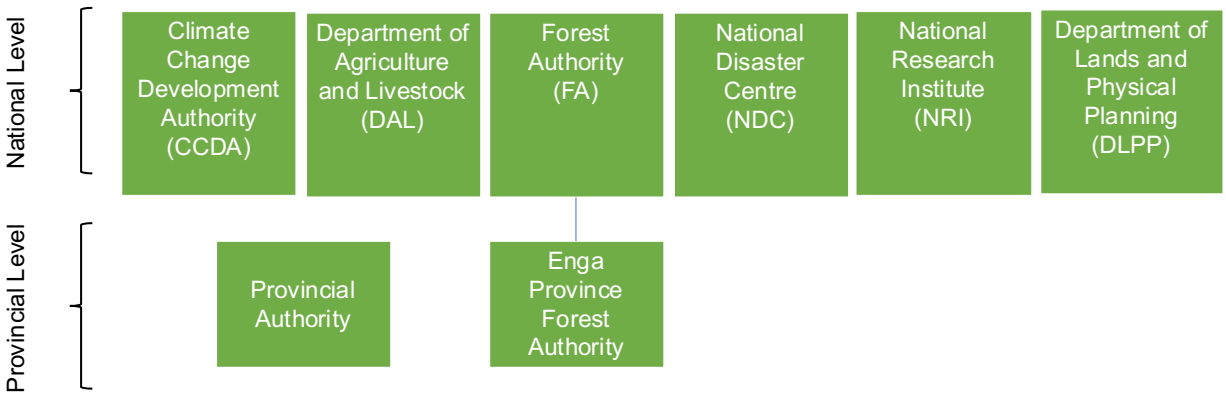

Figure 60. Relevant national and provincial level institutions

5.2 Institutional and governance necessities and opportunities

After discussions with provincial authorities in Enga Province, the consultant team identified institutional and governance gaps. The main struggles stated during the consultation were:

(i) lack of funding ("*Funding is an obstacle that hinders our work to be flexible to work closely with our rural communities*", "*Currently funding is a major issue, we have budget constraints, new projects to implement and our budget is cut down due to Pogera shut down*"),

(ii) lack of manpower ("*The main critical issue to implement the project is short of man power at the Provincial Level*", "*We also have capacity issues at the Provincial Level that is not enough man power*"),

(iii) Lack of capacity building and training on climate change and biodiversity issues. Provincial-level authorities could provide technical assistance to resource owners and increase extension services to remote villages by having more resources.

5.2.1 Lack of funding and budget constrains

The provincial economy in Enga is directly linked to the mining industry. The currently closed Pogera mine, which has been one of the main revenue sources of Enga Provincial Authority (EPA), has an important impact on the provincial budget. This is due to revenues and direct and indirect employment to many local people in Enga. This represents an opportunity to diversify the economy at the provincial level in the long term. Shorter-term opportunities could be seeking technical and capacity support for other organizations, including NGOs, international donors and financial institutions.

5.2.2 Lack of manpower

Linked to lack of funding, the provincial authority and the Enga Forest Authority currently experience lack of manpower. A key component in reaching out to local communities is extension activities related to agriculture, livestock and forestry. During interviews with both local communities and government institutions, the lack of extension activities and technical support to communities was mentioned several times.

5.2.3 Lack of training and capacity building

Provincial-level authorities could provide technical assistance to resource owners and increase extension services to remote villages by having more resources. Similarly, data access and data transfer are hindered by unstable internet connections in the province and a lack of online and digital databases at the institutional government level. Implementing digital databases would improve data flow and facilitate and speed up certain processes.

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5.3 Review of current provincial development plans

5.3.1 Previous development plans

For the Agriculture and Livestock branch, the strategic direction for Enga from the 2011-2015 development plan was to develop and grow the agriculture sector (food crop, cash crop and livestock), manufacturing, forestry, inland fisheries and eco-tourism sectors. Key areas on which the plans focused were: (i) Promotion of household food security and commercial food crops through expanded smallholder productions, (ii) Development of commercial cash crops using high potential agricultural land, (iii) Land rehabilitation and land tenure reform for poor households and new commercial farming enterprise.

For the Commerce branch, the five-year development plan from 2011 to 2015 was to redirect profits from non-renewable resources into supporting agriculture, forestry, tourism and inland freshwater fisheries. The aim is to grow and expand commercial activities and industry in the five districts. Key areas that the plans focused on were (i) Promoting local economic empowerment through small business development and community-based tourism initiatives. Contribute to GDP growth through increased job creation, redistribution and transformation using tourism and improving seasonality patterns; (ii) To promote and maintain cultural education.

For the community development branch, the key areas of focus in the 2011-2015 Development Plans were: (i) Create partnerships between NGOs, donor agencies, churches, CBOs, and private companies for the community development sector, (ii) Mobilise youth and women's group to address law and order and social problems affecting communities and ambitions to curb tribal fighting in the province, (iii) Mobilize women and youth to participate in development programs, township clean-up and economic projects for rural areas. (iv) Ensure Gender equality and equity in community-based activities, and (v) improve village people's social security and harmony.

5.3.2 Ongoing development plans

During the scoping and field survey phase, the consultant team requested provincial development plans for Enga. The consultant team was informed that the Enga Strategic 2022-2030 development plan is still being drafted, and hence, it could not be fully incorporated and analysed in the present report. Nevertheless, some components of this development plan are discussed during discussions with provincial authorities. The following table presents some of the findings regarding the upcoming provincial development plan (2002-2030) under different development sectors.

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Table 28. Some preliminary components of Enga's Provincial Development Plan (2022-2030)

Priority sectors/areas	Initiatives
Forestry / Biodiversity	- Implementation of REDD+ activities at the provincial level - Giving out tree seedlings to all farmers to plant along the river Lai together with the Department of Forestry (as natural barriers against flooding events) - Giving women tree seedlings to make a nursery to start tree planting - Community engagement to make a nursery for the seedlings of trees (*Eucalyptus*)
Energy	- Promotion of solar energy initiatives - Implementation of hydroelectric power plants in all Enga districts - Feasibility study regarding whether Lomban hydroelectric plant in Wabag can power the new hospital being built
Agriculture and Livestock / Food and Nutrition Security	- Crop rotation and integrated cropping - Poultry Processing Plan to encourage households to go into chicken raising - Support increase of fallow arable land - Introduction of new "kaukau" and sweet potato vine to farmers to breeding crops in less time - Issuing new corn seedlings to farmers - Supply of seedlings to farmers - Create an SME revolving finance to assist farmers in increasing the production and quality of livestock and cash crops. - Establish livestock and cash crop seedling distribution centres - Establish base camps for plant breeding and variety trials for smallholder farmers - Support coffee production - Support water harvesting and irrigation - Improve access to land for agriculture - Increase expenditure on extension services and agriculture research base camps and trailing to help smallholder farmers - Building food storage facilities (food/vegetable depots) and processing facilities to improve food security - Enhancing agroforestry to support food security - Promote food security through expanded smallholder village base productions - Establish soft finance as seed money for helping smallholder farmers to start agribusiness enterprise - Support SMART Family Business approach developed by the Community Development Branch of Provincial Authority to create enabling environment for resilient communities to improve food security and farming methods and to address law and order issues in the wards by networking with different actors and other branches of Enga Provincial Government

During conversations with provincial authority stakeholders, it was stated that the vision of Enga is to "*be a place of strong, healthy and safe communities able to provide for the social and economic*

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well-being of its people while sustaining its unique culture, language and environment". Similarly, the strategic plan includes eight key principles of action to support the vision:

- Partnerships
- An inclusive and tolerant society
- Environmental stewards
- Effective and efficient Enga Provincial Administration
- Growing Financial Self-sufficiency
- Awake to the transition from traditional to modern
- Leverage natural and human resources for long term prosperity
- Enga Provincial Government and Administration the driving force of change

The plan recognises the need for five (5) strategic game-changers: (i) law and order, (ii) climate change, (iii) jobs and skills development, (iv) access to renewable electricity and water, and (v) financing for development. Twenty (20) strategic initiatives were chosen to achieve Enga's vision.

Table 29. Enga Strategic Initiatives (Enga Provincial Administration 2022)

Topics	Strategic initiatives
Governance and Administration	1. Create and maintain Law and Order in Enga
	2. eEnga
	3. Improve Public Service Delivery
	4. Donor and development partner support
	5. StepUp! Enga Project Implementation Unit (PIU)
Environmental Sustainability	6. National Electricity Grid Supplied by Enga Hydropower and Renewable Energy Powe Stations
	7. Solar Household & Farm Pumps
	8. Climate Resilient Green Growth Projects
Social and Community	9. Improved Health Outcomes
	10. Sustainable Population Growth
	11. Tourism Ramp Up
	12. Tertiary and Vocational Education Excellence
	13. Improved Early Childhood, Junior and High School Outcomes
	14. Harmonise Local. District and Provincial Planning and Implementation
Economy and Infrastructure	15. 70% Access to Electricity and Water
	16. Enga Infrastructure Facility
	17. Commercial Agriculture
	18. Enga SME and Agribusiness Microfinance Facility
	19. Boosting Employment
	20. Enga Business, Investment and Trade Office

Strategic Initiative 8 (Climate Resilient Green Growth Projects) is directly linked to the scope of this report (Feasibility Studies on Improved biodiversity, conservation and land-use in Enga province). The main actions under this initiative include (i) sustainable forests (REDD+) and sustainable

landscape, (ii) climate-smart agriculture, (iii) water conservation and access, (iv) green industries and jobs, (v) green infrastructure, transport, energy and buildings and (vi) cross-cutting inclusive green growth interventions.

6 RECOMMENDATIONS

An important aspect of the "Improved biodiversity and land/forest ecosystems conservation restoration and sustainable use" study is related to potential mitigation actions in Enga Province. A priority sector in this context is forestry and land use. Policies, regulations, and plans on sustainable land use, biodiversity, and natural resources management must be prepared at the provincial level. The agriculture sector and food security are key in Enga, especially considering climate change's current and future effects and impacts. Therefore, we recommend that management plans for economically and traditionally important tree species are drafted, such as "karuka" (*Pandanus julianetti*), "kapiak" (*Ficus dammaropsis*) and "breadfruit" (*Artocarpus altilis*). These species provide habitat and food for fauna and are also important for food security and economic support in Enga.

Other potential sustainable land uses, biodiversity, and ecosystem management plans include riverbanks' revegetation within flooding areas and revegetation of mountain tops with high slopes where vegetation or forest cover has been removed. Different bamboo species (*Guadua spp*) are currently used and propagated in Enga province mainly for construction purposes. Bamboo species tend to have high growth rates and are suitable in areas with water accessibility, such as riverbanks. The forest authority is currently planning to increase the capacity of tree nurseries in Enga province, both for commercial species such as *Eucalyptus spp.* and *Pinus spp.* as well as native species such as *Nothofagus spp.* We recommend that the forest authority is given technical and financial support to implement its 5-year plans and objectives. Suppose there are enough seedlings of native species. In that case, it is recommended to establish enriching plantations in disturbed or secondary forests in order to improve habitat quality and conservation value of forest fragments in Enga.

After discussions with provincial authorities in Enga Province, the consultant team identified institutional and governance gaps. The main struggles stated during the consultation were: (i) lack of funding, (ii) lack of manpower and (iii) lack of capacity building and training on climate change and biodiversity issues. Provincial-level authorities could provide technical assistance to resource owners and increase extension services to remote villages by having more resources. Hence, it is recommended that provincial authority's capacities be strengthened in cross-cutting issues such as climate change, biodiversity, and environmental issues. For instance, the Enga PNG Forest Authority is planning to identify and further develop three afforestation and reforestation locations throughout Enga province and rehabilitating tree nurseries, both private and communal. The consultant team will give technical support for improving the existing plans and policies in the forestry sector in Enga. We recommend giving specific training to staff from Enga Forest Authority in terms of Geographic Information Systems (GIS), data management and data collection (e.g. using the OpenDataKit-ODK software)

In this report, preliminary degraded areas were identified by using freely available sources, including (i) soil organic carbon stock change, (ii) forest cover loss and (iii) land cover change layers. This preliminary identification of degraded lands is a desktop study done using available coarse resolution layers (up to 250-metre spatial resolution). Before the project implementation, the final identification of degraded areas should occur with ground-truth data to identify the final location of areas to be managed, restored, and reforested. We recommend carrying out participatory campaigns on land

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use cover classification, where different stakeholders participate (e.g. forest authority, UNDP, provincial authority and members of local communities).

The presence or absence of key species in Enga province should be confirmed during qualitative surveys or by community participation (e.g., using key species fact sheets). Once certain threatened species are confirmed, another species distribution models (SDM) approach should take place to update the species richness map. Similarly, it is recommended to study functional connectivity in Enga province once key species are determined. This could represent another important criterion for identifying potential conservation areas in Enga Province.

For the estimates of land-use change emission, we used available reference values (Cauya et al., 2019). We acknowledge that accurate carbon reference data should be provided in order to properly estimate the carbon balance due to land use chance (Vincent et al. 2015). GoPNG has advanced significantly in estimating carbon reference levels for forest ecosystems (Government of Papua New Guinea 2017) but not for all land cover or vegetation classes. For future estimates, it is recommended to use, if existing, primary calculations of carbon stock per land-cover type.

The consultant team proposes using a spatial-multicriteria analysis for identifying potential conservation areas in Enga. Some of these criteria include but are not limited to: (i) conservation needs assessment areas, (ii) biodiversity priority areas, (iii) species richness (red list), (iv) tree cover, (v) variation in temperature and (vi) variation in temperature. These are preliminary criteria that could be improved or modified in future studies.

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