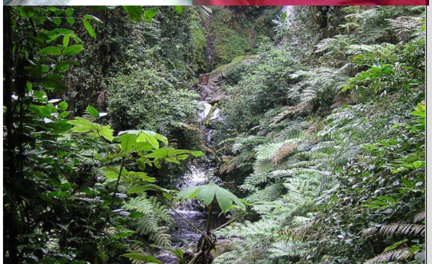
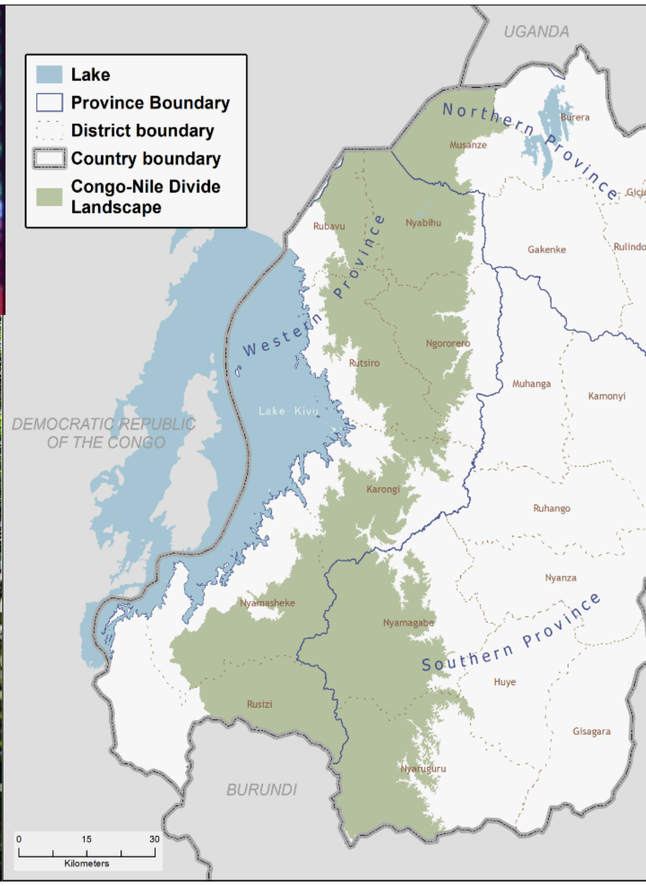
Rapid Systematic Conservation Plan

Congo Nile Divide - Rwanda





October 2022

Wildlife Conservation Society

Rapid Systematic Conservation Plan

Congo Nile Divide – Rwanda

Priority Areas for Intervention

October 2022

Suggested reference:

Wildlife Conservation Society. 2022. Rapid Systematic Conservation Plan for the Congo Nile Divide of Rwanda. Prepared for the Wildlife Conservation Society and Ministry of Environment. Unpublished Technical Report. Port Elizabeth.

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Cover images:

Centre Map sourced from the Wildlife Conservation Society's Feasibility Study (Wildlife Conservation Society, 2022).

Photographs: Top Left, Bottom Left, Top Right and Bottom Right sourced from Pangea Travel; Left Middle sourced from Photographer Bluesypete; and Right Middle sourced from Geoexo.

Funding was provided by the Green Climate Fund (GCF).

I. Executive Summary

The Wildlife Conservation Society (WCS), under the auspices of Rwanda's Ministry of Environment, initiated this rapid systematic conservation plan (SCP) for the Congo Nile Divide (CND) region. The area lies along the western boundary of Rwanda, where it subdivides the catchments of the Congo and Nile rivers. The Rwandan portion of the CND stretches from the Virunga Mountains and Volcanoes National Park (VNP) in the north, southward to Gishwati-Mukura National Park (GMNP) and then to Nyungwe National Park (NNP) at the southern boundary. The extensive Lake Kivu borders the western periphery. The majority of Rwanda's remaining montane forests are restricted to the national parks, which support a variety of threatened and endemic species. A few fragmented forest patches are situated outside of the National Park boundaries, including the Dutake and Karehe-Gatuntu Protected Forest Reserves.

Landcover change (especially for widespread smallholder agriculture), fuelwood harvesting, and human-induced fires, coupled with climate change impacts, especially landslides, erosion and downstream flooding, have compromised the delivery of critical ecosystem services derived from these forests. A detailed spatial analysis of biodiversity in the Congo Nile Divide was necessary to delineate priority areas for the long-term conservation and restoration of forests, and the sustainable management of landscapes, in order to secure the ecosystem services needed to improve the resilience of vulnerable communities to climate change impacts.

The Congo Nile Divide systematic conservation plan will assist with the implementation of the Rwanda Government's "*Building Resilience of Vulnerable Communities to Climate Variability in Rwanda's Congo Nile Divide through Forest and Landscape Restoration*" Project. The goal of the project is to enhance the resilience of vulnerable rural communities, reduce CO_2 emissions, build capacity for integrated spatial planning and increase the extent and integrity of forest ecosystems.

This spatial biodiversity assessment identified priority areas for a variety of place-bound project interventions, including the restoration of natural forest, establishment and improvement of protective forest on steep slopes and along riparian areas; and to implement biodiversity-friendly agroforestry in order to reduce landslides, erosion and downstream flooding (Wildlife Conservation Society, 2022). Over and above these place-bound interventions are a variety of other mechanisms for promoting the sustainability of rural livelihoods and protecting montane forest in the CND landscape.

<u>The Systematic Conservation Plan analyses covered a range of biodiversity features, including:</u>

- Terrestrial ecosystems, including their IUCN Redlist threat status and protection level. The analysis focussed on identifying priority remaining intact areas, based on the development of a map of ecological condition.
- Protected Areas, Protected Forests and Protected Wetlands. All the identified ecosystems to be gazetted for protection are included (Rwanda Environment Management Authority, 2015).
- Climate change refugia based on projected changes in bioclimatic envelopes under a range of climate change scenarios.
- Identification of key landscape linkage areas and bottlenecks.
- Hydrological process areas – Rivers and Streams, including buffers.
- Hydrological process areas – Wetlands and Lakes, including buffers.
- Hydrological process areas – Areas with high rainfall.
- Landscape process areas - Steep slopes (over 55%) which are most important for minimizing erosion and landslide risk.

Individual species were not separately considered in the assessment as all key species are tightly linked to their underlying intact habitat (in particular intact forest patches as well as wetlands and riparian areas); and available distribution data for species was much broader than the ecosystem data.

In selecting priority conservation areas, the SCP methodology always attempts to be spatially efficient by meeting conservation targets in as small an area as possible, while avoiding conflict with other land users, at the lowest possible cost for other sectors. The following was taken into account in the prioritisation:

- Urban and dwellings, tea, roads, plantations, cultivated pasture, coffee, bamboo and agriculture.
- Areas of greatest population density.
- Areas with highly impacted landcover classes.

Results of the MARXAN spatial analysis:

The MARXAN landscape prioritization (**Figure 1**), which builds in landscape connectivity, climate change refugia, biodiversity values, ecosystem services, and social costs (in terms of avoiding, where possible, areas with highest population density, agriculture etc), splits the landscape into four key planning categories (**Figure 2**):

- **Core Protected Area (PA) Nodes:** National Parks comprise the "Core PA Nodes" that need to be secured and well managed, which include Volcanoes, Gishwati-Mukura and Nyungwe National Parks. Priority activities include strengthening PA management and sustainability, rehabilitation and restoration of natural forests, other conservation-oriented land use activities that reduce stress on PAs and natural forests (e.g. improved wood stove efficiency to reduce pressure on natural forests) and supporting sustainable biodiversity compatible activities (e.g. improved beekeeping). These nodes also include buffer areas around the National Parks.
- **Stepping Stones:** These are priority nodes outside of the current National Parks that are critical for maintaining landscape connectivity, comprising of small, isolated patches of forest, at Dutake and Karehe-Gatuntu Protected Forests and the extensive Gishwati Pastures. These areas would be a sensible focus for some (patches of) forest restoration and protection, beekeeping and energy efficient stoves. The Gishwati Pastures are a focus for agroforestry on pastoral land to increase the coverage of native trees to secure reasonable landscape connectivity for forest species.
- **Landscape linkages:** These are key landscape linkages and knickpoints in the farming landscape that require afforestation on steep slopes and riparian areas to link the CND at a landscape scale. Compatible land use activities include agroforestry, increasing the use of native species, reforesting steep slopes, beekeeping and energy efficient stoves. **Note that the analysis is based on some level of improved connectivity via patches of protective forest and riparian strips, as well as overall improved species composition and tree coverage (within mixed agroforestry systems). It does not imply a continuous natural forest corridor; as this potential no longer exists, and its creation would not be possible in this highly used landscape without unacceptable impacts on livelihoods.**
- **Broader Farming Mosaic:** These are broader areas of moderate priority where conservation interventions can support broader sustainable landscapes and ecosystem service delivery but are

likely to be beyond the scope of most project interventions except for those linked to land use planning.

To aid prioritization and description of the landscape categories above, the four categories were further split into specific areas, referred to as “Landscape Implementation Sectors”, as shown in **Table 1** and **Figure 2** below.

Table 1: Summary table of landscape categories and associated implementation sectors for the CND.

Landscape Category	Landscape Implementation Sector	Area (ha)
Core PA Nodes	Volcanoes NP and “Buffer”[1]	19 487,0
	Nyungwe NP and Buffer	116 794,9
	Mukura NP and Buffer[2]	4 713,5
	Gishwati NP and Buffer[2]	4 013,7
Stepping Stones	Gishwati Pastures Stepping Stone	15 547,4
	Karehe-Gatuntu Stepping Stone	401,1
	Dutake Stepping Stone	903,0
Landscape Linkages	Nyungwe NP to Mukura NP Linkage	23 375,4
	Gishwati NP to Volcanoes NP Linkage	5 014,8
	Mukura N to Gishwati NP Linkage	7 823,7
Broader Farming Mosaic	Nyungwe to Mukura Broader Farming Mosaic	21 164,4
	Volcanoes Broader Farming Mosaic	11 694,4
	Mukura Broader Farming Mosaic	4 814,0
	Gishwati Broader Farming Mosaic	28 433,2
	Nyungwe Broader Farming Mosaic	11 437,0

<u>Priority Areas for Implementation Activities:</u>

Specific priority areas for a range of interventions were spatially identified, including:

- Natural forest rehabilitation and restoration with the National Parks (and their buffers) and in the Stepping Stones.
- Protective forests for steep slopes and riparian areas, particularly in the Landscape Linkages.
- Agroforestry interventions in key highland Landscape Linkages.
- Specific agroforestry priorities on pastoral land (silvo-pastoral practices).
- Indigenous shade trees for tea and coffee plantations.
- Beekeeping in National Park buffers and Stepping Stone buffers.

<u>Limitations of the current Study:</u>

Importantly, this study is a rapid assessment to support project proposal development and does not replace a full conservation planning process. There are significant additional steps which are required to develop a product that is useful for land use planning. These changes include:

- A robust stakeholder engagement process, at a national, district and local scale.

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[1] *Note that buffers refer to both the specific legally designated buffers around Nyungwe and Gishwati-Makura NPs, as well as broader buffer areas adjacent to all these NPs, as well as Volcanoes NP.*

[2] *In order to allow for specific landscape description, we separately refer to Gishwati NP and Makura NP where necessary, even though these areas are managed as Gishwati-Makura NP.*

- Incorporation of issues relating to land use rights, both of landowners and farm tenants.
- Incorporation of issues relating to social safeguards, especially for marginalized groups.
- Inclusion of issues related to planning processes and strategies, at a national and local scale.
- Finer scale planning (ideally at a 1:50 000 scale).
- Improved biodiversity data, including revised data on forest degradation, validation of the ecological condition map, and specific species data where possible.

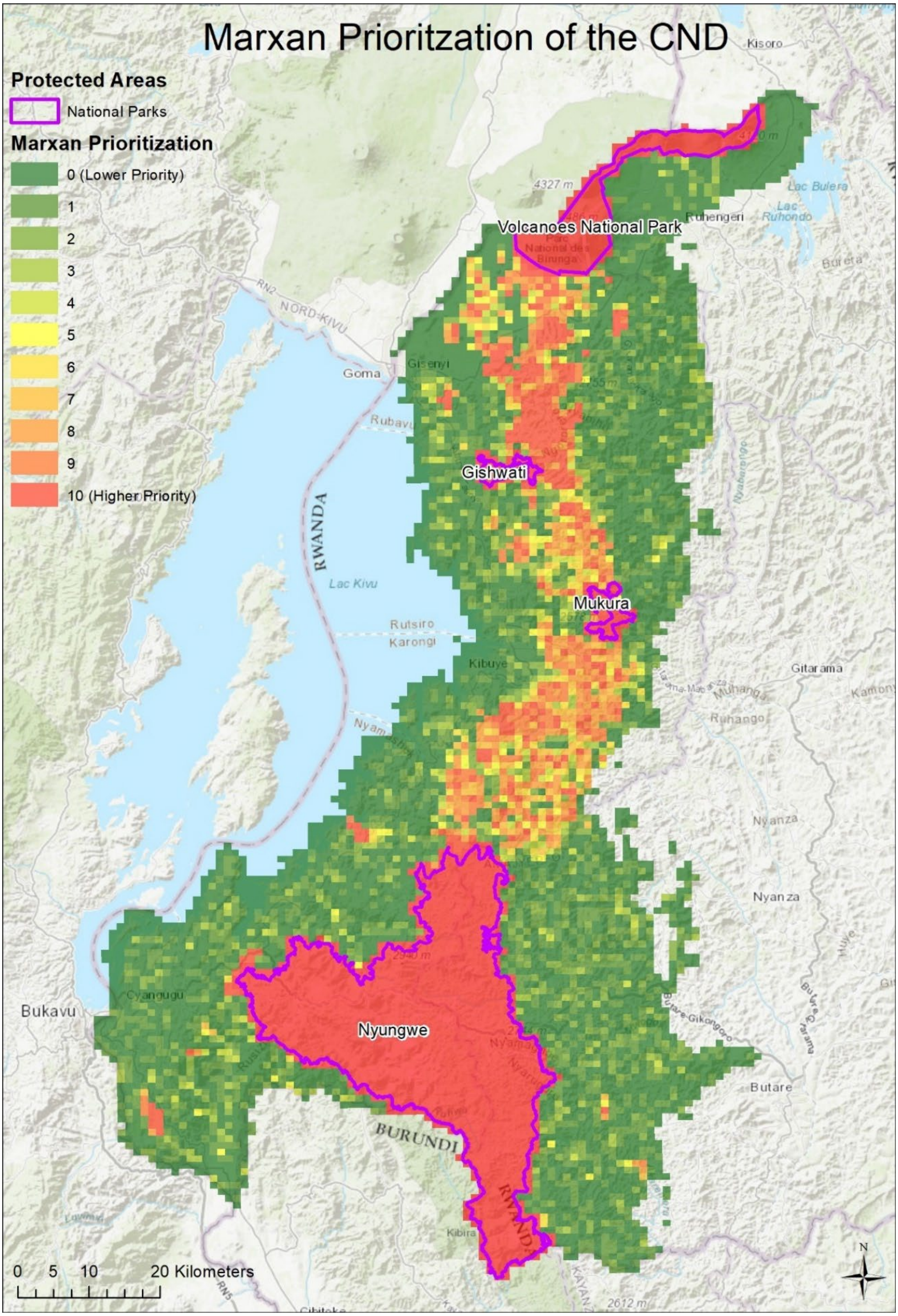

Figure 1: The MARXAN irreplaceability map for the Congo Nile Divide showing the landscape prioritization, ranging from high priority in red to low priority in green.

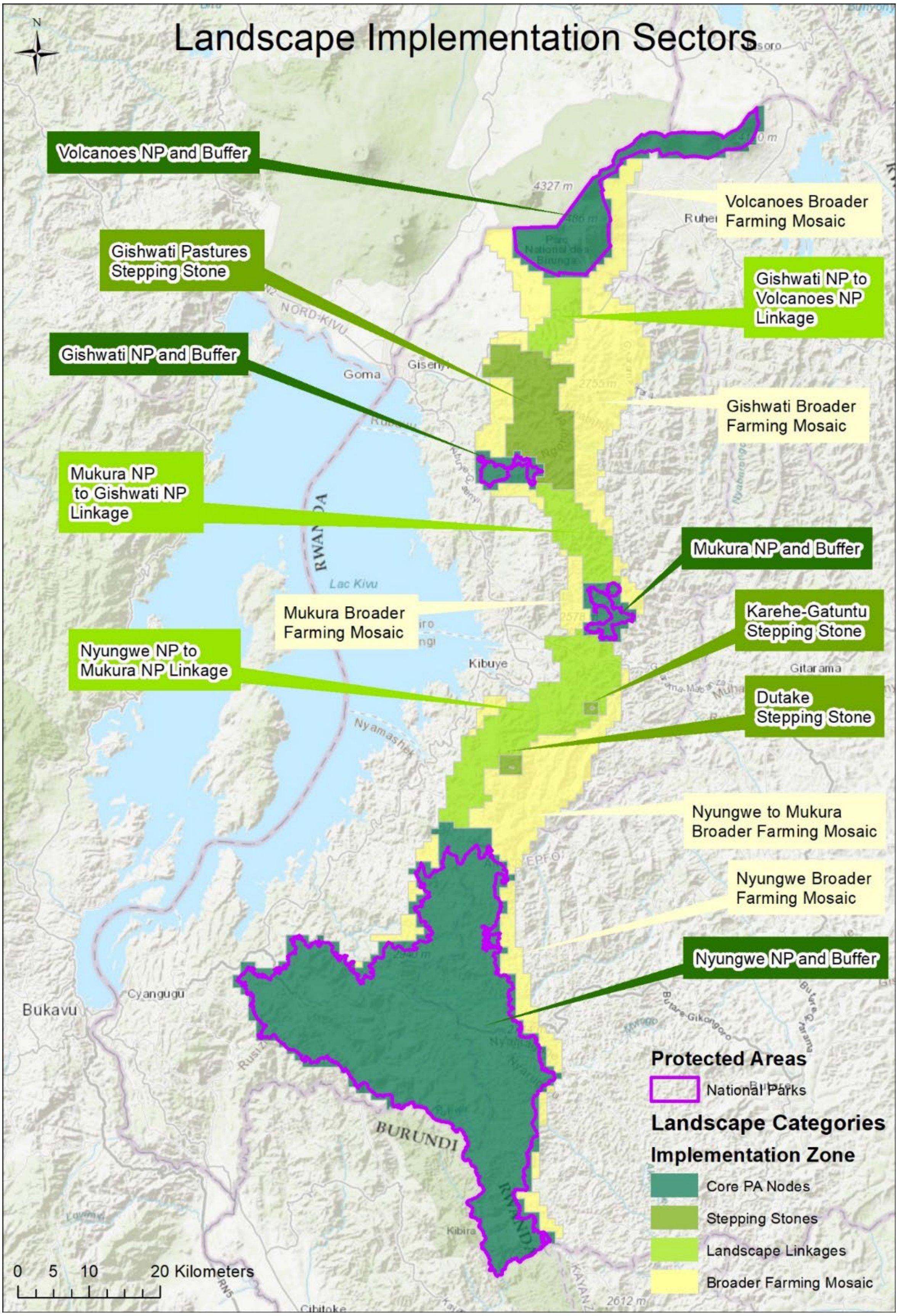

Figure 2: The four major landscape categories (Core PA Nodes, Stepping Stones, Landscape Linkages and the Broader Farming Mosaic) were split into specific areas to aid prioritization and description.

1 Contents

II. List of Figures

III. List of Tables

IV. Acronyms and Abbreviations

BLM	Boundary Length modifier
CMIP6	Coupled Model Intercomparison Project Phase 6
CND	Congo Nile Divide
DEM	Digital Elevation Model
EAGLE	East African Great Lake Environment project
ESGF	Earth System Grid Federation
GEnS	Global Environmental Stratification
GMNP	Gishwati Mukura National Park
IUCN	International Union for Conservation of Nature
LAFREC	Landscape Approach to Forest Restoration and Conservation
NNP	Nyungwe National Park
NP	National Park
OECM	Other Effective Place Based Conservation Measures
PA	Protected Area
RCP	Representative Concentration Pathway
RLE	Red List of Ecosystems
SCP	Systematic Conservation Planning
SPARC	Spatial Planning for Area Conservation in Response to Climate Change
SPF	Species Penalty Factor
SRTM	Shuttle Radar Topography Mission
WCS	Wildlife Conservation Society

1 Introduction

The Wildlife Conservation Society (WCS), under the auspices of Rwanda's Ministry of Environment, initiated this rapid systematic conservation plan (SCP) for the Congo Nile Divide (CND) region. The area lies along the western boundary of Rwanda, where it subdivides the catchments of the Congo and Nile rivers. The Rwandan portion of the CND stretches from the Virunga Mountains and Volcanoes National Park (VNP) in the north, southward to Gishwati-Mukura National Park (GMNP) and then to Nyungwe National Park (NNP) at the southern boundary. The extensive Lake Kivu borders the western periphery

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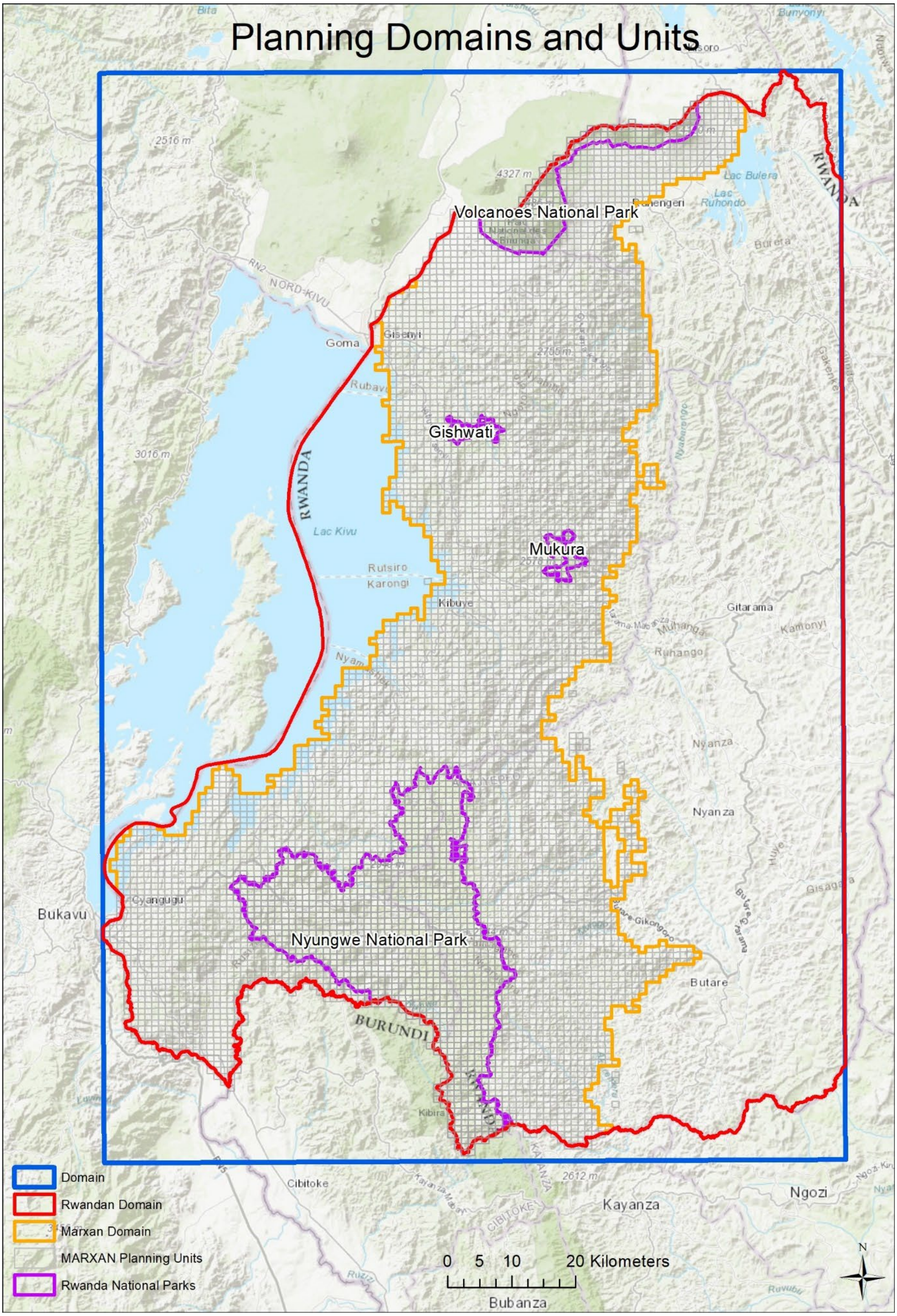

Planning Domains and Units
Volcanoes National Park
Gishwati
Mukura
Nyungwe National Park
Goma
Gisenyi
Lac Kivu
Rutsiro
Karongi
Kibuye
Cyangugu
Bukavu
RWANDA
BURUNDI
Lac Bulera
Lac Ruhondo
Gitarama
Muhanga
Ruhango
Kamonyi
Nyanza
Butare
Cibitoke
Kayanza
Ngozi
Bubanza
Domain
Rwandan Domain
Marxan Domain
MARXAN Planning Units
Rwanda National Parks
0 5 10 20 Kilometers
N

Figure 3). The majority of Rwanda's remaining montane forests are restricted to these national parks, which support a variety of threatened and endemic species. A few fragmented forest patches are situated outside of the National Park boundaries, including the Dutake and Karehe-Gatuntu Protected Forest Reserves.

Landcover change (especially for widespread smallholder agriculture), fuelwood harvesting, and human-induced fires, coupled with climate change impacts, especially landslides, erosion and downstream flooding, have compromised the delivery of critical ecosystem services derived from these forests. A detailed spatial analysis of biodiversity in the Congo Nile Divide was necessary to delineate priority areas for the long-term conservation and restoration of forests, and the sustainable management of landscapes, in order to secure the ecosystem services needed to improve the resilience of vulnerable communities to climate change impacts.

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This spatial biodiversity assessment identified priority areas for a variety of place-bound project interventions, including the restoration of natural forest, establishment and improvement of protective forest on steep slopes and along riparian areas; and to implement biodiversity-friendly agroforestry in order to reduce landslides, erosion and downstream flooding (Wildlife Conservation Society, 2022). Over and above these place-bound interventions are a variety of other mechanisms for promoting the sustainability of rural livelihoods and protecting montane forest in the CND landscape.

1.1 Planning Objectives

Specific Scope of Work to achieve the planning objectives:

- Use existing datasets to map current and future biodiversity priorities of the Congo Nile Divide (CND), based on as far as possible the current and predicted distributions of key ecosystems/vegetation types and species; and identifying areas and gradients in abiotic conditions which are likely to support a diverse set of habitat types, today and under future climate change. This analysis should be done in close collaboration with the climate change expert. The analysis should focus on priority areas under a range of agreed plausible scenarios.
- Identify where critical dispersal areas and corridors outside Protected Areas should be located in the CND to increase resilience to climate change, under a range of agreed plausible scenarios. Climate corridors should attempt to optimize the value for endemic biodiversity, for climate adaptation of biodiversity, the value for mitigating disaster risk (this will depend on elevation and slope), the value for connectivity between Protected Areas, and the value for avoiding forest loss (and other natural ecosystems) and associated CO_2 emissions.
- Provide inputs on management actions that will be required to improve the ecological value of the identified corridors, increase the value for endemic biodiversity, for climate adaptation of biodiversity, the value for mitigating disaster risk (this will depend on elevation and slope), the value for connectivity between Protected Areas, and the value for avoiding forest loss (and other natural ecosystems) and associated CO_2 emissions.

2 Planning Approach

2.1 Planning Domain

Critical components of a systematic conservation plan's planning domain include identifying and mapping (i) the extent and distribution of biodiversity; (ii) the ecosystem processes that sustain biodiversity; and (iii) human activities that impact on and threaten it.

The core planning domain or footprint is Rwanda's Congo Nile Divide (CND) landscape (

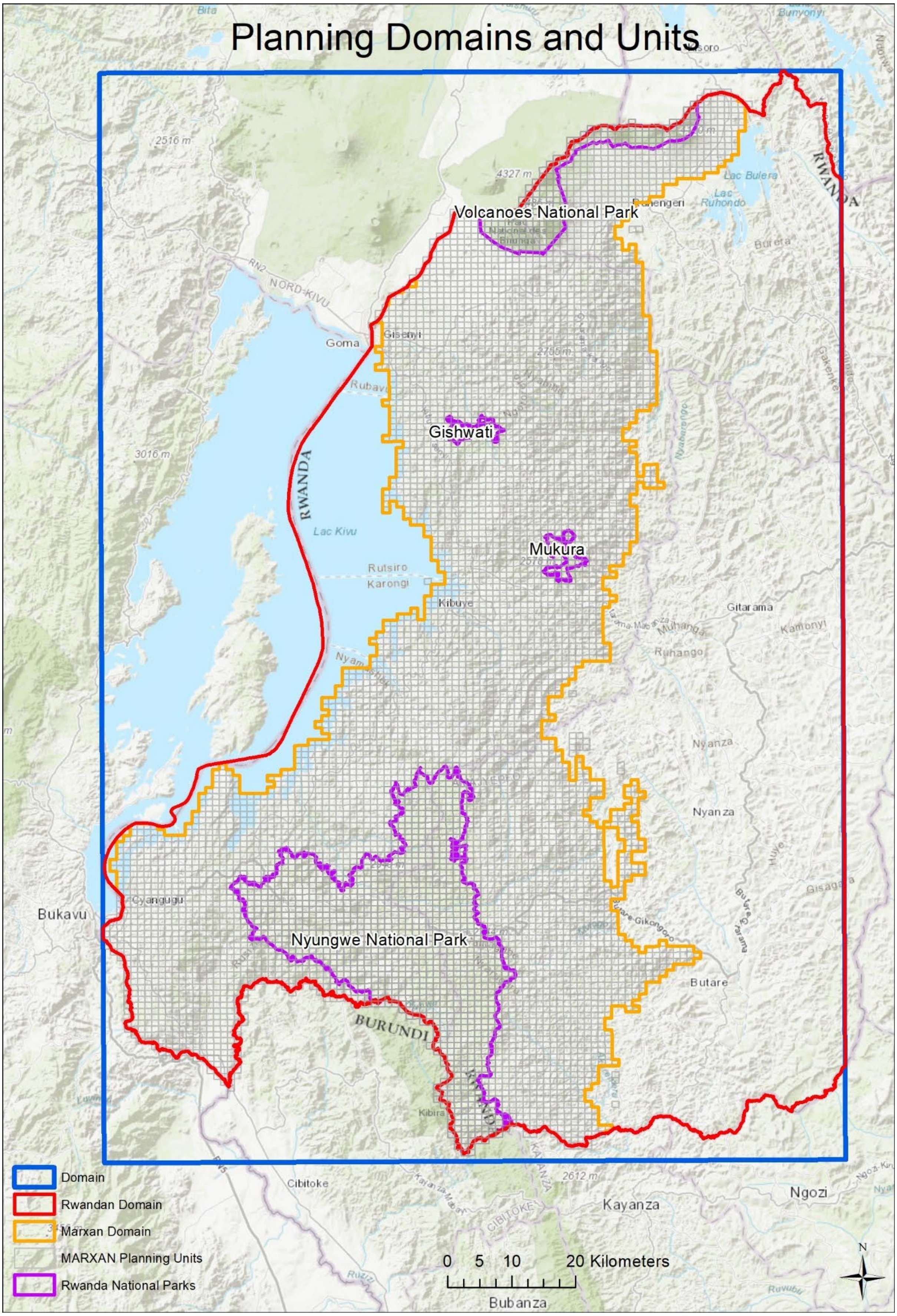

Figure 3). This covers an area of roughly 700 000 ha. The CND region includes the high-altitude mountain range system which subdivides the Congo and Nile watersheds. It extends from the Volcanoes National Park (VNP) and Virunga Mountains in the north, to Gishwati-Mukura National Park (GMNP) and then further southwards to Nyungwe National Park (NNP), with a portion of Lake Kivu at the western boundary of the planning domain. This area is the focus for conservation prioritization and detailed spatial data.

For the climate change and landscape connectivity analysis, however, a broader area must be assessed. Thus, biodiversity and landcover data was gathered in a broad rectangular area covering just under 2 million ha, including areas beyond Rwanda's boundaries. It is therefore important to note that much of this area is not part of the Congo Nile Divide and extends well beyond the area included in the MARXAN analyses (see **Figure 3** and **Figure 4**). The broader planning domain includes, for example, areas outside the Montane Woodland and Afroalpine Mountain Biomes, low altitude areas, and large lakes whereas the MARXAN domain excludes these areas.

Key parameters used to define the boundary of the MARXAN planning domain (Figure 3 and Figure 4) were as follows:

- Full inclusion of the 1 900m contour definition of the CND by the Wildlife Conservation Society, as per the feasibility study (Wildlife Conservation Society, 2022).
- The core CND ecosystem types, namely: Montane and Afroalpine forests; as well as transitional types to the west extending down to the edge of Lake Kivu. Intervening areas of non-forest ecosystem types were included and were available for the MARXAN analysis (see Section 2.3.2).
- The associated GEnS bioclimatic envelopes linked to forest ecosystems under current and future conditions, described in **Section 3.2** and shown in **Figure 11** to **Figure 13** .
- The full extent of the protected areas, including the eastern boundaries of Volcanoes NP.
- The inclusion of areas around the low altitude knickpoint located in the middle of the CND highlands. This relatively low point on the divide, east of Kibuye, is of particular relevance in the context of climate change (Seimon, 2022).

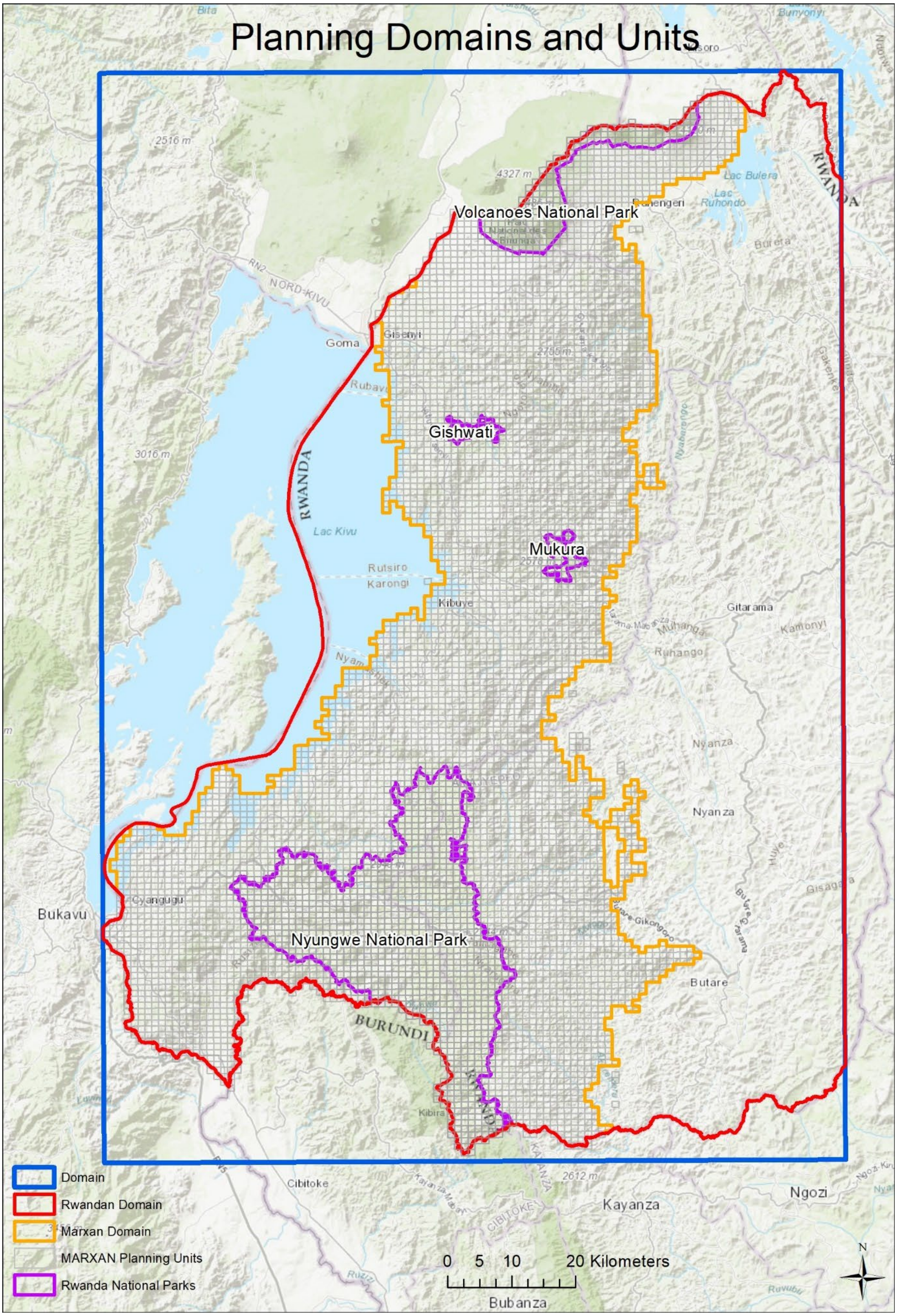

Figure 3: Map of the broader planning domain within which data was collected, and the MARXAN planning domain with 1 km² planning unts.

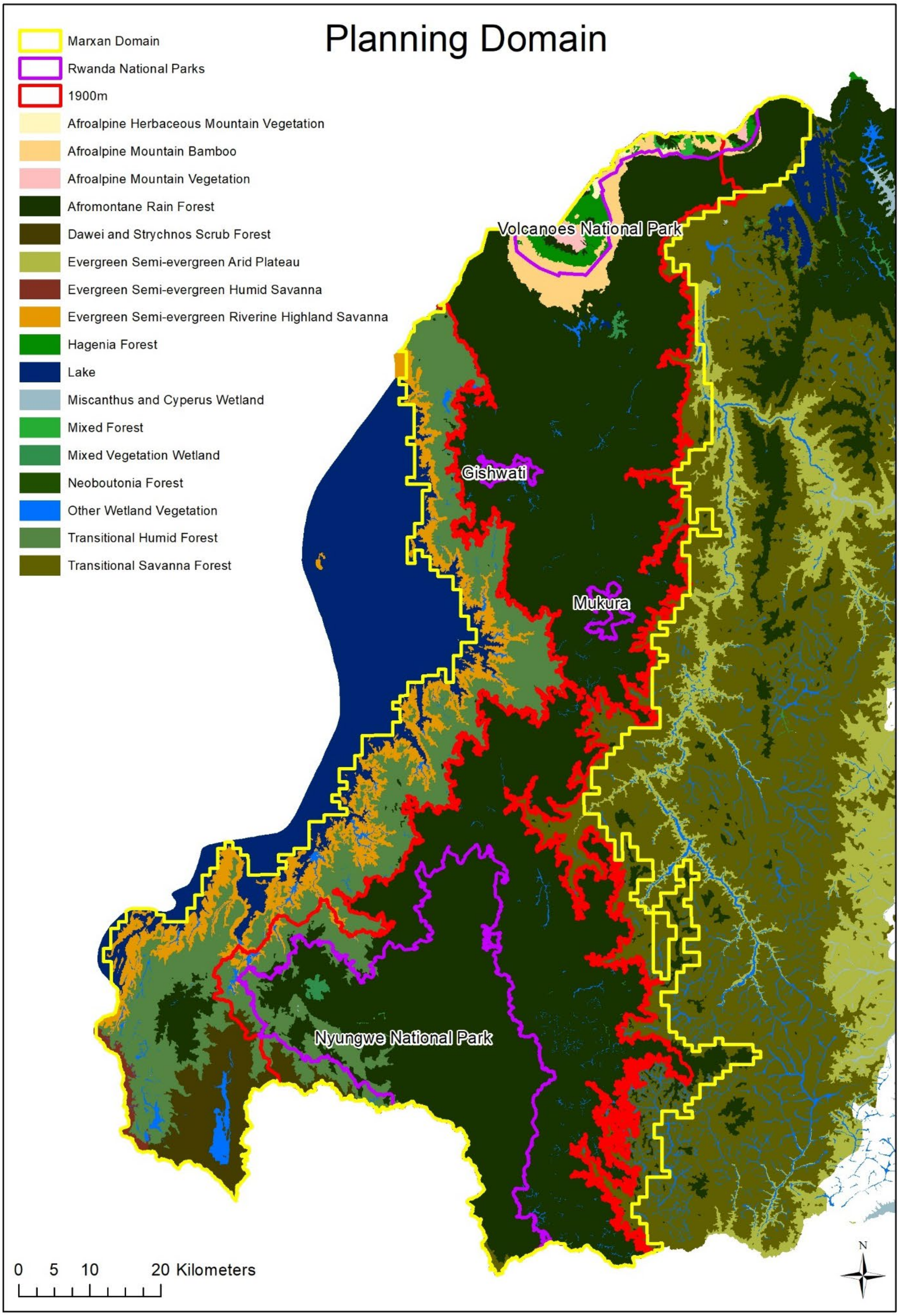

Figure 4: The MARXAN planning domain, in relation to key ecosystems, altitude divides and protected areas.

2.2 Systematic Conservation Planning Concept

This assessment is based on a Systematic Conservation Planning (SCP) concept. SCP is the process of deciding where, when and how to allocate limited biodiversity conservation resources to minimize the loss of biodiversity, ecosystem services and other valuable aspects of the natural environment at the least cost to other conflicting sectors. The benefits of such a robust evidence-based, conservation planning approach have been demonstrated in a wide variety of terrestrial, aquatic and marine environments and scales, from regions to reserves, across the globe.

Since it emerged in the 1990s (Margules and Pressey, 2000) and coupled with decision-support software such as MARXAN (Ball et al., 2009), GIS-based SCP has rapidly become an important tool for planning for biodiversity conservation at various scales. SCP provides efficient spatial solutions to resource allocation problems, and explicitly considers ecological representation and long-term persistence requirements. Often SCP processes are used to identify ecologically representative and well-connected systems of Protected Areas and other effective area-based conservation measures. SCP is also cost efficient and reduces conflicts by minimizing spatial competition with other sectors.

The planning process is essentially a sequential data-integration method that builds on the input of the best available data. The SCP process can be broken down into a series of inter-linked activities that are summarised in **Figure 5** and **Figure 6** below. Each individual activity can consist of several iterative steps and may require adaptive feedback loops. These stages for the assessment are explained in more detail in the subsequent sections of this report.

Figure 5: Systematic Conservation Planning process summary.

2.3 MARXAN Analysis

The MARXAN decision support tool developed by Ian Ball and Hugh Possingham (2009) was utilised for the spatial prioritization. This is the most widely adopted site-selection tool used by conservation groups globally, having been applied to local and regional planning efforts in over 60 countries around the world (Ball et al., 2009). MARXAN is designed to provide an objective approach to spatial prioritization that is adaptable and repeatable, based on an algorithm that evaluates very large numbers of possible alternatives, and retains the most efficient solutions given a specific set of criteria. It is a stand-alone software program that provides decision support to conservation planners by identifying efficient areas that combine to satisfy ecological, social and economic objectives. It utilises data on species, ecosystems and other biodiversity features, combined with data on planning unit costs (or constraints), to identify sets of sites that meet all biodiversity representation goals, while minimizing the total cost of the solution. Hence, it ensures a spatially optimal configuration of sites.

The approach follows a number of steps (

Figure 6). Firstly, key input data on biodiversity features were collated, as were data on pressures and ecological condition of habitats, and the existing Protected Areas and Conservation Areas. Quantitative targets were set for how much of each biodiversity feature needs to be retained in a natural or semi-natural state. The initial data were used to identify the areas of least cost to conservation or existing resource users and activities. These components were iteratively combined in MARXAN to identify the highest priority natural areas that should be kept in this state to support long-term sustainable non-destructive use and secure the region's ecological and aesthetic value.

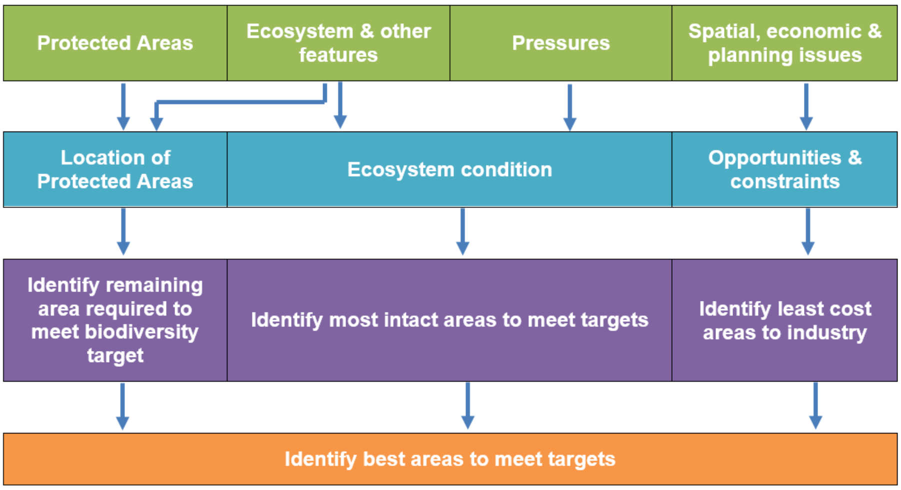

Figure 6: Summary of the Systematic Conservation Planning (SCP) process applied in this project. Note that although some sections are shown as separate processes to aid understanding of the approach, in the actual SCP process they are part of a single optimization.

Several design principles or rules were implemented during the spatial prioritization:

- The assessment intended to meet targets (see **Table 3**) for all features while reducing conflict with other competing activities. Targets were set to ensure a complementary and efficient set of priority areas was identified. This approach is intrinsically more spatially efficient than a multi-variate approach.
- The assessment aimed to meet all targets as far as possible but did not force the selection of poor condition areas. This balance was obtained by an iterative calibration of the MARXAN input variables.
- The approach was designed to identify priority areas under both current and a range of future climate scenarios. The incorporation of future spatial scenarios was primarily achieved through the use of modelled climate refugia based on GEnS climate envelopes (Section 3.2), incorporation of a new landscape connectivity analysis (Section 3.3) and the inclusion of a range of future precipitation models to focus on the areas of high rainfall most suitable for tropical forest (Section 4.1.5).
- The assessment aimed to avoid a fragmented set of priority areas as far as possible. This issue was addressed using two approaches:
    - Condatis connectivity analysis software focusing on connectivity, climate change refugia and restoration potentials in the landscape (Computational Biology Facility, University of Liverpool, 2022; Hodgson et al., 2016, 2012).
    - Use was made of MARXAN boundary length approaches to prioritize adjacent rather than scattered solutions. An attempt was made to identify contiguous blocks of high priority areas rather than a scatter of priority sites. This was done through careful

calibration of the boundary length modifier to ensure the production of an appropriately clumped output without becoming unnecessarily spatially inefficient.

- A cost surface was used to: (1) avoid areas in poor ecological condition where possible; (2) favour areas where habitats were likely to be in the best ecological condition, where opportunities existed for conservation activities, and where costs for implementing conservation were lowest; and (3) to avoid areas with highest levels of conflict with major sectors and activities (crop production and urban areas) where the opportunity cost for society of implementing conservation activities is highest. These concepts were incorporated through basing the cost of a planning unit on the level of intensity of key sectors and activities present in the unit.
- Areas in good ecological condition were strongly favoured using a cost surface where sites in poor ecological condition or that contained high levels of competing or incompatible activities were avoided (see cost surface explanation below).
- The spatial requirements for meeting targets for biodiversity features were deliberately aligned with the spatial requirements of project activities. Priority sites were identified for forest restoration, protective forests on steep slopes and riparian areas and agroforestry best practice. These were explicitly included in the conservation plan.

A set of priority landscapes for conservation intervention were identified using the following method:

- Data layers were prepared using ESRI ArcGIS 10.6.
- The analyses used a 1 km^2 grid (**Figure 3**) for the spatial prioritization, which divided the landscape into 19,764 planning units across the broader domain, of which 7,057 were available in the final analysis in the core CND landscape. Current Protected Areas were embedded into the planning unit grid in order to facilitate the evaluation of priority areas that could connect to the PAs in the MARXAN analysis.
- Boundary lengths between each planning unit were calculated in meters. These boundary lengths are used, in combination with the Boundary Length modifier (BLM), to identify spatially efficient and connected combinations of planning units.
- Data, targets and cost surfaces were inputted into the MARXAN decision support tool using the CLUZ interface in ArcView 3.2 developed by Dr Bob Smith, Durrell Institute of Conservation and Ecology (http://www.kent.ac.uk/dice/cluz/).
- Data on distinct biodiversity and use features were included into the analysis. These were used to develop a site-by-features matrix that describes how much of each feature is found within each planning unit.
- The analysis used MARXAN version 1.8.10.
- The analysis followed standard MARXAN processes as outlined in the MARXAN good practices handbook (Ardron et al., 2008).
- A cost surface was used to ensure preferential selection of sites that are in the best possible ecological condition and where there are the lowest levels of conflict with other incompatible activities. This cost surface development is described in the **Section 4.1.6**.
- An iterative approach was used to identify appropriate Species Penalty Factor (SPF) values and Boundary Length modifier (BLM). Satisfactory inclusion of biodiversity features in a spatially efficient and ecologically connected layout was obtained using an SPF value of 1,000,000,000 and a BLM of 2. These values were calibrated using an iterative manual calibration method, compliant with the objectives outlined in the MARXAN good practices handbook (Ardron et al., 2008).

- A final MARXAN spatial prioritization was undertaken using 1 000 runs of 1 000 000 iterations each. The basic output of the MARXAN-based process described here is a **selection frequency map**. This map gives a representation of how important each planning unit is for meeting targets and summarizes the number of times (expressed as a percentage) that a planning unit is included in potential spatial configurations that meet the targets and minimize costs according to the parameters used in the MARXAN analysis.
- The results were split into a set of priority areas based on selection frequency and location in the landscape in terms of the Condatis connectivity analysis (Section 3.3). To do this, the most frequently selected planning units were identified (generally areas selected more than 50% of the time, but with some manual interpolation to produce coherent units – see **Table 11** for the relationship between irreplaceability values and categories). These priority areas and categories aid in understanding the spatial prioritization, are useful for describing selected areas, and are easier to include in implementation plans (**Table 2**).

Table 2. The MARXAN planning units were split into four spatial landscape categories

Spatial Planning Category	Definitions
Core Protected Area (PA) Nodes	National Parks comprise the "Core PA Nodes" that need to be secured and well managed, which include Volcanoes, Gishwati-Mukura and Nyungwe National Parks (See **Protected Areas** Section).
Stepping Stones	These are priority nodes outside of the current PAs, comprising of small, isolated patches of forest, at Dutake and Karehe-Gatuntu Protected Forests and the more extensive Gishwati Pastures.
Landscape linkages	These are key landscape linkages and knickpoints in the farming landscape that require reasonable retention and restoration of landscape function to link the CND at a landscape scale. **Note that the analysis is based on some level of improved connectivity via patches of protective forest and riparian strips, as well as overall improved species composition and tree coverage (within mixed agroforestry systems). It does not imply a continuous natural forest corridor; as this potential no longer exists, and its creation would not be possible in this highly used landscape without unacceptable impacts on livelihoods.**
Broader Farming Mosaic	This category includes the broader landscape mosaic, where agroforestry, tea, and improved farming practices (e.g. avoidance and reforesting of steep slopes, use of indigenous species) all support broader sustainable landscapes and ecosystem service delivery.

2.3.1 Target Setting

Setting quantitative targets for biodiversity features is central to the systematic conservation planning methodology. It allows the planning process to efficiently identify places that can achieve targets for multiple features. Quantitative targets were set for how much of each biodiversity feature needs to be retained in a natural or semi-natural state in order to safeguard a representative portion of that feature such that it will persist in the future (see **Table 3**).

Targets were set for the range of biodiversity features used in the planning process (**Table 3**). As a starting target value for ecosystem types, the 30% target set out in Target 2 of the Post 2020 Global Biodiversity Framework was used (Erdelen, 2020; Nicholson et al., 2021). Targets for individual features were then either increased or decreased based on their conservation value, and on importance for the CND landscape with its strong climate change and connectivity focus (see **Table 3**).

Table 3: Targets used for the spatial prioritization.

Broad Category	Specific Feature	Target %
Ecosystem Types	Targets set for individual ecosystem types	30
	Intact areas of forest ecosystems	90
Climate Refugia (from GEnS Analysis)	Short term refugia	50
	Long term refugia	50
	Short term refugia (intact areas only)	50
	Long term refugia (intact areas only)	50
Landscape Connectivity (Condatis analysis)	High linkage areas	80
	High and moderate linkage areas	50
	Key landscape knickpoints	80
Protected Areas and OECMs	National Parks	100
	Protected Forests	100
	Fully Protected Wetlands	100
Ecological Processes	Rivers and streams 10m buffer	30
	Wetlands and 20m buffer	30
	Lakes and 50m buffer	30
Ecosystem Services	Steep Slopes	30
Ecosystem Services - Precipitation (Current and Future)	Current precipitation	30
	Precipitation from 7 moderate and 7 more extreme climate models (individually included)	30

2.3.2 Planning Units

To facilitate data collection and analysis, the planning domain was divided into 19,674 1x1-km planning units of which 7,057 were available for selection in the core CND landscape. This was done in order to:

- Provide a framework for integration of datasets of varying types (biodiversity features, pressures, human uses etc.).
- Ensure that all data collected were in a compatible format.
- Allow for the summary of continuous data layers to useable units.
- Provide a background map for experts/stakeholders to identify priority areas for specific features and uses, either manually or electronically.
- Provide required units for the Systematic Conservation Planning software MARXAN (Ball et al., 2009).

The 1 km^2 unit size was chosen because:

- This planning unit size had successfully been used in previous mapping processes.
- It was reasonably matched to the range of resolutions of different spatial data inputs.
- The unit size was feasible for the Condatis connectivity analysis, which is processing heavy.

3 Key Ecological Analyses

3.1 Remaining Intact Areas of Natural Forest and Other Ecosystems – Ecological Condition

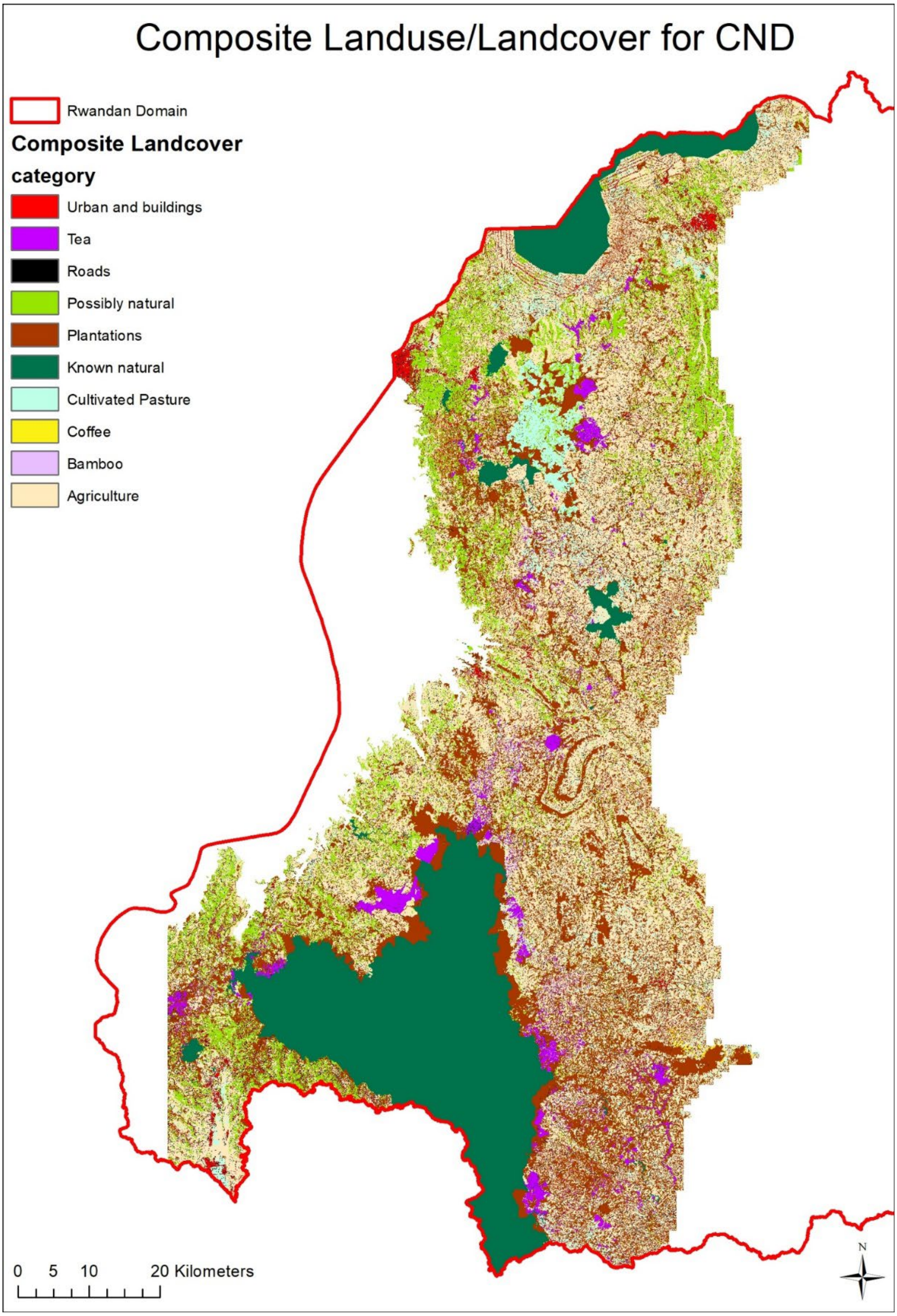

Figure 7: A composite land use and landcover map was developed for the core Congo Nile Divide (CND) landscape, Rwanda.

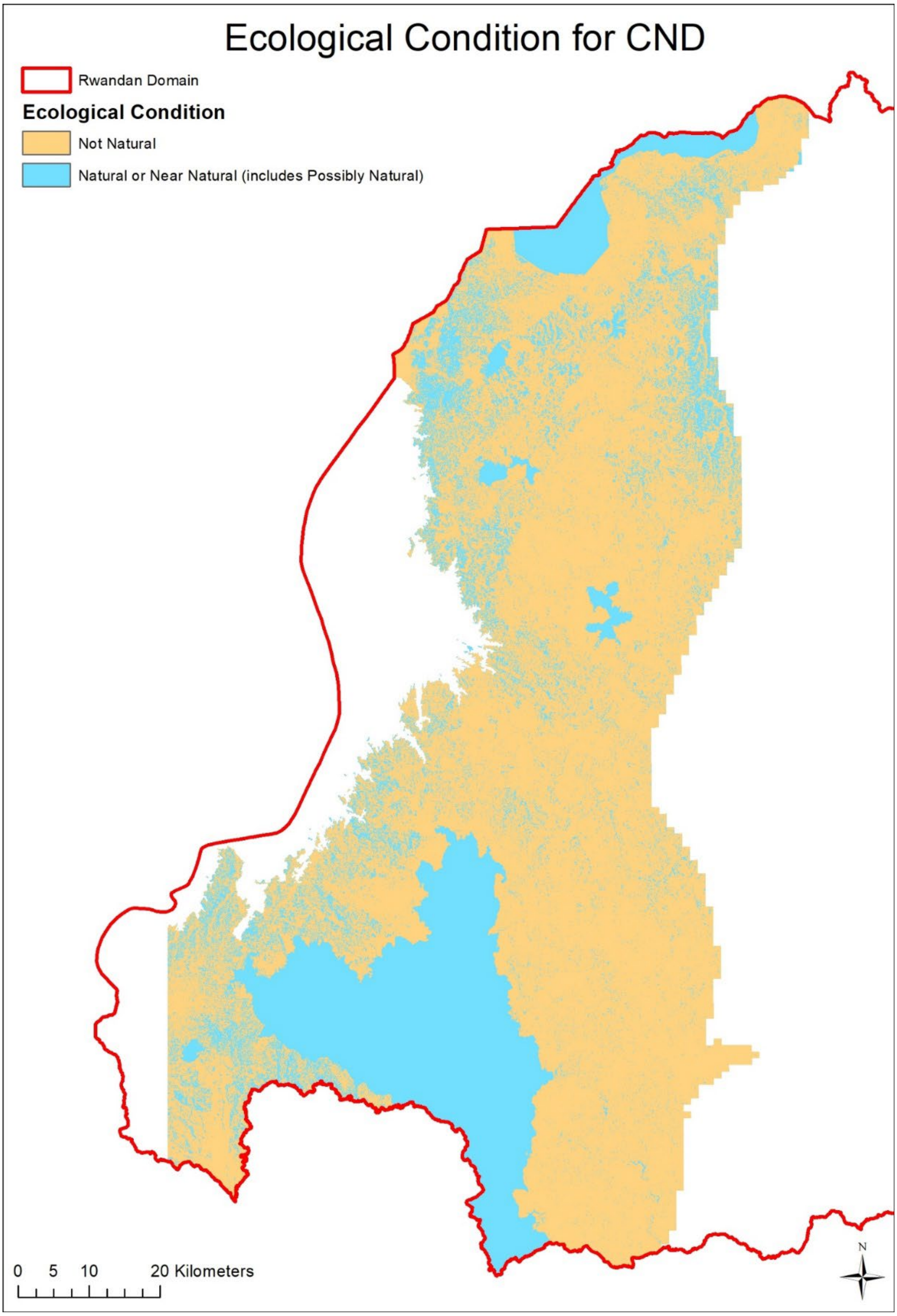

Figure 8: Ecological condition map prepared for the Congo Nile Divide (CND) landscape, Rwanda.

One of the key steps in any Systematic Conservation Planning process is the development of an ecological condition map (**Figure 8**) which shows the remaining intact areas of natural ecosystems (SANBI and UNEP-WCMC, 2016), which is primarily based on a land use/ land cover map (**Figure 7**). The map of ecological condition defines the degree of modification of the landscape, varying from areas that remain in a natural or near-natural condition, to those that are severely or irreversibly modified (SANBI and UNEP-WCMC, 2016). The purpose of the map of ecological condition is to determine the amount and location of natural habitat that remains available for achieving biodiversity targets. Maps of ecological condition combine information on the impact of different drivers of ecosystem change (such as land cover change, forest loss and overharvesting of resources) into a single map. Thus, mapping ecological condition is a way of summarising the many pressures acting on ecosystems, since an ecosystem with many severe pressures is likely to be in poor ecological condition. Similar to the use of ecosystem types as a surrogate for biodiversity, ecological condition is a surrogate for a range of human pressures on the natural environment.

3.1.1 Landcover

Typically, a landcover map would be used to easily produce a map of ecological condition. The recent Rwanda landcover map (Esri Rwanda Ltd., 2018) is a useful starting point nationally but has a number of issues when examined at the scale of the Congo Nile Divide:

- The landcover map was produced at 20m resolution; but is based on much coarser underlying Landsat 8 data. Some important features are not included in the dataset as they are below the resolution of the satellite and/or analysis:
    - Although urban areas are well covered, individual buildings and even villages in rural areas are often below the resolution of the dataset.
    - Roads are not mapped.
- In a number of cases natural and severely or irreversibly modified areas are combined in a single category:
    - Natural forests and artificial forest plantations are a single category.
    - Dams and lakes are not distinguished from each other.
    - Natural open areas and open ground are not distinguished from impacted land cover classes.
- Some important landcover classes are not mapped:
    - Tea plantations are included with other agriculture types.
- Some natural landcover classes are misidentified as impacted classes:
    - For example, large areas of alpine herbaceous vegetation within Volcanoes NP are mapped as agriculture.

Therefore, for the Congo Nile Divide (CND) analysis a new landcover was produced based on the best available data from several sources:

- Selected landcover classes were used from the land use /land cover map (Esri Rwanda Ltd., 2018). These were:
    - Permanent and seasonal agriculture.
    - Settlements and buildings (covering urban areas, including industrial and mining areas).
    - Cultivated pasture/ grassland areas which were assumed to be artificial if located in the forest ecosystems of the CND.
- Point data on 593 644 buildings (especially useful for rural villages and households in farmland) were collated from the OpenStreetMap data (Open Street Map, 2022a).

- Roads data on roads and tracks were collated from the OpenStreetMap data (Open Street Map, 2022b).
- Selected landcover classes, such as coffee, were specifically mapped in the erosion mapping dataset (Ministry of Environment, 2020a).
- Dams were identified from the Rwandan toposheet data (Rwanda Surveys and Mapping, 2022a).
- Plantations (Eucalyptus and Pine), including small woodlots were mapped from the 2019 forest dataset (Rwanda Ministry of Environment, 2019).
- Alien bamboo areas were mapped from the 2019 forest dataset (Rwanda Ministry of Environment, 2019).
- Tea plantations were mapped from a slightly older but high quality spatial dataset (National Agricultural Export Development Board, 2016).

To reduce misclassification, natural areas were identified from a number of data sources. These were used to over-ride more general data from the land use/ land cover dataset (Esri Rwanda Ltd., 2018):

- Natural forest specifically mapped in the 2019 forest dataset (Rwanda Ministry of Environment, 2019).
- Data on intact natural wetlands from the 2016 SWAM wetlands dataset (Rwanda Water Resources Board, 2016) was used to identify intact natural areas of wetlands.
- It was assumed that high altitude herbaceous alpine areas within national parks were natural rather than agricultural lands. This was based on a combination of the draft ecosystem map (SANBI, 2022) and the Protected Areas dataset (IUCN, 2021; Ministry of Environment, 2022a).
- It was assumed that the fine scale ecosystems specifically mapped and identified for gazetting as protected ecosystems are natural (Biodiversity Conservation, Environmental Management and Rural Development, 2015; Ministry of Environment, 2022b).

The approach used to integrate a land use/ land cover map at a 10m resolution (**Figure 7**):

- Where there are known natural areas mapped from specific and accurate datasets (i.e. the forest, wetland, Protected Area and protected ecosystems layers), these took priority. These areas were classified as “Known natural”.
- The land cover category “Possibly natural” was introduced to include any other areas that were not specifically identified as a specific landcover category. Importantly, large portions of these areas are likely to be highly impacted. A key initial project step would be confirming the status of these sites in key areas.
- Small scale or detailed datasets (e.g. buildings and roads) trumped other more broadly mapped landcover classes.
- Specifically mapped agricultural or cultivated features trumped other more broadly mapped land use classes. These specially mapped features were tea, bamboo, coffee, artificial plantations and dams.
- Finally, the general categories from the Rwanda ESRI landcover were used in areas not otherwise mapped as another landcover class. These were permanent and seasonal agriculture (combined as agriculture); settlements, industry and mining (added to the ‘urban and buildings’ category); and cultivated pasture.

3.1.2 Ecological Condition

The composite land use / land cover map (**Figure 7**) was then converted into a **map of ecological condition** (**Figure 8**) using the classification set out in **Table 4**. This was used to produce the integrated map of ecological condition which is shown in **Figure 8**. The areas are summarised in **Table 5**.

Table 4: Classification scheme used for allocating land use or land cover categories to ecological condition categories for the Congo Nile Divide, Rwanda.

Ecological Condition	Land Use or Land Cover
Natural or Near Natural	Known natural
	Possibly natural
Not Natural	Agriculture
	Bamboo
	Coffee
	Cultivated pasture
	Plantations
	Roads
	Tea
	Urban and buildings

Table 5: Summary of ecological condition and specific landcover classes across the Congo Nile Divide, Rwanda.

Ecological Condition and Landcover	Area (ha)	Area (%)
Natural or Near Natural	**213 338**	**29,5%**
Known natural	127 400	17,6%
Possibly natural	85 938	11,9%
Not Natural	**508 711**	**70,5%**
Agriculture	259 022	35,9%
Bamboo	135	0%
Coffee	546	0,1%
Cultivated Pasture	36 520	5,1%
Plantations	163 093	22,6%
Roads	22 132	3,1%
Tea	16 673	2,3%
Urban and buildings	10 590	1,5%
Grand Total	**722 049**	**100%**

The map of ecological condition, with landcover classes summarized above, were incorporated via the systematic plan cost surface, with higher costs associated with the “Not Natural” classes (See the Cost Surface Section 4.1.6).

3.2 Modelling Bioclimatic Change and Climate Change Refugia

3.2.1 Modelling Bioclimatic Change – GEnS Climate Envelopes

One of the key activities of the spatial analysis, as outlined in the "Planning Objectives" (Section 1.1), is to map current and future biodiversity priorities of the Congo Nile Divide (CND). This should be based on, as far as possible, the current and predicted distributions of key ecosystems (vegetation types) and species (endemic and threatened large mammals, birds and plants). Additionally, identifying areas and gradients in abiotic conditions which are likely to support a diverse set of habitat types, today and under future climate change.

The modelling approach has focussed on the core biomes and ecosystem types of the CND, namely the range of Montane Woodland types (the vast majority of which is Afromontane Rain Forest) and to a lesser extent the Afroalpine ecosystems (typical of the Volcanoes NP). These biomes and vegetation types were included in the recently integrated draft national ecosystem map (SANBI, 2022), based on the East Africa Potential Vegetation Map (Kindt et al., 2011; van Breugel et al., 2015; Van Breugel et al., 2011).

The modelling focussed on core biomes and ecosystems rather than individual species, as the key species of the CBD are all closely associated with specific Afromontane and Afroalpine ecosystems, primarily various natural forest types. Wetland types could not be modelled as there is insufficient data on wetland type distribution to support robust modelling.

Generally, it is difficult to understand the ecological consequences of different climate change models as they interact with the environment via a wide range of variables. In order to simplify the process, a range of bioclimatic variables can be derived from the monthly temperature and rainfall values in order to generate more biologically meaningful variables (Fick and Hijmans, 2017). The bioclimatic variables represent annual trends (e.g., mean annual temperature, annual precipitation), seasonality (e.g., annual range in temperature and precipitation) and extreme or limiting environmental factors (e.g. temperature of the coldest and warmest month, and precipitation of the wet and dry quarters). These are then used in the ecological modelling under different climate change scenarios.

We used the underlying data from the Spatial Planning for Area Conservation in Response to Climate Change (SPARC) project (Roehrdanz et al., 2019; SPARC, 2019), which undertook a robust ensemble integration process (i.e. it used the range of feasible models and results rather than a single model) for moderate (RCP 2.6) and more extreme (RCP 8.5) climate change scenarios. These are aligned with the climate change scenarios used in the climate change assessment undertaken for the current study (Seimon, 2022).

A **Global Environmental Stratification (GEnS)** process was then used, as set out in (Metzger et al., 2013), to map three scenarios:

- A baseline scenario (1961-1990) (**Figure 11**).
- A moderate (or more honestly a minimum plausible, given current climate responses) scenario based on the RCP 2.6 pathway for 2060-2080 (**Figure 12**).
- A higher change scenario based on the RCP 8.5 pathway for 2060-2080 (**Figure 13**).

Each of these maps are presented in the same format and with the same legends (**Figure 9** and **Figure 10**) to allow for easy comparison. This process classifies climate types based on a combination of temperature, precipitation and environmental variability statistics. Each discrete colour represents a unique climate class that approximates an ecosystem type. Those climate classes are then mapped in the baseline climate (**Figure 11**) and projected into future climate scenarios to show both how climate will redistribute on the landscape and represent potential ecosystem level changes that produce an integrated picture of the likely change at a biome or bioregional level. In simple terms, how climate change will impact on the distribution and extent of Afromontane Rain Forest and Afroalpine types in the CND.

The data show how the climate envelope for the rainforests of the CND is likely to become more limited and migrate upslope, with hotter and drier climate envelopes replacing the rainforest envelope. This aligns with the broad scenario set out in the climate change report (Seimon, 2022). This does not imply the rainforest will immediately be replaced by other ecosystems, but rather that it will be under pressure.

It will be critical to:

- Reduce other pressures on forest systems (alien species, fire, edge effects).
- Maintain and expand core forest areas, especially ensuring that some of the smaller areas around Gishwati and Mukura NPs, to avoid edge effects and optimize the retention of forest microclimates.
- Ensure landscape connectivity to allow species to migrate, to allow for optimal adaption to changing climates by the range of forest species.

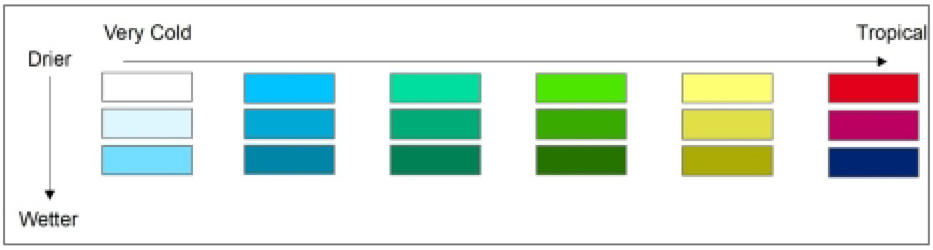

Figure 9: Generalized legend for climate envelope maps.

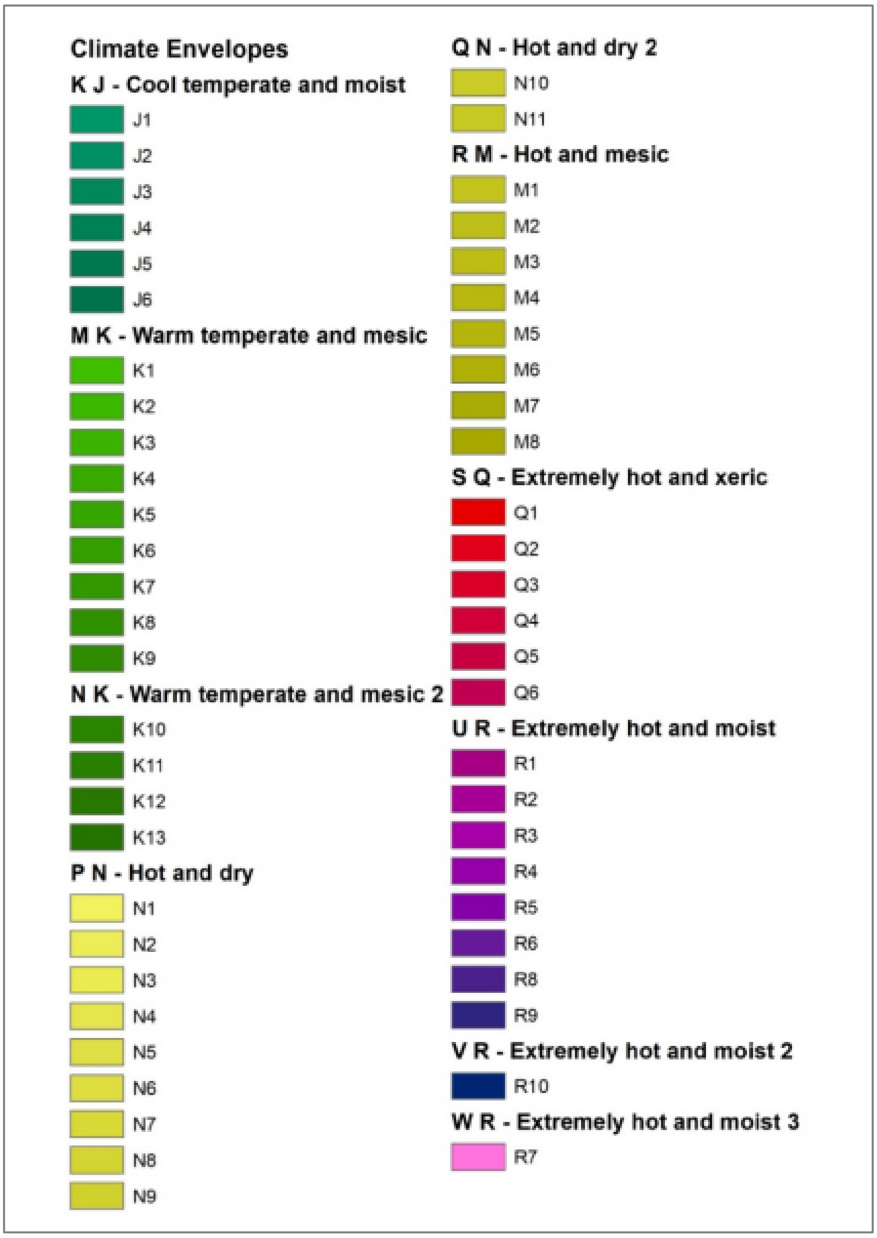

Figure 10: Specific legend categories for the climate envelope maps.

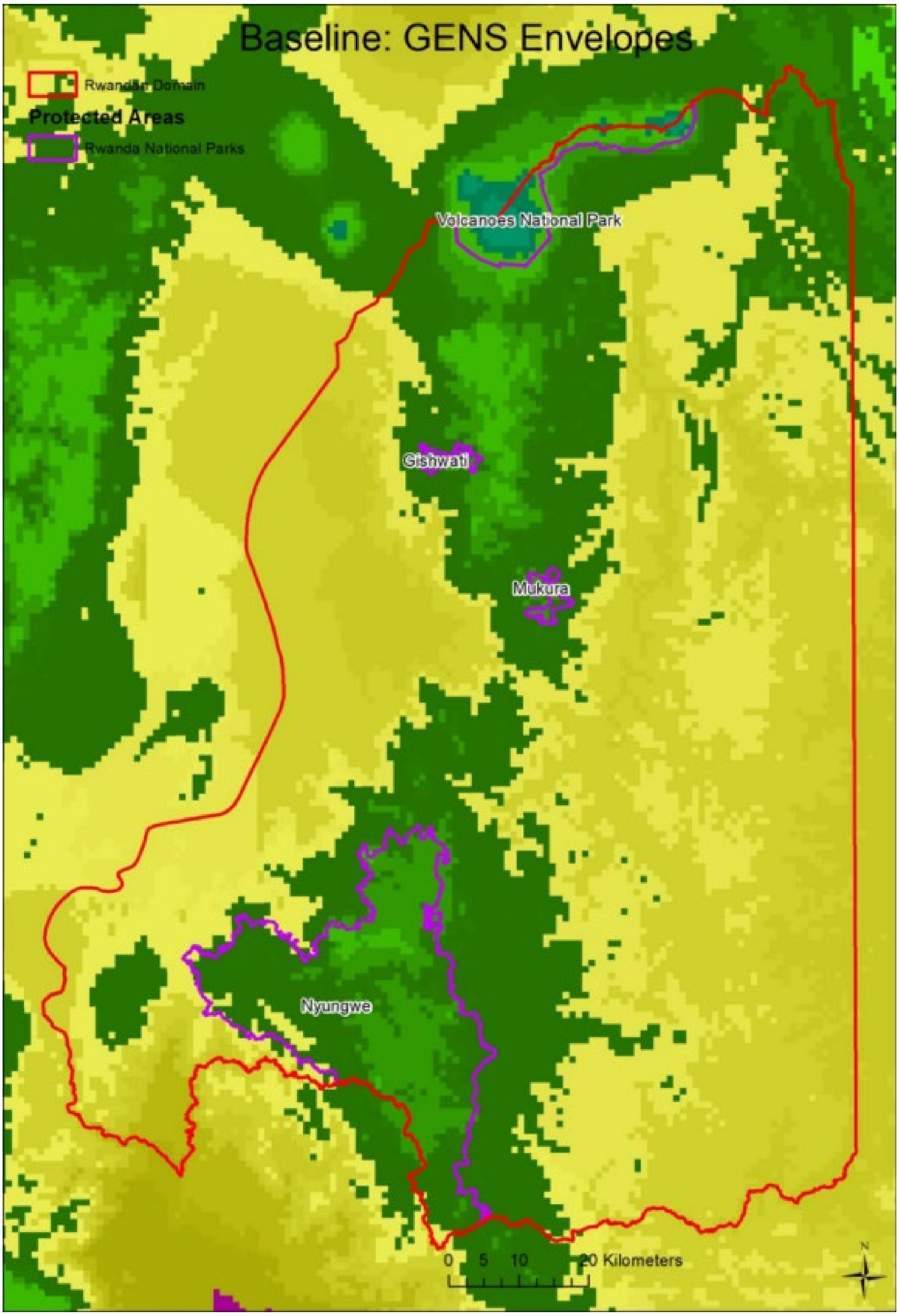

Figure 11: <u>Baseline bioclimatic envelopes scenario (1961-1990)</u> were categorised using the specific Global Environmental Stratification (GEnS) approach (Metzger et al., 2013). This process classifies climate types based on a combination of temperature, precipitation and environmental variability statistics. The analysis used the climate variable data produced by the Spatial Planning for Area Conservation in Response to Climate Change (SPARC) project (Roehrdanz et al., 2019; SPARC, 2019) using the Worldclim 2 dataset (Fick and Hijmans, 2017). Each discrete colour represents a unique climate class that approximates an ecosystem type. The approach closely models the distribution of the key Montane Rain Forest woodland types of the CND as well as the Afroalpine ecosystems (typical of Volcanoes NP). The legends are given in Figure 9 and Figure 10.

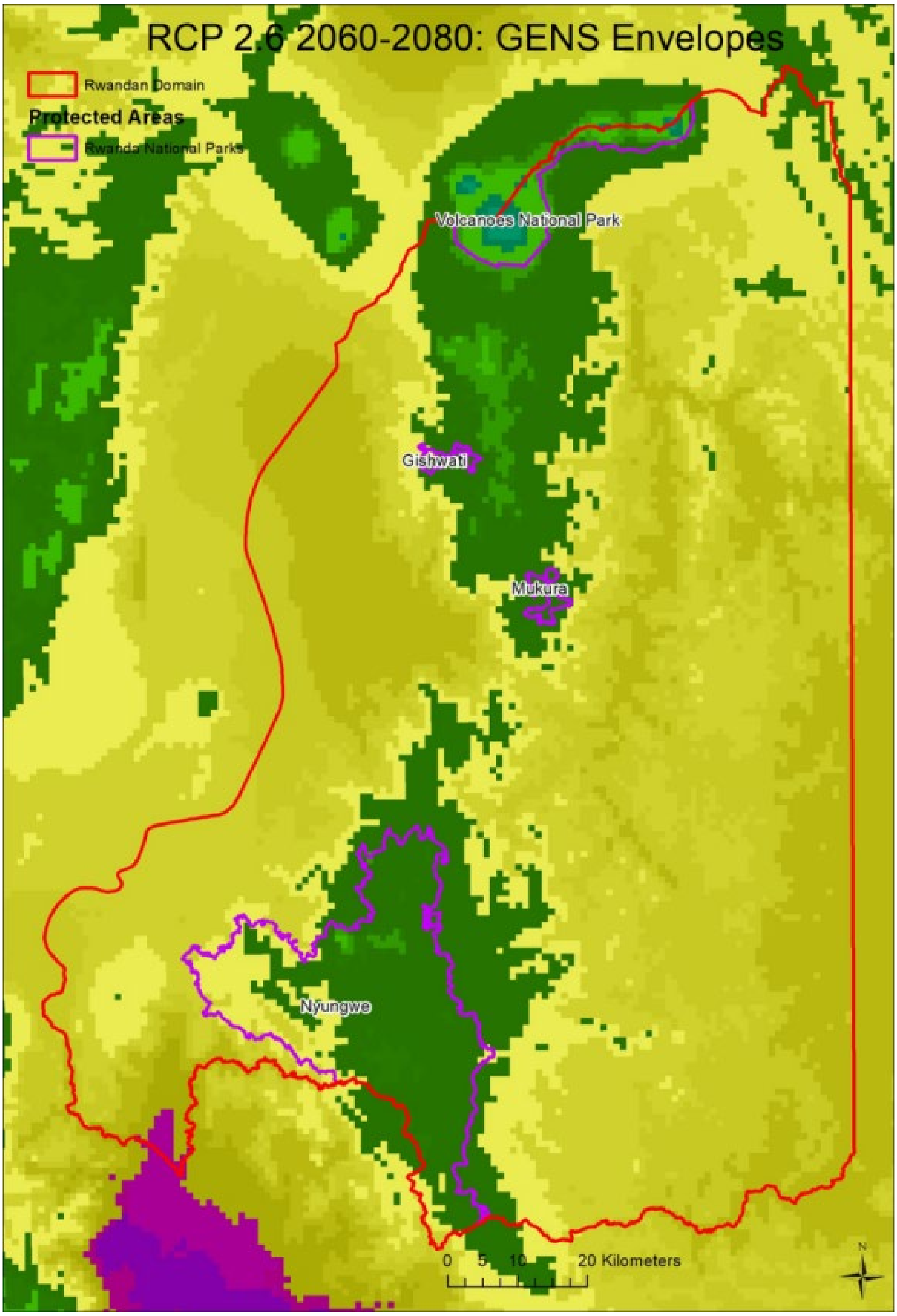

Figure 12: Projected bioclimatic envelopes <u>for a moderate (RCP 2.6) scenario (for 2060-2080)</u>. Projections based on underlying climate data collated by the Spatial Planning for Area Conservation in Response to Climate Change (SPARC) project based on a robust ensemble integration process (i.e. it used the range of feasible models and results rather than a single model). The subsequent bioclimatic envelope analysis process classifies climate types based on a combination of temperature, precipitation and environmental variability statistics. The maps show how the specific Global Environmental Stratification (GEnS) categories for a moderate (RCP 2.6) scenario (for 2060-2080) differ from the baseline (1961-1990). The data show how the tropical montane rain forest of the CND are likely to retreat upslope.

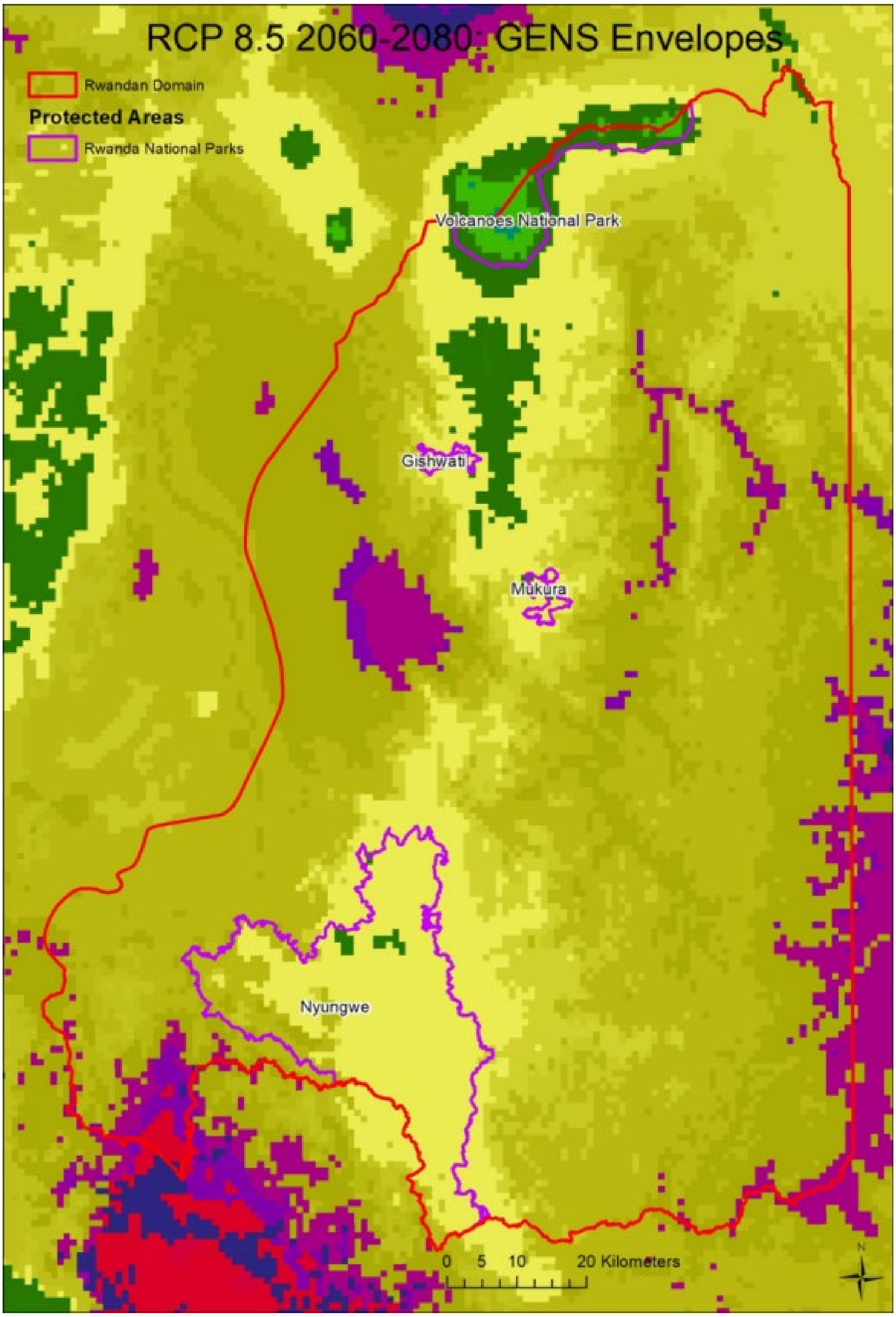

Figure 13: Projected bioclimatic envelopes <u>for an extreme (RCP 8.5) scenario (for 2060-2080)</u>. Projections are based on underlying climate data produced by the Spatial Planning for Area Conservation in Response to Climate Change (SPARC) project based on a robust ensemble integration process (i.e. it used the range of feasible models and results rather than a single model). This process classifies climate types based on a combination of temperature, precipitation and environmental variability statistics. The maps show how the specific Global Environmental Stratification (GEnS) categories for an extreme (RCP 8.5) scenario (for 2060-2080) differ from the baseline (1961-1990). Each discrete colour represents a unique climate class that approximates an ecosystem type. The data show how under more extreme scenarios relatively small areas of the CND retain the climate envelopes characteristic of current tropical montane rain forests.

3.2.2 Climate Change Refugia

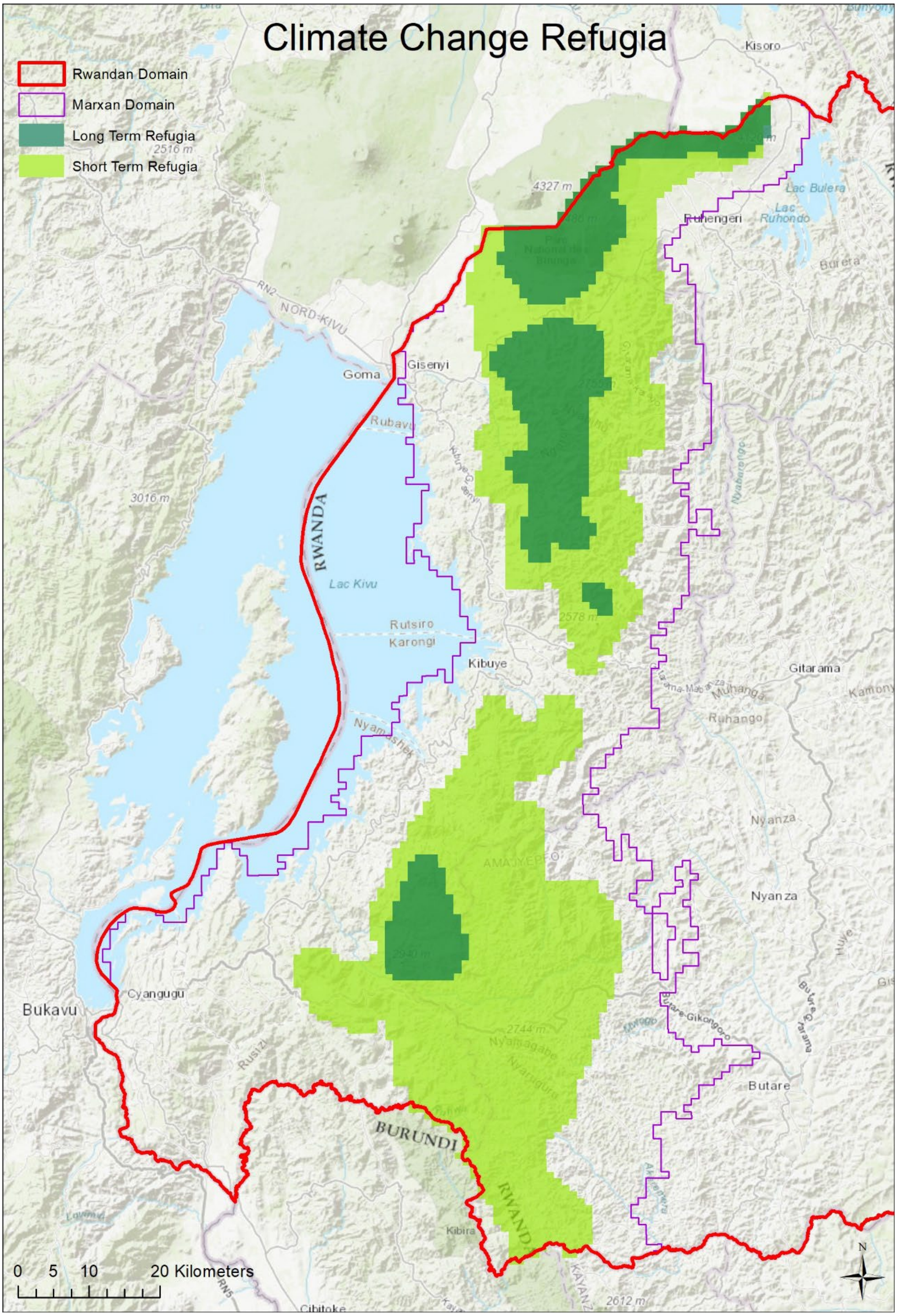

Figure 14: Long-term and short-term climate change refugia as outputs of the MARXAN analysis based on the two climate change scenarios, for a moderate (RCP 2.6) scenario (for 2060-2080) and an extreme (RCP 8.5) scenario (for 2060-2080) – showing the potential climate envelopes of core forest and Afroalpine ecosystem types.

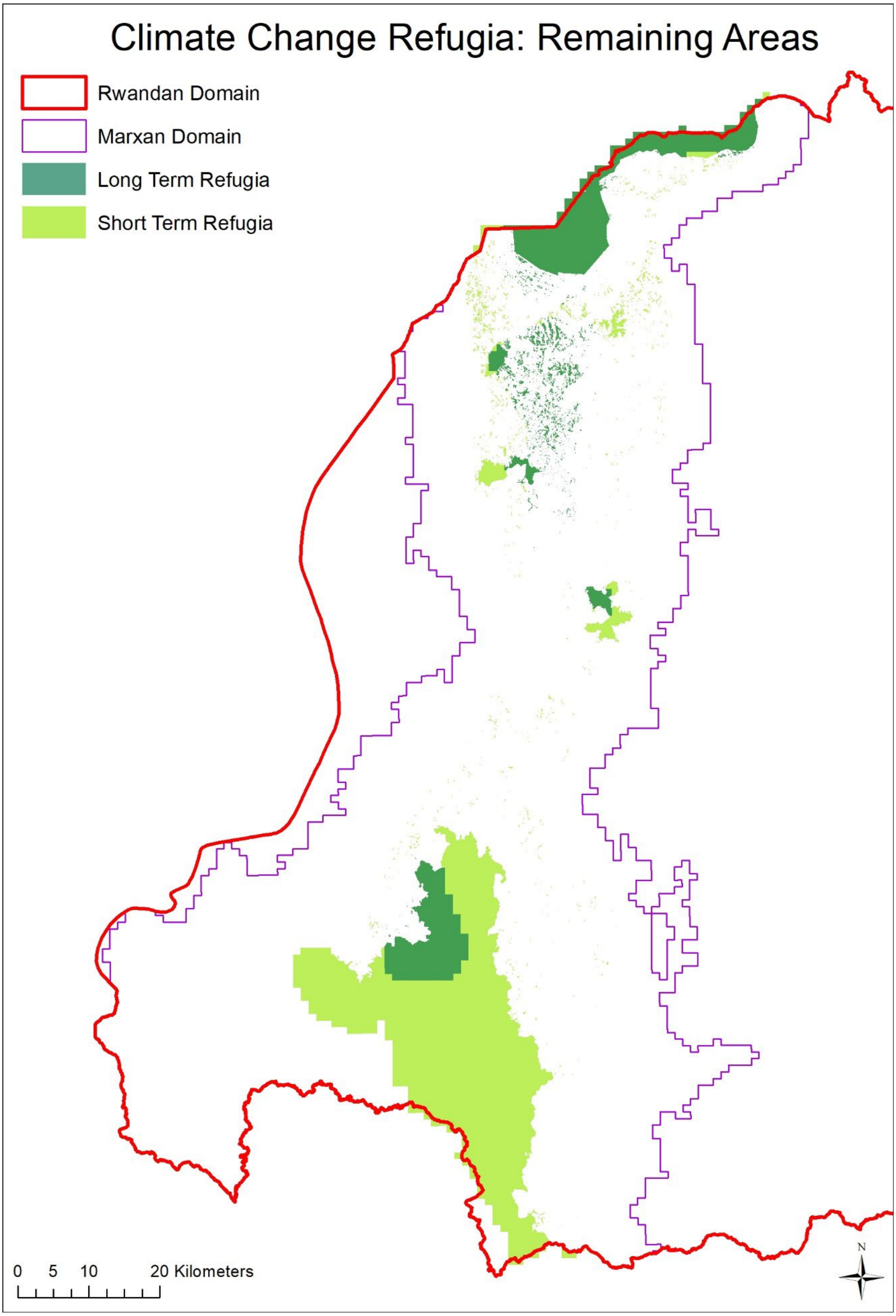

Figure 15: Long-term and short-term climate change refugia as outputs of the MARXAN analysis based on the two climate change scenarios, for a moderate (RCP 2.6) scenario (for 2060-2080) and an extreme (RCP 8.5) scenario (for 2060-2080) – showing the remaining intact areas of potential climate envelopes of core forest and Afroalpine ecosystem types.

The climate change refugia include the persistence of core forest types under the two climate change scenarios, moderate and extreme, described in the introductory section above “Modelling Bioclimatic Change”. The climate change refugia thus include a moderate (RCP 2.6) scenario (for 2060-2080) (**Figure 14**) and an extreme (RCP 8.5) scenario (for 2060-2080) (**Figure 15**). The ecological condition map (**Figure 8**) was used to identify remaining natural or possibly natural areas within these climate change refugia.

The moderate climate change scenario represents the short term refugia, meaning an initial area of persistence of the climate envelope under either smaller changes or in a shorter term. The short term refugia cover an area of 334 446 ha; of which 135 602 ha remain intact. In contrast, the long term refugia are areas that remain within the climate envelope under either larger changes in climate and/or are likely to persist for the longest time. The long term refugia cover 82 554 ha, of which 42 594 ha remain intact.

3.3 Condatis Landscape Connectivity Analysis

Condatis is a software tool designed to aid conservation planning by evaluating the connectivity of an existing habitat network and prioritising potential restoration opportunities (Computational Biology Facility, University of Liverpool, 2022; Hodgson et al., 2016, 2012; Wallis and Hodgson, 2015). The Condatis software is written by David W. Wallis, Jenny A. Hodgson and the Computational Biology Facility team at the University of Liverpool. The approach has been used in a variety of landscapes in the United Kingdom (notably used Natural England and Natural Resource Wales) and in rapidly developing, biodiverse areas such as Java, Sabah and Ghana. Similar landscape analysis methods (e.g. the conceptually similar Circuitscape approach) are experiencing widespread adoption in climate change linked analyses of landscape connectivity (Jennings et al., 2021; Justen et al., 2021; Laliberte, J. and St-Laurent, M-H., 2020; Maiorano et al., 2019).

Condatis is a highly flexible and very powerful tool designed for landscape scale studies of connectivity over successive generations of species. It is a modelling program for use in landscape planning to better understand the implications of climate change on biodiversity, and how we might mitigate any negative impacts. Specifically, Condatis was developed to deal with the dual challenges of habitat fragmentation and climate change. These phenomena are causing a reduced amount and connectedness of habitat, which in turn, makes it more difficult for populations to shift in response to changes in temperature and precipitation.

It works particularly well for habitats that are well-defined and patchy, and hence it is ideal for examining connectivity between remnant patches of montane forests within the Congo Nile Divide of Rwanda. The approach examines directional connectivity over a landscape; and helps pick out the most effective sites for habitat creation, tests climate change resilience and runs a number of directly comparable colonisation scenarios.

3.3.1 Analysis Approach

Condatis models a landscape of habitats as if it were an electrical circuit. A circuit board consists of a number of wires joining up resistors in combinations. When a voltage is applied to the board at one end, the current will pass through the board to the other end but the amount of current passing through each wire will vary according to the resistances it meets through each pathway. Condatis considers a landscape as analogous to a circuit board, with a source population of species being the voltage, the links between habitat useable by these species being the resistors, and the flow of species colonising the available habitat across those links being the current.

Using Condatis begins by developing a habitat map on which the conservation scenario will be based. The combined landcover map developed by the current project was used (**Section 3.1**). This map was converted into a habitat suitability map (**Figure 16**). This was based on the percentage of remaining intact terrestrial habitat (i.e. effectively the CND landscape) within each square kilometre planning unit. The layer preferentially values fully intact forest ecosystems, and strongly avoids intensively used ones (e.g. farmland, tea, coffee, urban). Intermediate values are given to open areas and pasture (as these have reasonable potential for restoration) and plantations (where improved species composition could be introduced to improve connectivity value). The latter was based on the logic that the quality of the matrix in fragmented landscapes influences movement, for example, woodland-dependent species may more readily travel between woodland patches interspersed with a pine plantation matrix than one that is more structurally different to the woodland (Cosgrove et al., 2018; Driscoll et al., 2013).

Next, source and target locations are specified: the source either representing the habitat of a nominal population of species or an actual population, the target representing an area for eventual colonisation. The direction of travel is defined by the placement of source and target and will depend on the purpose of study. For instance, if looking at likely species movement due to climate change, a south to north or lowland to upland direction might be required. Condatis looks at how the habitat in between the source and target could contribute to the species progress over multiple generations, so it is not designed to look in detail at individual patch-to-patch movements. For the CND study, an overall South-North axis was primarily used (with Nyungwe NP as the source and Volcanoes NP as the target). To improve overall understanding of the landscape, the landscape was divided into sections, with separate analyses being undertaken for NP to Mukura NP, Mukura NP to Gishwati NP and Gishwati NP to Volcanoes NP.

Each habitat cell is assumed to be linked with every other habitat cell; the strength of each of these links is dependent on the time it would take for the population of one cell to send colonists to populate the other cell. The time taken is considered analogous to resistance in the Condatis model. By selecting a dispersal distance (the average dispersal distance per generation) and the reproductive rate of a species (either known or representative), Condatis will calculate the overall flow from source to target and the portion of this flow travelling through each individual habitat cell. This is plotted on a map, colour coded to highlight the areas of most concentrated flow. Condatis also calculates the overall speed which is a measure of how quickly the target can be reached from the source via any route; and can be used as a directly comparable landscape connectivity metric across different scenarios and habitats. For the CND analysis, the following values were utilized after calibration and testing:

- Reproductive Rate - 1,000 individuals per km^2.
- Dispersal Distance - 2.5km.

Condatis measures the amount of flow through each cell and the distance travelled across its links to other habitat cells. It uses this to calculate the power of each cell link, which is considered the strain that each link is under. By ranking these it can produce a map showing these links of highest strain, which are “bottlenecks” in the landscape where a high proportion of the species flow is travelling through relatively few links. Often, a small number of links carry a disproportionately high amount of power. If habitat could be created around the bottlenecks it would disproportionately increase range-shifting connectivity. The **bottlenecks output is a key result** (**Figure 17**) of the Condatis analysis; and provides a clear indication of places in the landscape where any increased habitat suitability (e.g. restoration of natural forest; or increase in the permeability / suitability of farmland or plantations by increasing tree diversity in plantations, or shade trees and indigenous trees in tea plantations; or other agroforestry approaches, to increase trees and landscape diversity in farm landscapes).

A summary of the key Condatis variables used are outlined in **Table 6** below.

Table 6: Summary of key Condatis variables used.

What kind of species are you interested in?	Range of rainforest resident plant, bird and mammal species representative of the full range of CND rainforest diversity. A 2.5km dispersal distance was assumed per generation after testing, and cross checking against literature on movements of frugivorous birds among fragmented rainforests.
What is your source and target?	Primary analysis: • South-North axis Nyungwe NP as the source and Volcanoes NP as the target). Additional analyses: • Nyugwe NP to Mukura NP, • Mukura NP to Gishwati NP, • Gishwati NP to Volcanoes NP.
Why do your species need to move between the focal source and target?	For larger total populations, long-term resilience and genetic exchange, and also to avoid isolation as the climate changes.
What constitutes habitat?	Forest percentage per $1km^2$ block. Additional land use types (plantations, open land and pasture weighted by 50% suitability).
What kind of prioritisation are you performing?	Testing and comparing scenarios for restoration of degraded forest.

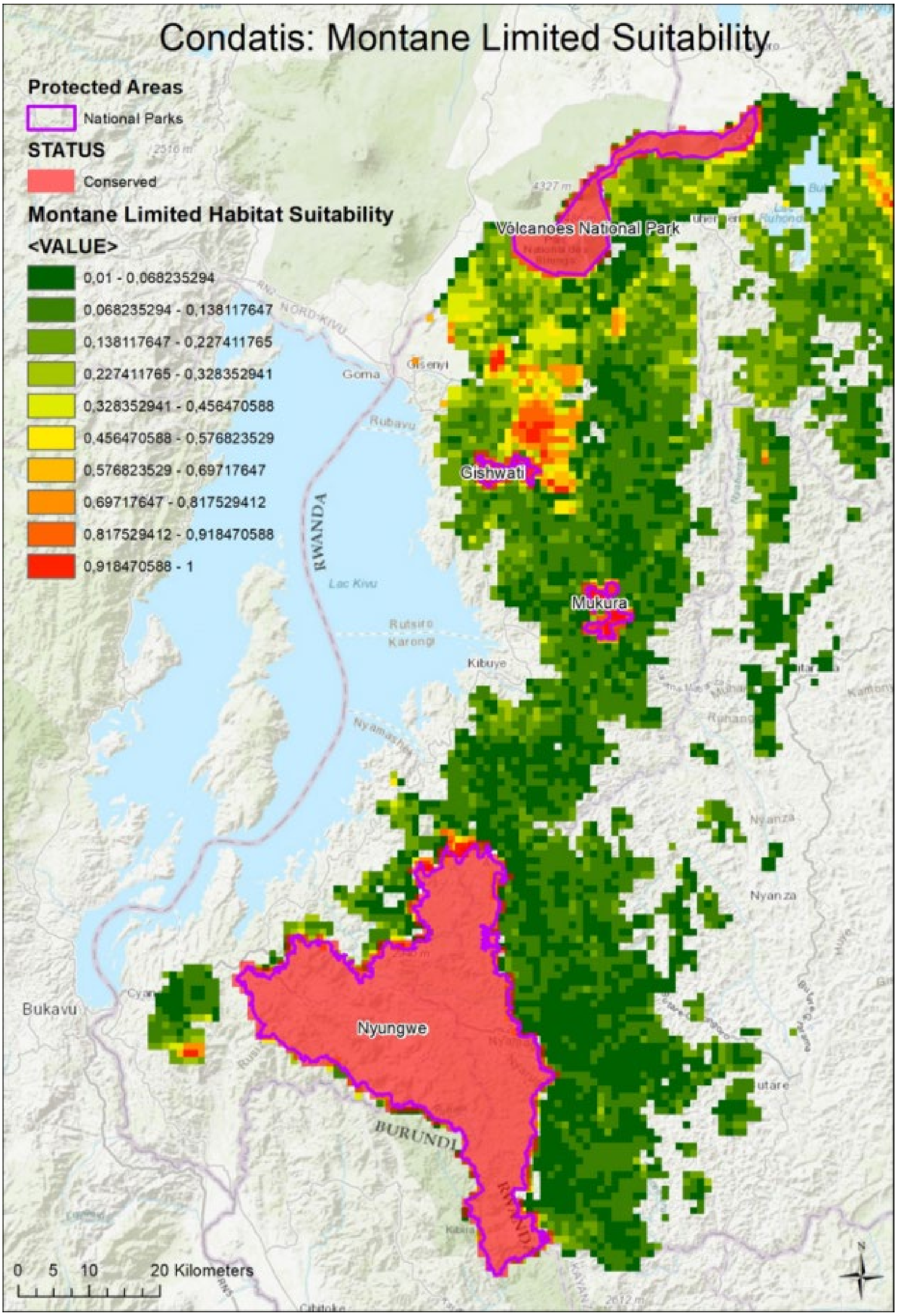

Figure 16: The montane habitat suitability map was developed as an input into the Condatis analysis. This was based on the percentage of remaining intact montane forest types (i.e. effectively the CND landscape) within each square kilometre planning unit. The layer preferentially values fully intact forest ecosystems, and strongly avoids intensively used ones (e.g. farmland, tea, urban). Intermediate values are given to open areas and pasture (as these have reasonable potential for restoration) and plantations (where increased native tree species could be introduced to improve connectivity value).

3.3.2 Condatis Key Landscape Bottlenecks

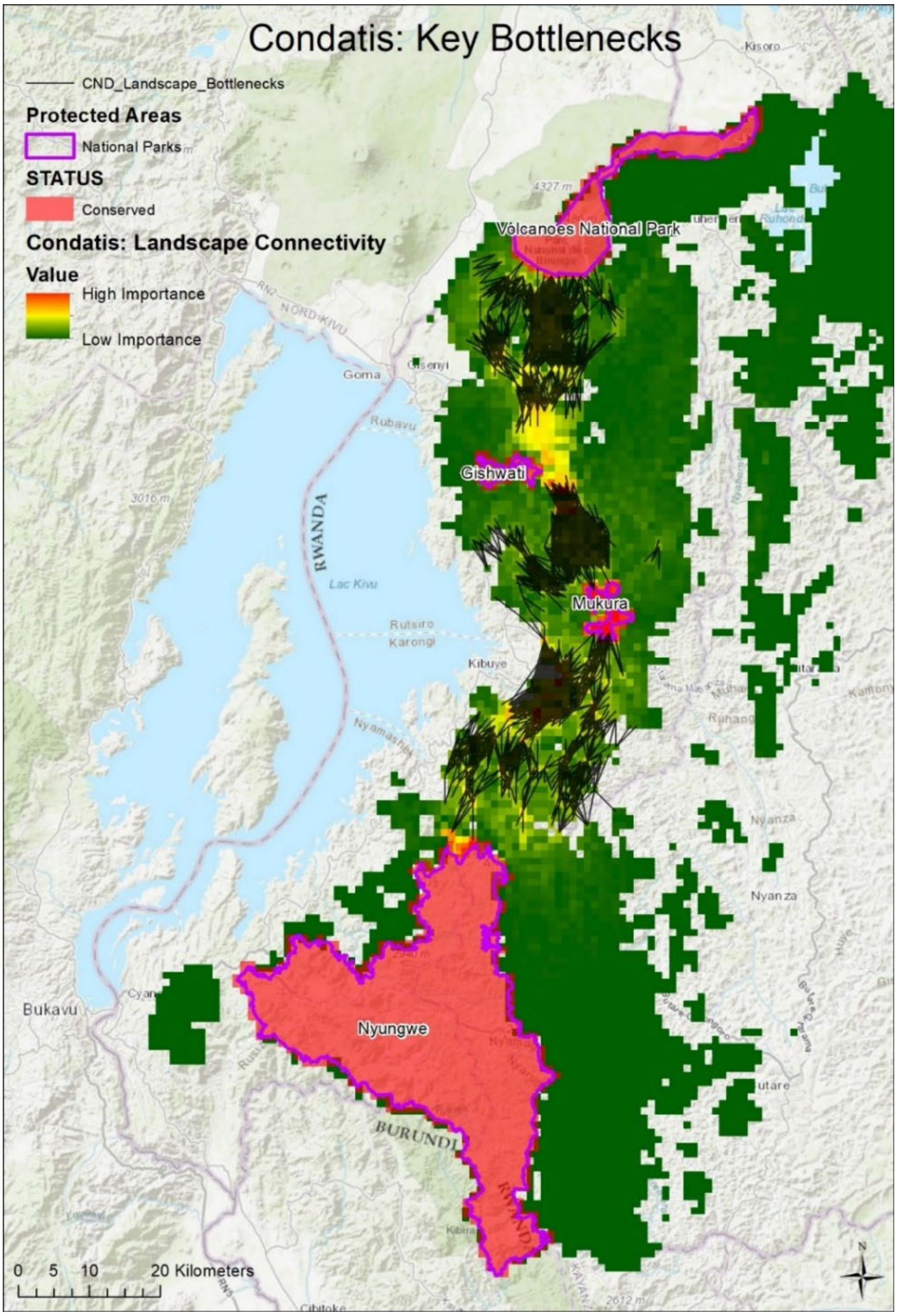

Figure 17: Key landscape connectivity bottlenecks in the Congo Nile Divide landscape, Rwanda.

The Condatis Landscape Connectivity software aids in delineating key bottlenecks which effectively represent areas where no natural habitat exists and, consequently, where natural pathways for migration are lost or limited (**Figure 17**). This is a result of the extensive agricultural activities in the CND. Effectively, the bottlenecks represent areas for project intervention, such as restoration and biodiversity-friendly agroforestry.

3.3.3 Condatis Landscape Connectivity Analysis

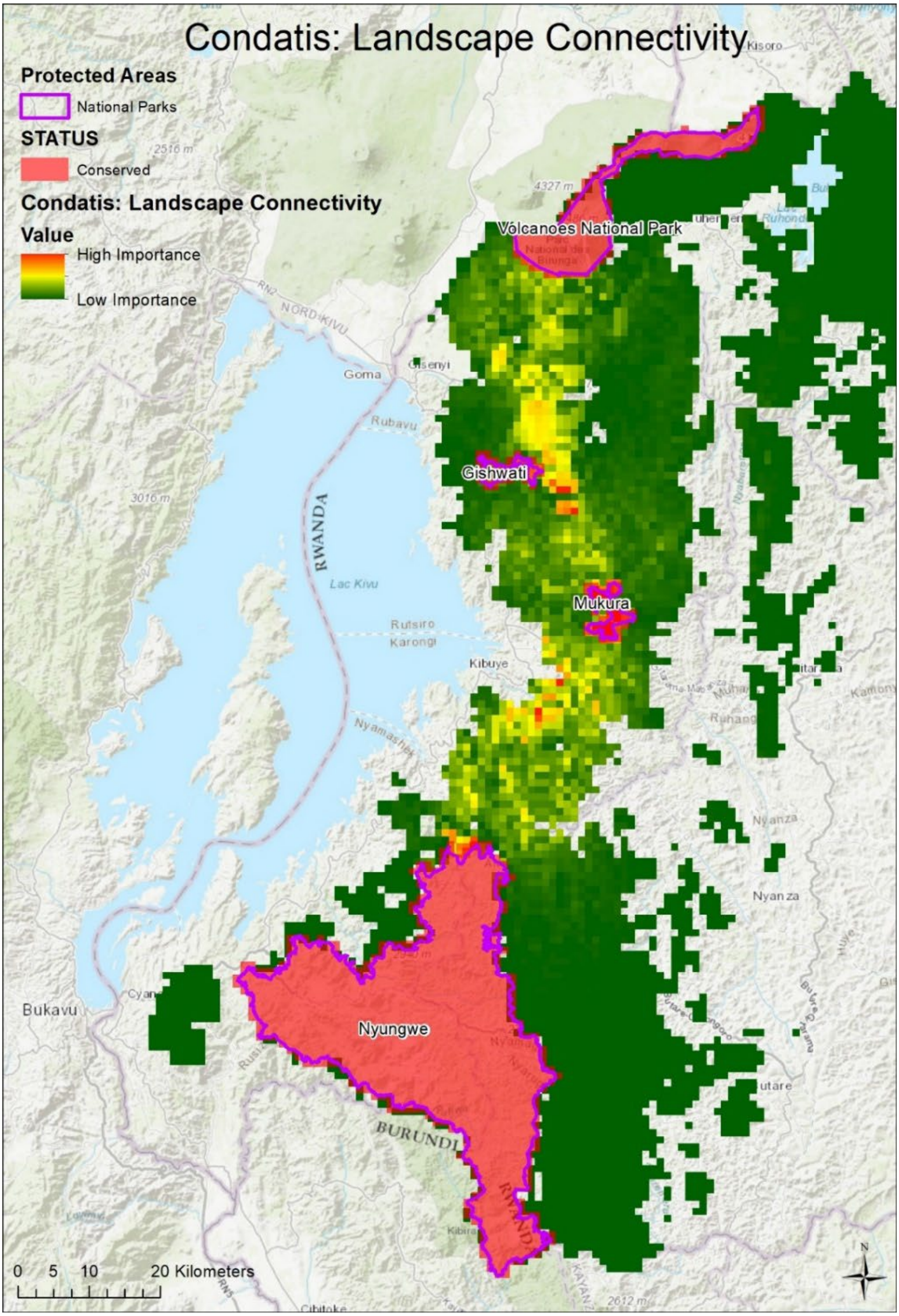

Figure 18: Key areas for landscape connectivity within the Congo Nile Divide identified in the Condatis assessment.

Based on the Condatis analysis, high and moderate climate change linkage (landscape connectivity) values, based on three quantiles, were mapped (**Figure 19**). These effectively delineate the higher value landscape connectivity pathways, shown in **Figure 18**, more specifically so that they can be included as features in the MARXAN analysis.

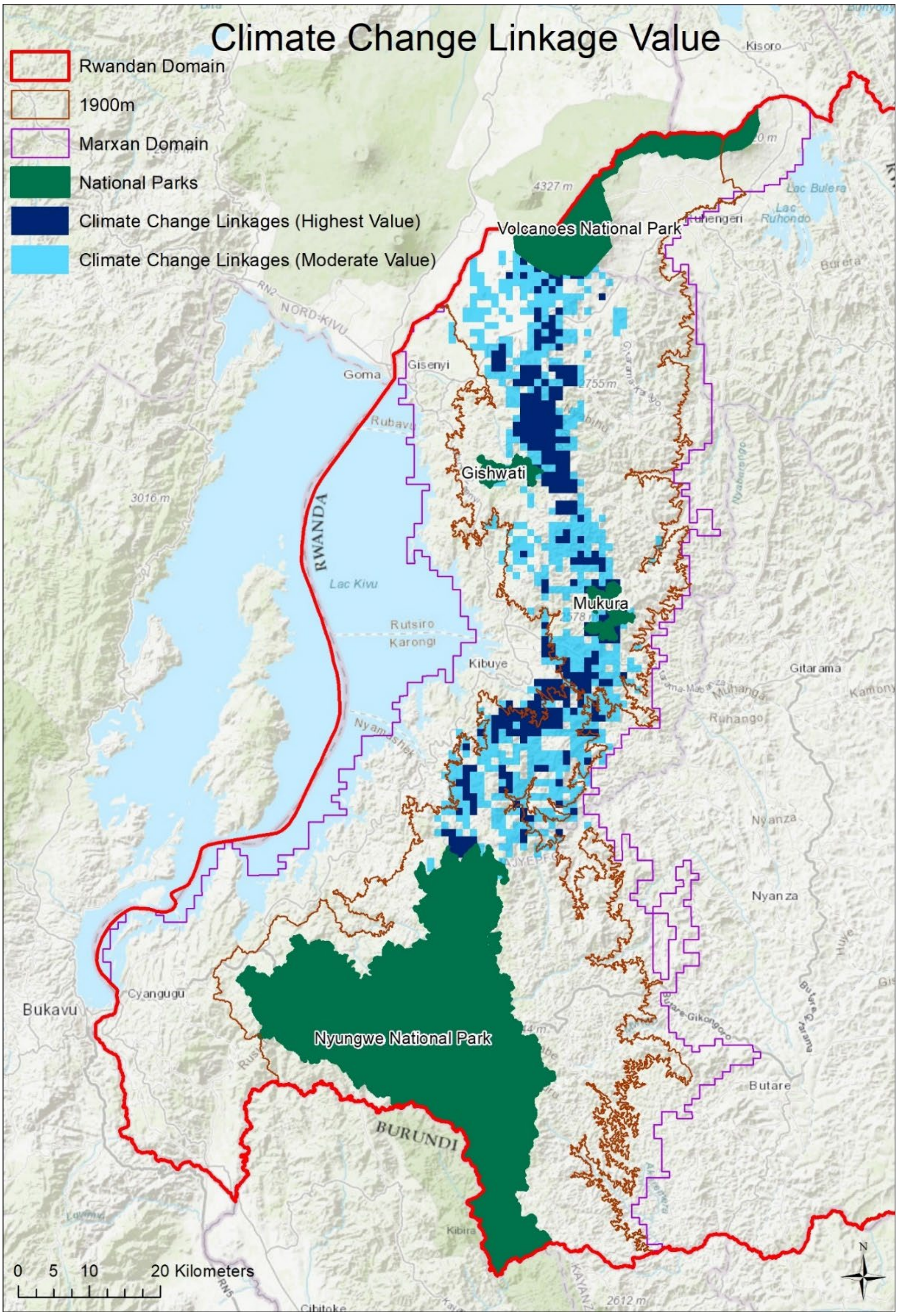

Figure 19: High and moderate climate change linkage values (based on the three quantiles) generated by the Condatis analysis.

3.4 Ecosystem Types, Threat Status and Protection Levels

3.4.1 Ecosystem Types

The draft vegetation map for Rwanda was developed in 2020 by the SANBI Ecosystems Mapping, Classification and Assessment team, and updated in 2022, with guidance from Rwandan experts. The Rwandan Vegetation Map was compiled by gathering all available data from continental, global and local data sources, with assistance from partners within the country. A first version of the ecosystem map was prepared, including terrestrial and aquatic ecosystems, for review by country experts (SANBI, 2022). The map was primarily based on a refinement of the regional potential vegetation map (Kindt et al., 2011; van Breugel et al., 2015; Van Breugel et al., 2011). The map is at a suitable scale for use in the Congo Nile Divide (CND) planning process. **Figure 21** and **Figure 22** present the seventeen (17) vegetation types that occur in the broader MARXAN planning domain. The maps show the original extent and the remaining intact vegetation respectively. Ecosystem threat status and protection levels are shown in **Figure 23** to **Figure 25**; and the associated statistics are in **Table 8** and **Table 9** below.

3.4.2 Ecosystem Threat Status

Ecosystem threat status indicates the degree to which ecosystems are still intact or alternatively losing vital aspects of their structure, function and composition, on which their ability to provide ecosystem services ultimately depends. The relatively new International Union for Conservation of Nature (IUCN) Red List of Ecosystems (RLE) methodology (Rodriguez et al., 2015) is used.

For the current project we are using and updating exploratory assessments being completed by the author of the current report for a training workshop in Kigali in September 2022 (African Biodiversity Challenge, 2022).

Rwanda is one of the first African countries to apply the internationally-accepted IUCN RLE standard (African Biodiversity Challenge, 2022), which consists of a suite of categories that rank how close each ecosystem type is to collapsing (**Figure 20**).

Threatened ecosystems are ecosystems close to collapse; and are referred to as Critically Endangered, Endangered, and Vulnerable. Near Threatened ecosystems are not yet threatened but are close or may qualify in the near future, whereas Least Concern ecosystems are still intact or in a relatively healthy state (Bland et al., 2017).

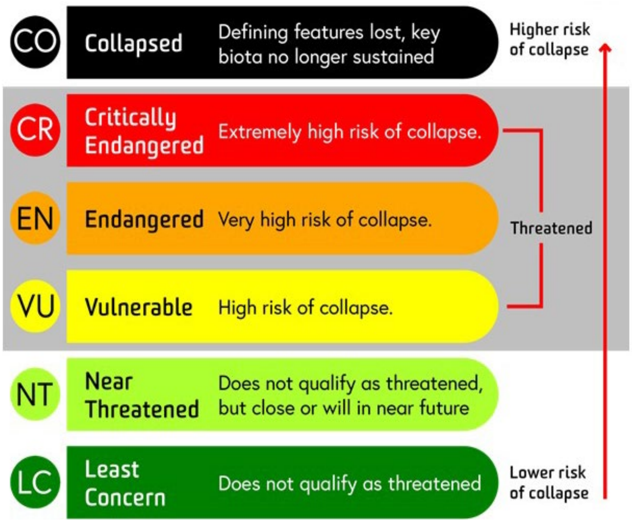

Figure 20: IUCN Red List of Ecosystems categories (Adapted from Keith et al., 2020).

Although six potential criteria are used to assess the risk of ecosystem collapse, for this assessment Criteria A3 was applied, which is for the reduction in geographical distribution over a long time period (i.e. since 1750) (Bland et al., 2017; Rodriguez et al., 2015). This approach has been repeatedly applied in other assessments such as South Africa's National Biodiversity Assessment (Skowno et al., 2019). Experience has shown that in initial assessments it is preferable to use this criterion as it generates robust results, rather than applying the full range of criteria when not all supporting data is available (e.g. of degradation processes or robust time series of loss).

Under the A3 criteria various thresholds are set for reduction in distribution of ecosystems compared with the original extent of each ecosystem type. To evaluate the criteria all that is needed is:

- The **map of ecosystem types** which shows the **original extent** of each ecosystem (**Figure 23**). This provides an historical snapshot of original extent that for practical purposes is assumed as a 1750 baseline. This date predates large scale industrial and arable agriculture activities, and expansion of human populations.
- The **map of ecological condition** showing **remaining or current extent** of natural and semi-natural areas (**Figure 8**).

A basic GIS process was then used to evaluate the areas which have been lost, as shown in **Figure 7** and **Figure 8**. This allows a calculation of threat status for each ecosystem type, as shown in **Figure 24**. These results are similar to those produced by the recent exploratory assessment in Kigali (African Biodiversity Challenge, 2022), but there are some minor differences as a result of us applying the improved ecological condition map developed for the current project (**Section 3.1.2**).

3.4.3 Ecosystem Protection Level

Ecosystem protection level indicates whether ecosystems are adequately protected (Well Protected) or are under-protected (Moderately Protected, Poorly Protected, Not Protected) (**Table 7**). This is computed by overlapping the remaining natural areas in the ecosystem type map (**Figure 22**) with the protected areas map (**Figure 27**). Protection level for each ecosystem is then categorised based on the proportion of percentage target for each ecosystem type that is included within protected areas.

Protection level evaluations are relative to the percentage target of the original extent of each ecosystem type. The post-2020 global biodiversity target, Draft Target 2, is: '*By 2030, protect and conserve through a well-connected and effective system of protected areas and other effective area-based conservation measures at least 30 percent of the planet with the focus on areas particularly important for biodiversity*.' This assessment has used the likely 2030 target (30% of each ecosystem type) as the baseline for the CND protection level evaluation.

As for the ecosystem threat status, a minor update has been applied to the exploratory assessments, which are being completed by the author of the current report for a training workshop in Kigali in September 2022 (African Biodiversity Challenge, 2022).

Table 7: Ecosystem protection levels are calculated based on the proportion of the target met in a protected area (or other effective area-based conservation measure).

Proportion of Target Met in a Protected Area	
Not protected	*Zero or less than 5% of target*
Poorly protected	*5% or less than 50% of target*
Moderately protected	*50% or less than a 100% of target*
Well protected	*100% or more than a 100% of target*

Calculating protection levels require a basic GIS calculation using the following components and method:

- The **ecosystem types map** shows the **original extent** of each ecosystem (**Figure 21**). This provides an historical snapshot of original extent that can be used to calculate the 30% target requirement.
- The **protected areas map** shows areas within Protected Areas and OECMs (Other Effective Areas-based Conservation Measures) (**Figure 27**). This is used to identify the areas of each ecosystem type that are protected.
- The **ecological condition map** showing **remaining natural and semi-natural areas** (**Figure 8**) is used to ensure that only these natural areas contribute to meeting the 30% target. This ensures that fields, dams, planation forest (e.g. eucalypts), urban areas etc are not counted in the calculation of effective protection.

A basic GIS process was used to evaluate the area of each ecosystem type that is in a Protected Area or OECM (Other Effective Areas-based Conservation Measures) and is in an intact, natural or semi-natural ecological condition. These values are compared to the 30% target and a protection level category is calculated for each ecosystem type.

3.4.4 Ecosystem Types, Threat Status and Protection Level in Rwanda's Congo Nile Divide

The core ecosystem of the Congo Nile Divide (CND) is the **Afromontane Rain Forest**, which is the most extensive montane forest type in the landscape. Originally it covered 418 524 ha of the CND (**Table 8** and **Figure 21**), but nationally there has been a 77% loss of Afromontane Rain Forest in the country (**Figure 22**). Most of the remaining extent of approximately 96 402 ha are restricted to Protected Areas, with very little remaining intact outside of the PAs. Given this high level of loss, Afromontane Rain Forest is classified as **Endangered** under the IUCN Red List of Ecosystems (**Table 9** and **Figure 24**). Furthermore, the ecosystem is under-represented in the PA network – it is classified as **Moderately Protected**, and very little habitat remains in an intact state outside of the PAs (**Figure 25**). It is therefore **critical to protect and restore what little montane forest is remaining** in the Congo Nile Divide, to at least approach the 30% post 2020 CBD target as closely as possible.

Although there are other important Afroalpine ecosystem types in the CND, notably Afroalpine Mountain Bamboo, Afroalpine Mountain Vegetation, Hagenia Forest, Mixed Forest and Afroalpine Herbaceous Mountain Vegetation (**Table 9** and **Figure 21**), these are largely conserved within the Volcanoes National Park (VNP) and hence are classified as Least Concern and all are Well Protected, apart from the Afroalpine Mountain Bamboo which is Vulnerable. At the lower altitudes, numerous threatened ecosystems that are under-represented in the PA network occur, but these ecosystems are peripheral to the CND and are not the focus of Rwanda's CND project.

Table 8: Ecosystem types of the Congo Nile Divide (CND), showing key metrics of original and remaining extent.

Biome	Ecosystem Type	National Extent					CND Extent	
		National Extent (Original Extent) (ha)	Intact Extent (ha)	% Loss	Intact in PA (ha)	% of National PA Target	Extent in CND (Original Extent) (ha)	% of National Extent in CND
Core CND Ecosystem								
Montane Woodland	Afromontane Rain Forest	550 967	126 413	77.1	96 403	58.3	418 524	76
Afroalpine Mountain	Hagenia Forest	6 318	6 185	2.1	6 130	323.4	6 202	98.2
Humid Savanna	Evergreen Semi-evergreen Riverine Highland Savanna	37 295	5 228	86	104	0.9	36 676	98.3
Humid Savanna	Evergreen Semi-evergreen Humid Savanna	2 254	551	75.6	0	0	2 222	98.6
Afroalpine Mountain	Neoboutonia Forest	972	933	3.8	629	216.1	972	100
Humid Savanna	Transitional Humid Forest	102 736	17 475	82.9	9 213	30	102 736	100
Afroalpine Mountain	Afroalpine Mountain Bamboo	14 020	6 214	55.6	4 864	116	14 020	100
Afroalpine Mountain	Mixed Forest	546	542	0.5	535	327.4	546	100
Afroalpine Mountain	Afroalpine Mountain Vegetation	1 537	1 532	0	1 530	332.7	1 537	100
Humid Savanna	Dawei and Strychnos Scrub Forest	22 365	4 270	80.8	99	1.5	22 365	100
Afroalpine Mountain	Afroalpine Herbaceous Mountain Vegetation	606	603	0	584	323.2	606	100
Peripheral to CND								
Wetland	Miscanthus and Cyperus Wetland	110 182	92 078	16.4	42 199	127.7	9	0
Highland Plateau	Evergreen Semi-evergreen Arid Plateau	128 739	7 824	93.9	23	0.1	1 194	0.9
Wetland	Mixed Vegetation Wetland	14 932	6 673	55.3	1 660	37.1	1 393	9.3
Highland Plateau	Transitional Savanna Forest	421 785	11 589	97.3	828	0.7	53 214	12.6
Lake	Lake	144 352	143 399	0.7	15 364	35.5	20 184	14
Wetland	Other Wetland Vegetation	43 745	8 239	81.2	1 439	11	10 910	24.9

Table 9: Redlist threat status and protection level of ecosystem types of the Congo Nile Divide (CND).

Biome	Ecosystem Type	Extent in CND (Original Extent) (ha)	IUCN Redlist of Ecosystems Threat Status	Protection
Core CND Ecosystem				
Montane Woodland	Afromontane Rain Forest	418 524	Endangered	Moderately Protected
Afroalpine Mountain	Hagenia Forest	6 202	Least Concern	Well Protected
Humid Savanna	Evergreen Semi-evergreen Riverine Highland Savanna	36 676	Endangered	Not Protected
Humid Savanna	Evergreen Semi-evergreen Humid Savanna	2 222	Endangered	Not Protected
Afroalpine Mountain	Neoboutonia Forest	972	Least Concern	Well Protected
Humid Savanna	Transitional Humid Forest	102 736	Endangered	Poorly Protected
Afroalpine Mountain	Afroalpine Mountain Bamboo	14 020	Vulnerable	Well Protected
Afroalpine Mountain	Mixed Forest	546	Least Concern	Well Protected
Afroalpine Mountain	Afroalpine Mountain Vegetation	1 537	Least Concern	Well Protected
Humid Savanna	Dawei and Strychnos Scrub Forest	22 365	Endangered	Not Protected
Afroalpine Mountain	Afroalpine Herbaceous Mountain Vegetation	606	Least Concern	Well Protected
Peripheral to CND				
Wetland	Miscanthus and Cyperus Wetland	9	Least Concern	Well Protected
Highland Plateau	Evergreen Semi-evergreen Arid Plateau	1 194	Critically Endangered	Not Protected
Wetland	Mixed Vegetation Wetland	1 393	Vulnerable	Poorly Protected
Highland Plateau	Transitional Savanna Forest	53 214	Critically Endangered	Not Protected
Lake	Lake	20 184	Least Concern	Poorly Protected
Wetland	Other Wetland Vegetation	10 910	Endangered	Poorly Protected

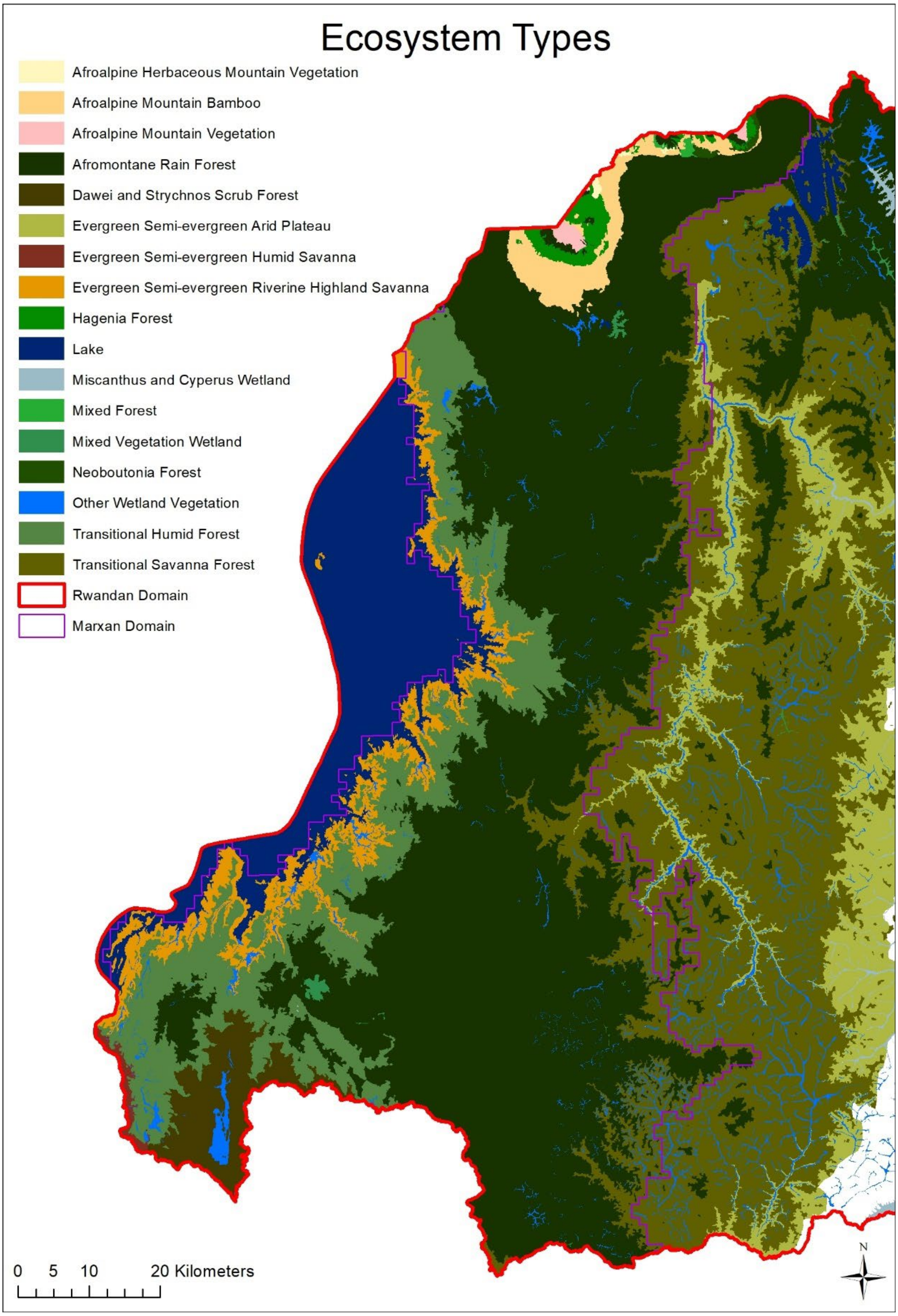

Figure 21: The ecosystem map for the Congo Nile Divide showing the historical extent of ecosystem types. Data from the Rwanda draft ecosystem map (SANBI, 2022).

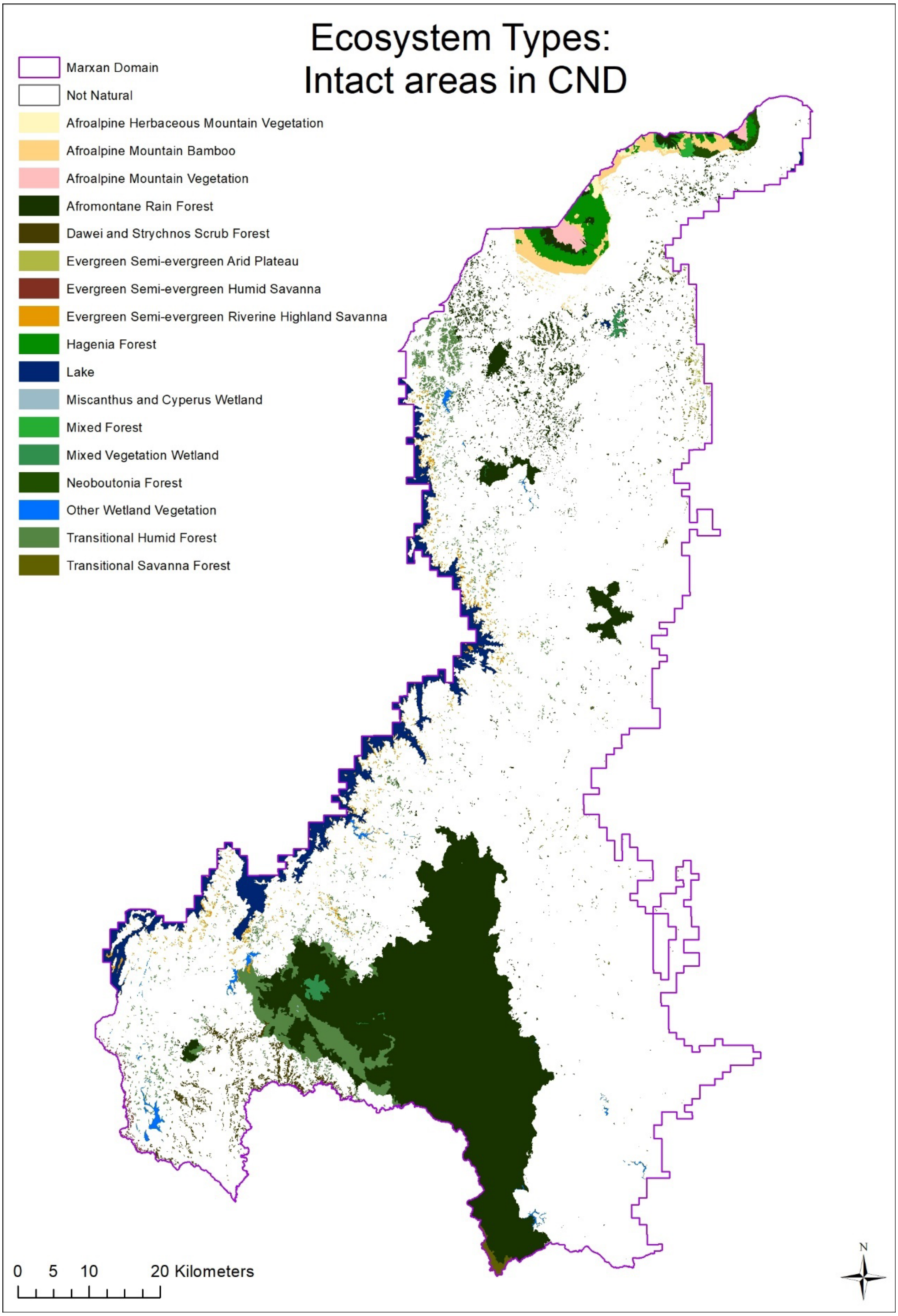

Figure 22. Remaining intact areas of each ecosystem type in the Congo Nile Divide.

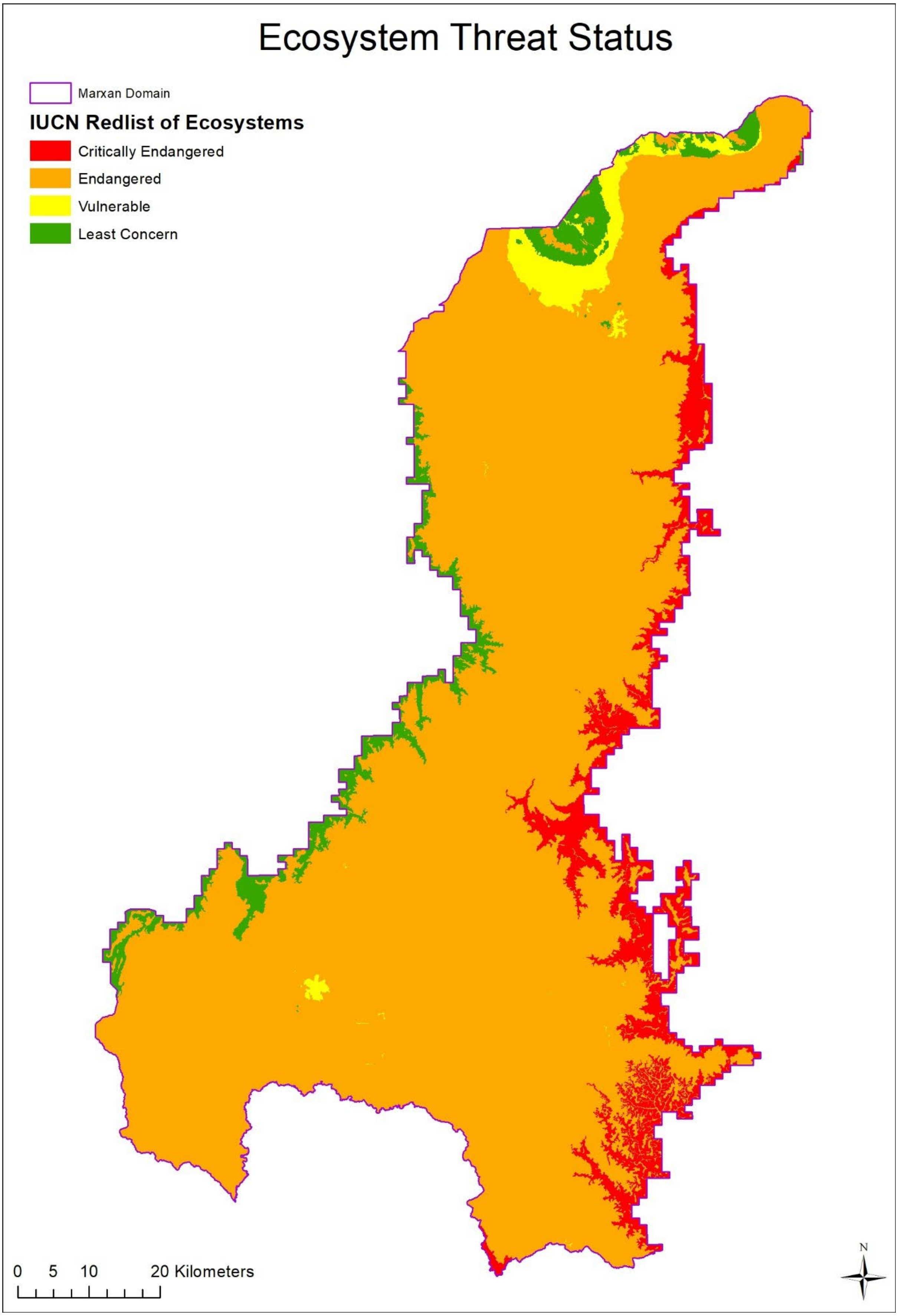

Figure 23. Ecosystem threat status of the different vegetation types in the Congo Nile Divide showing the original historical extent of vegetation prior to human impacts on the landscape.

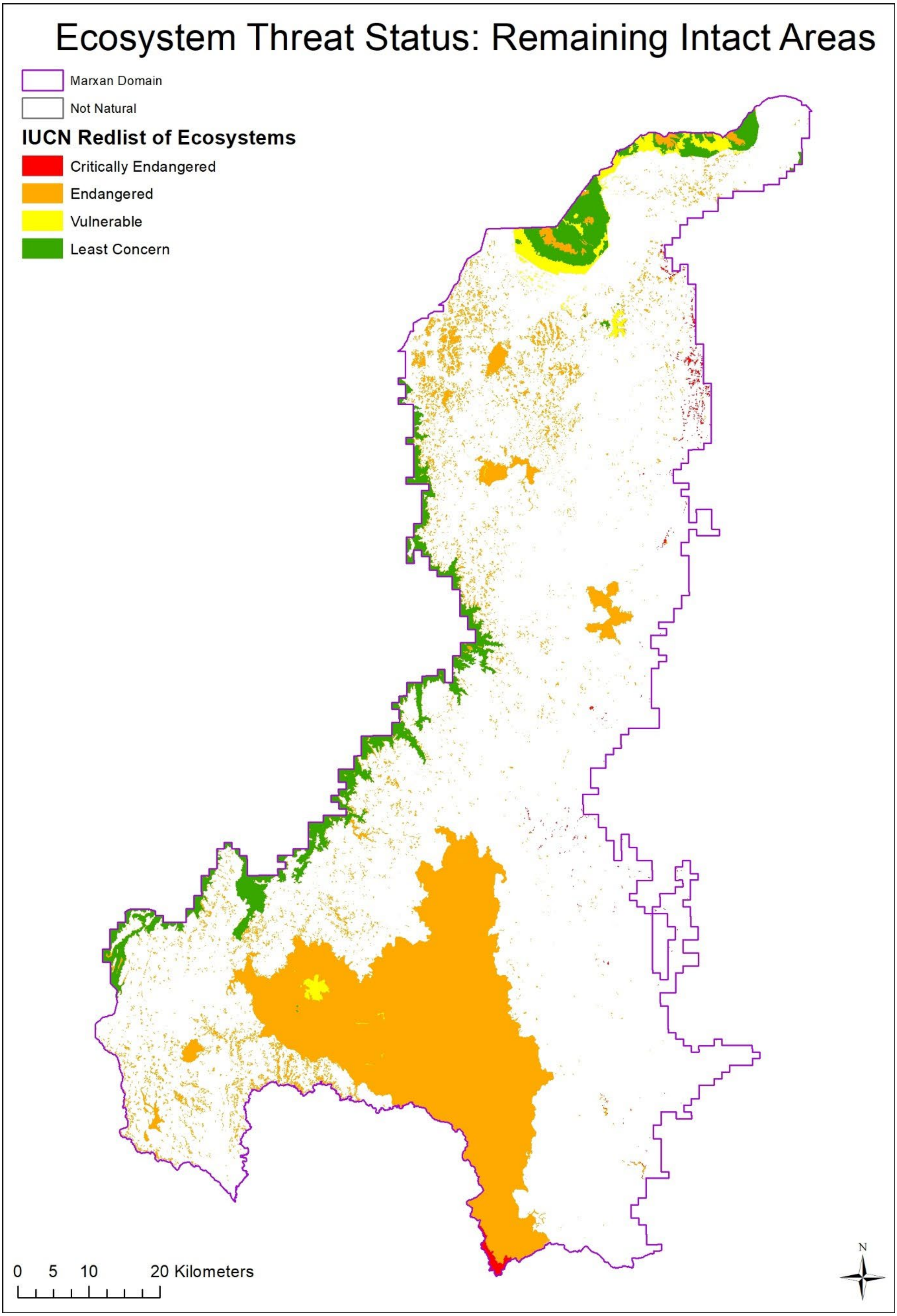

Figure 24. Ecosystem threat status of the different vegetation types in the Congo Nile Divide showing the current extent of remaining intact areas. The "Not Natural" landcover is shown in white.

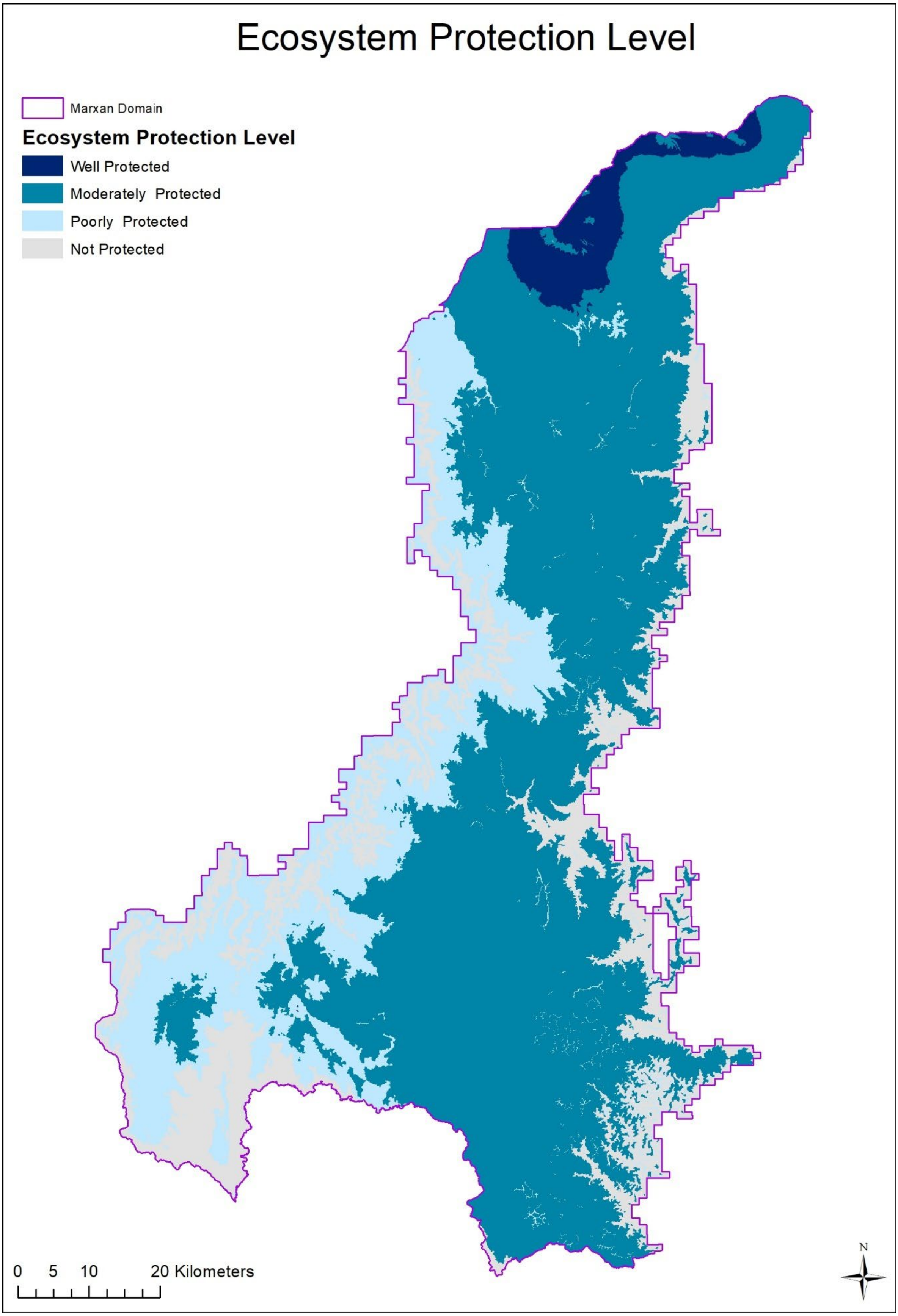

Figure 25. Ecosystem protection levels of the different vegetation types in the Congo Nile Divide. The map shows the original extent of vegetation cover prior to human induced landcover change.

Remaining natural patches of Montane Rain Forest and other Afroalpine types are a focus for the CND programme intervention. Thus, the specifically identified natural forest remnants from the national forest map were included as an additional feature in the MARXAN analysis. Approximately 123 403 ha of intact forest patches were mapped. Most of these are encapsulated within the boundaries of the NPs, however, some patches occur in the park buffers with a few fragmented patches scattered elsewhere in the CND landscape (**Figure 26**).

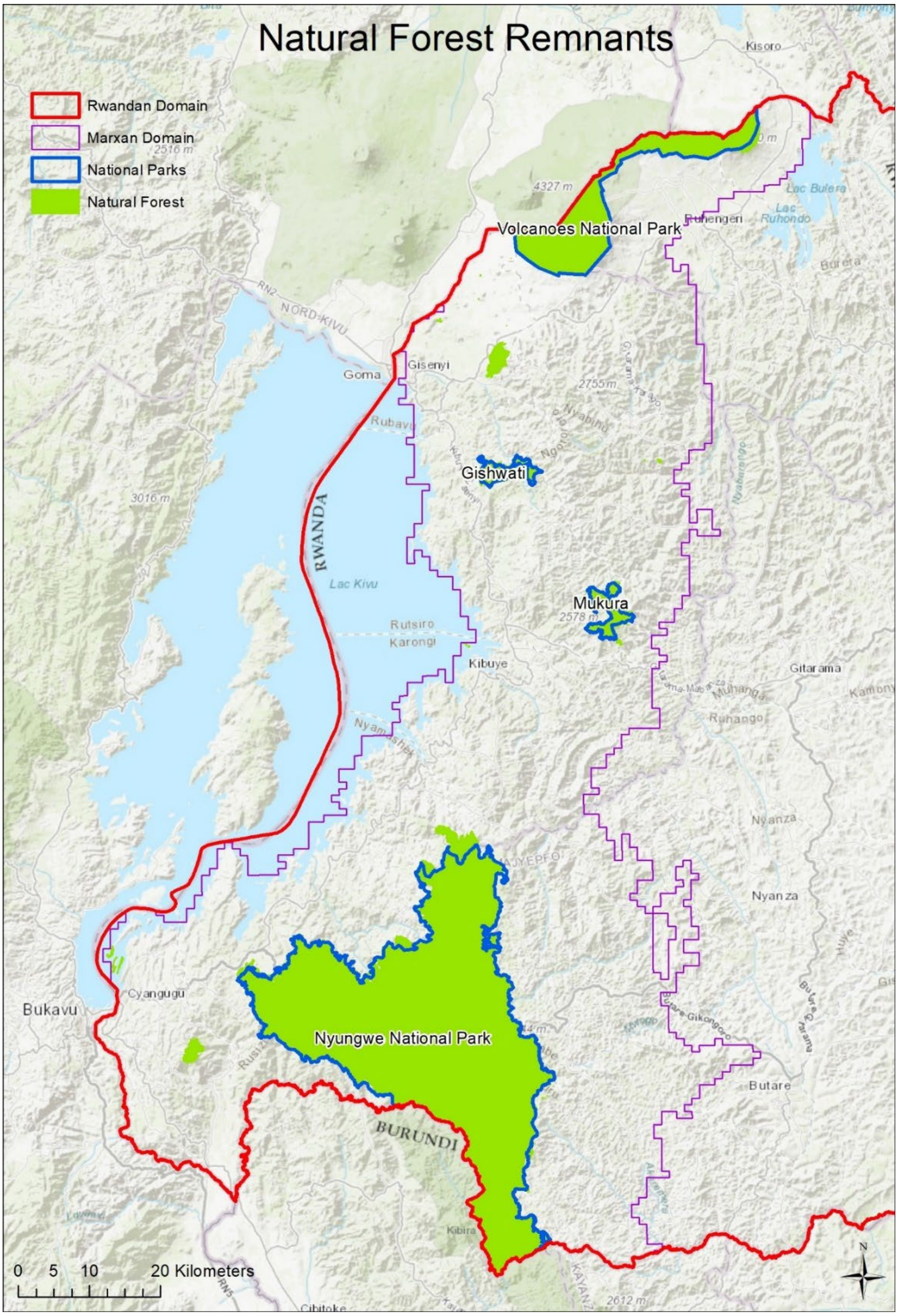

Figure 26: Map of specifically identified natural forest remnants from Rwanda's National Forest Map. Sourced from the Rwanda Forest Cover Map (Rwanda Ministry of Environment, 2019).

4 Additional Spatial Data Included in the MARXAN Analysis

4.1.1 Protected Areas and Other Effective Place Based Conservation Measures

The Protected Areas and Other Effective Place Based Conservation Measures (OECM) that fall within the Congo Nile Divide landscape are shown in **Figure 27**. These include the three National Parks, their buffers, two Protected Forests and 14 Protected Wetlands.

The formal Protected Areas are comprised of the large Nyungwe National Park (NNP) in the south, the Volcanoes National Park (VNP) in the north and Gishwati-Mukura National Park (GMNP) situated roughly in the central region of the CND. Since the GMNP is comprised of geographically separate areas, Gishwati in the north and Mukura to the south, for descriptive and planning reasons we frequently refer to them separately. This is particularly important as linkages between these two sections is a key intervention in maintaining connectivity across the CND. The much smaller Dutake Protected Forest is just north of Nyungwe NP and the Karehe-Gatuntu Protected Forest is situated south of Mukura portion of the MGNP. All the identified ecosystems found in the CND to be gazetted for protection are included (Rwanda Environment Management Authority, 2015).

Fully Protected Wetlands (Rwanda Water Resources Board, 2016) can be considered to form part of Other Effective Place Based Conservation Measures (OECM).

Cumulatively, the National Parks, their buffers, the Protected Forests and Protected Wetlands (located outside of the NPs), secure 133 510 ha of the CND planning domain (

Table 10).

Table 10: Formal Protected Areas and OEMS in the Congo Nile Divide, Rwanda. Note: Roughly 1 722ha of Protected Wetlands occur outside of the NPs, with 882 ha situated within the NPs.

Protected Areas and OEMS	Ha	Protected Wetlands (In and Outside of NPs)	Ha
National Parks (NP)	**120 449.4**	Mwaga	173.7
Nyungwe NP	101 005.1	Gaseke-Matyazo	207.6
Volcanoes NP	16 003.7	Gishoma	453.0
Mukura NP	1 989.3	Kamiranzovu	790.4
Gishwati NP	1 451.3	Akanyaru Amont	185.8
Park Buffers	**11 309**	Kilimbi	256.4
Gishwati NP Buffer	511	Nyirakesha	3.7
Nyungwe NP Buffer	10 074	Pfunda-Sebeya	323.3
Mukura NP Buffer	724	Nyirabanda	3.3
Protected Forests	**29.9**	Buvuje-Bwuje	119.6
Dutake	10.8	Pfunda-Rushubi (Mubuga-Nyabirasi)	24.5
Karehe-Gatuntu	19.1	Rubyiro-Rubona	9.1
Protected Wetlands Outside of NPs	**1 722.1**	Shyara (Nyungwe)	39.0
Grand Total	**133 510.4**	Shyara	14.6

The following approach was taken for inclusion into the conservation analysis:

- The Protected Areas (National Parks, Protected Forests and Protected Wetlands) were hardwired into the conservation planning results, as “Conserved”, which is effectively a 100% target. This is a planning category within MARXAN which guarantees that the PAs are consistently part of the identified conservation network.

- The buffers of the National Parks, Nyungwe and Gishwati-Mukura NPs, were included as separate features with targets. See **Table 3** for the targets set.

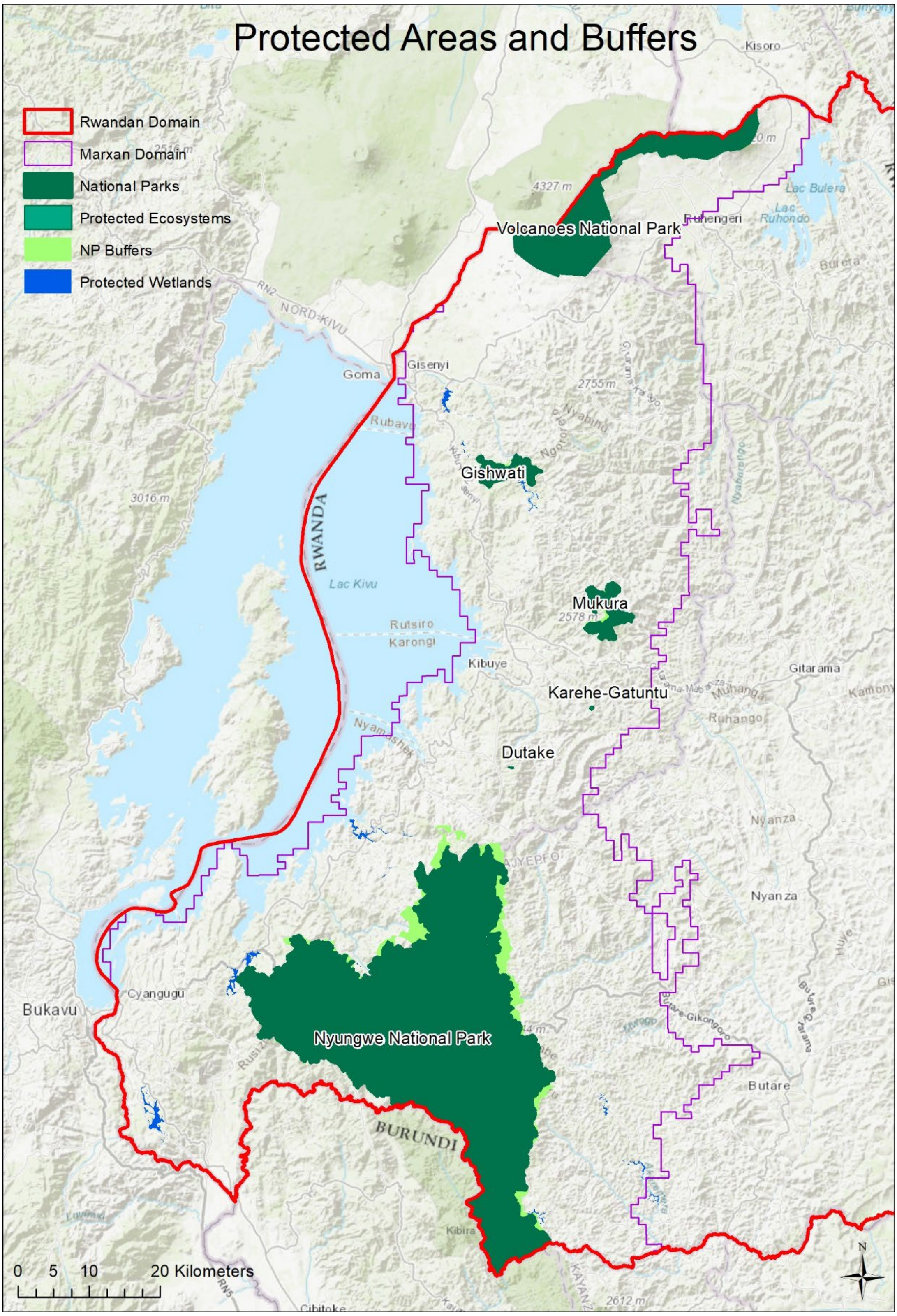

Figure 27: Map showing Protected Areas (i.e. National Parks with buffers) and Protected Forests; as well as Protected Wetland Ecosystems which are considered to be Other Effective Place Based Conservation Measures (OECMs).

4.1.2 Ecological Processes – Rivers and Streams

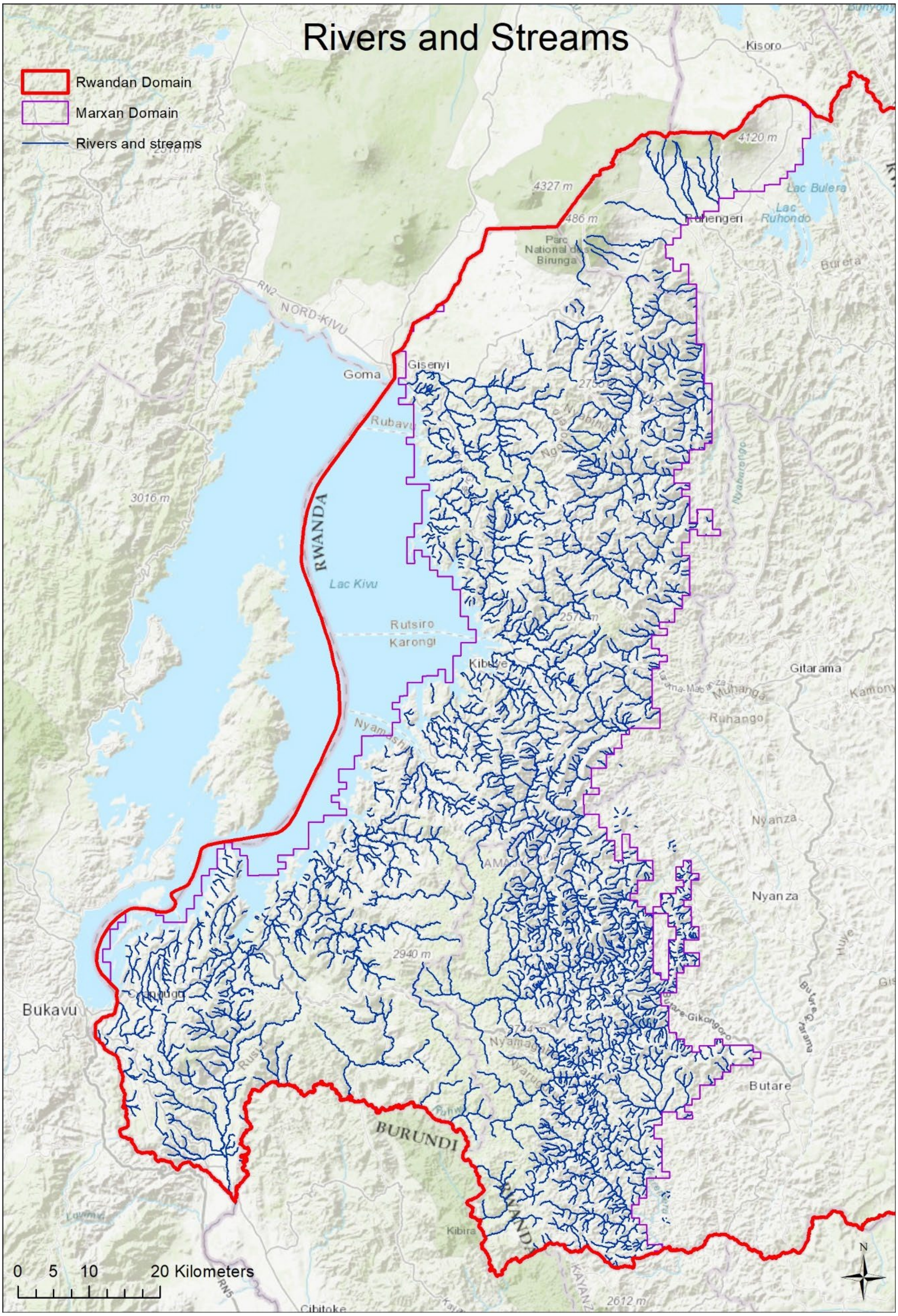

Figure 28: Rivers and streams are key ecological (hydrological) process areas within the Congo Nile Divide.

Rivers and streams are key ecological (hydrological) process areas within the Congo Nile Divide. Parts of the extensive Congo River drainage basin lies (roughly) in the western portion of the CND, and the Nile River drainage basin in the eastern portion. A complex network of perennial and non-perennial rivers and streams criss-cross and drain from the mountain watershed. Some of these drain westward, feeding Lake Kivu, situated along the planning domain's western periphery. The Nyungwe Forest, in the south, is the wettest region, and is of critical importance in sustaining river flows downstream during the mid-year dry period (Seimon, 2012 cited in Seimon, 2022). Most of the rivers are fed by marshes, which in turn are fed by seasonal floods and shallow groundwater. Pressure on these water resources is due to socio-economic development, involving agriculture livelihoods; and meeting basic household needs (Ministry of Environment, 2020b). Together there are over 5 398 km of rivers and streams in the MARXAN planning domain (**Figure 28**).

Data from 1:50 000 toposheets based on underlying mapping, mostly from 2008/09 Orthophotos, was utilized (Rwanda Surveys and Mapping, 2022b). To align with the National Land Use and Development Master Plan (NLUDMP) (Ministry of Environment, 2020), rivers and streams were buffered by 10m to identify a riparian zone. The rivers and the riparian zones were included in the MARXAN analysis as features. These were incorporated into the systematic conservation plan as process areas with a target as described in the targets section (**Table 3**).

4.1.3 Ecological Processes – Wetlands and Lakes

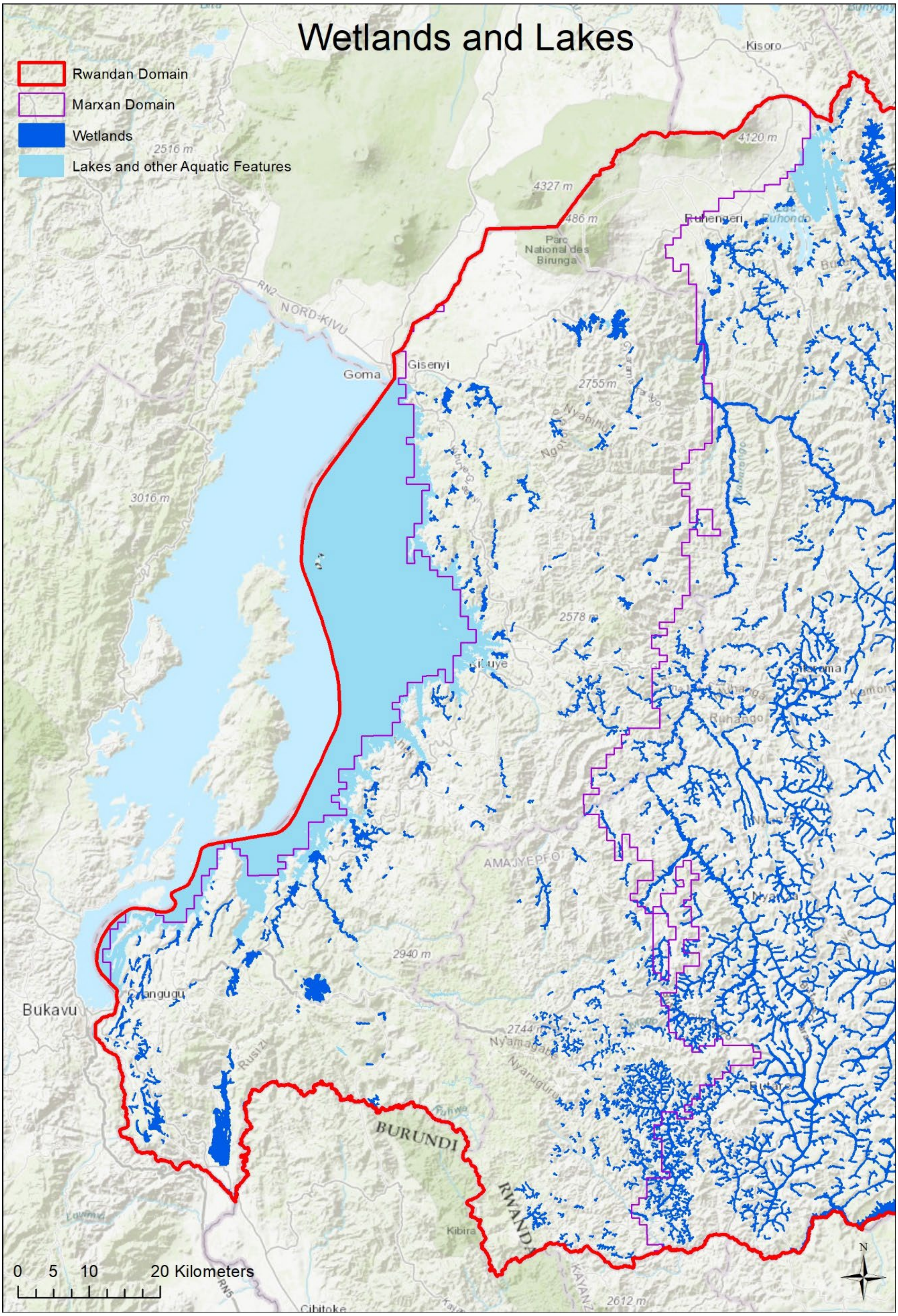

Figure 29: Wetlands and lakes are key ecological (hydrological) process areas in the Congo Nile Divide.

Wetlands and lakes are important ecological process features within the CND, are shown in **Figure 29**. In total there are 12 245 ha of wetland areas in the MARXAN planning domain. Most of these are however peripheral to the main highland areas. Compared to the total Rwandan wetlands area of 330 711 ha, the CND wetland extent is relatively small.

Although lakes of the CND total 22 279 ha out of the national area (of 106 551 ha), this is largely an artificial number (as the large lakes are peripheral and are cut by the planning domain) given the deliberate focus of the project on terrestrial ecosystems. Although large lakes are an important ecological feature, in the context of the CND Lake Kivu and other larger lakes are largely a barrier to terrestrial species in terms of climate change adaptation.

Wetlands data was primarily sourced from the 2016 SWAM wetlands dataset (Rwanda Water Resources Board, 2016). Wetlands were buffered by 20 m, as per the National Land Use and Development Master Plan (Ministry of Environment, 2020b). The Lakes data was derived from 1:50 000 toposheets (Rwanda Surveys and Mapping, 2022) (Rwanda Surveys and Mapping, 2022c), supplemented by the landcover and Rwanda’s draft ecosystem map (Esri Rwanda Ltd., 2018; SANBI, 2022). These were incorporated into the systematic conservation plan as process areas with a target as described in the targets section (**Table 3**).

4.1.4 Ecosystem Services - Stabilization of Steep Slopes

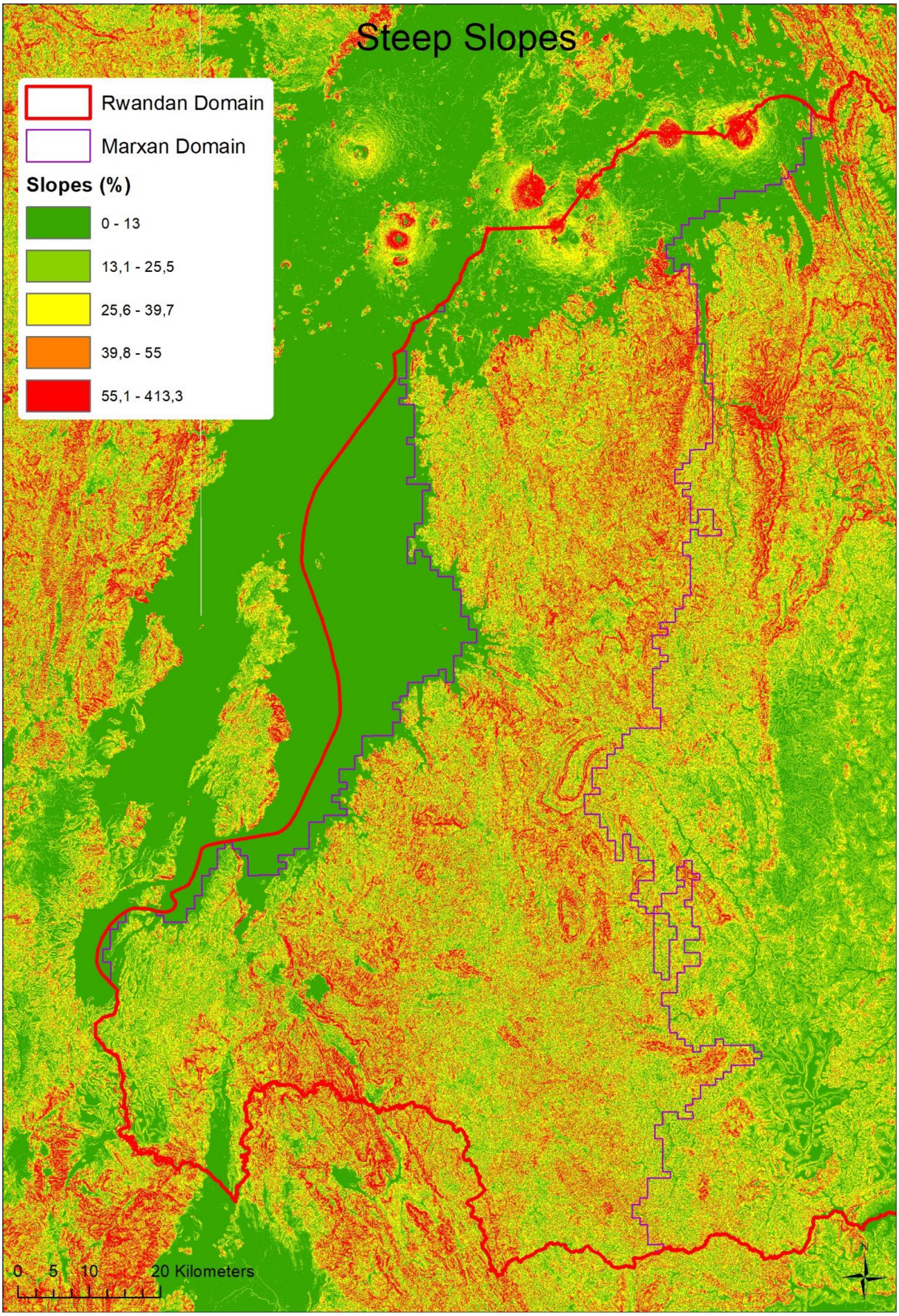

Figure 30: A slope model based on the 30m DEM was used for the identification of steep slopes (> 55%) in the Congo Nile Divide.

Since landslides and accelerated soil erosion are a major issue in the Congo Nile Divide's hilly topography, slopes with a gradient above 55% were identified for project intervention and to align with Rwanda's National Land Use Plan (Ministry of Environment, 2020b) (**Figure 30**). The steep, hilly slopes of Rwanda's CND have the highest level of landslide susceptibility (40.47%) in the country (Nsengiyumva et al., 2018). Landslides are a deadly natural disaster that takes lives, destroys extensive croplands, and encroaches upon forest habitat. Every year Rwanda loses on average 15 000 000 tons of fertile soils. High, intense rainfalls, mainly from March to May and from October to December, cause extreme soil saturation leading to more frequent landslide events. This is further exacerbated by high population densities with associated settlements and agricultural activities, including other soil related risk factors (Nsengiyumva et al., 2018).

In addition to landslides, steep slopes are highly prone to erosion when native vegetation is cleared. Nyesheja et al. (2019) concluded that roughly 85% of the CND was predisposed to erosion, with unsustainable average soil loss rates, especially in croplands.

The 30m Digital Elevation Model was derived from the Shuttle Radar Topography Mission (SRTM), which obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during 2000. SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA). The data was sourced from https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-shuttle-radar-topography-mission-srtm-1 (Earth Resources Observation And Science (EROS) Center, 2017).

The 30m Digital Elevation Model was analysed ArcGIS in order to identify steep slopes over 55% (**Figure 30**). Steep slopes were incorporated into the systematic conservation plan as process areas with a target as described in the targets section (**Table 3**).

4.1.5 Ecosystem Services - Precipitation (Current and Future)

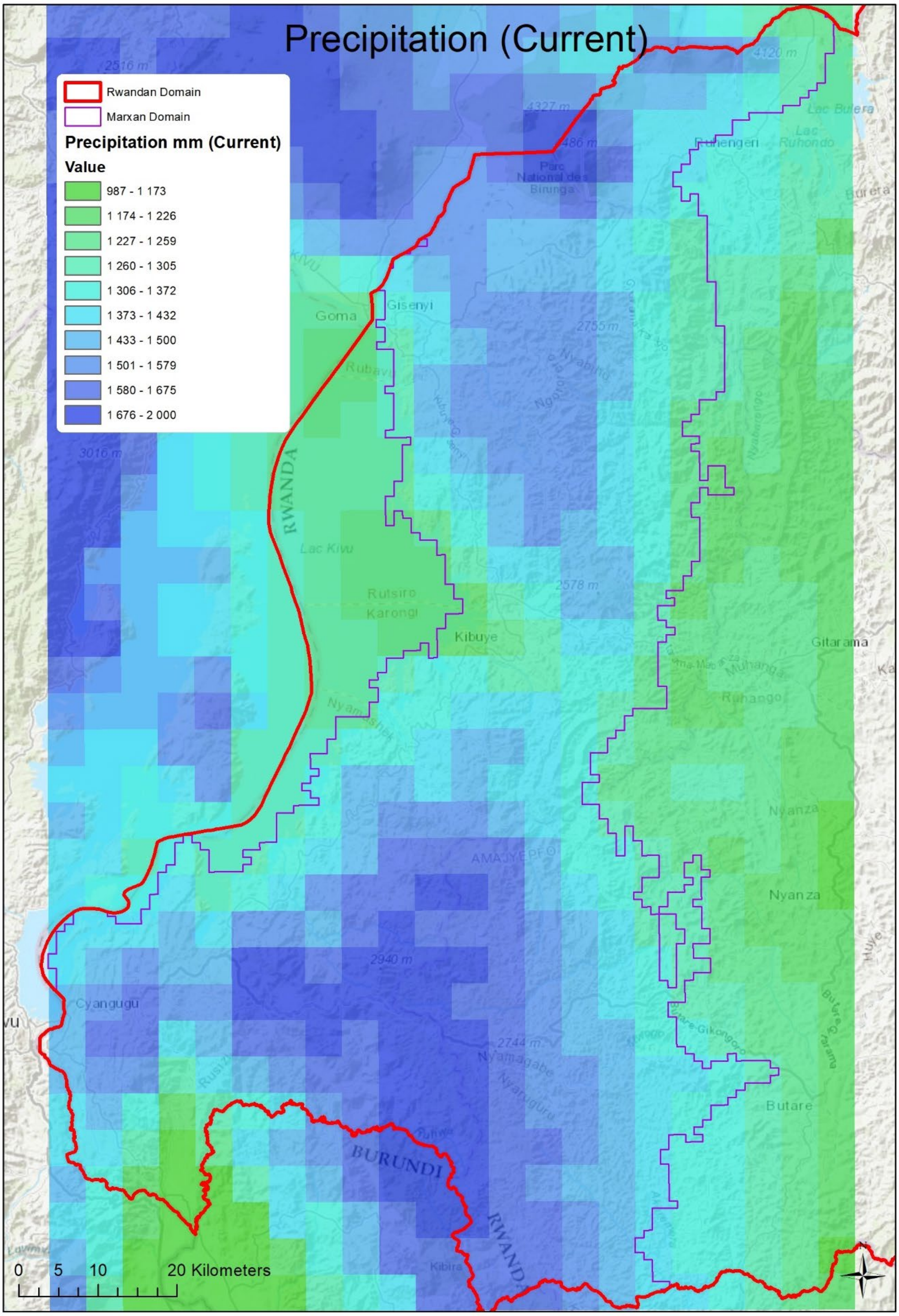

Figure 31: Current precipitation (mm/ annum) in the Congo Nile Divide, with highest levels corresponding with the highland areas.

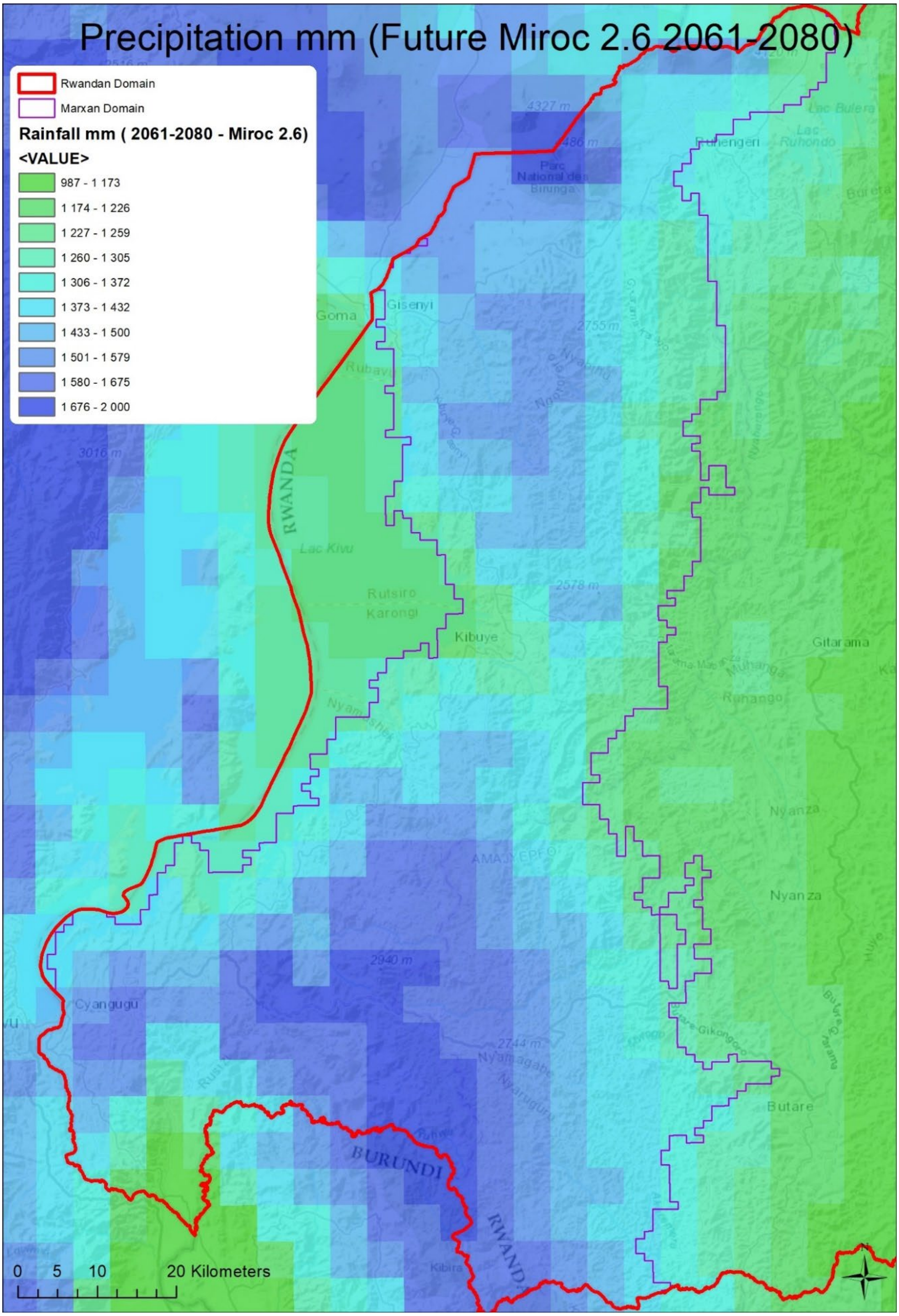

Figure 32: Future precipitation (mm/ annum) modelled for a moderate (RCP 2.6) climate change scenario (for 2061-2080), in the Congo Nile Divide. This is an example from the Miroc model, of one of the 7 modelled layers included for RCP 2.6.

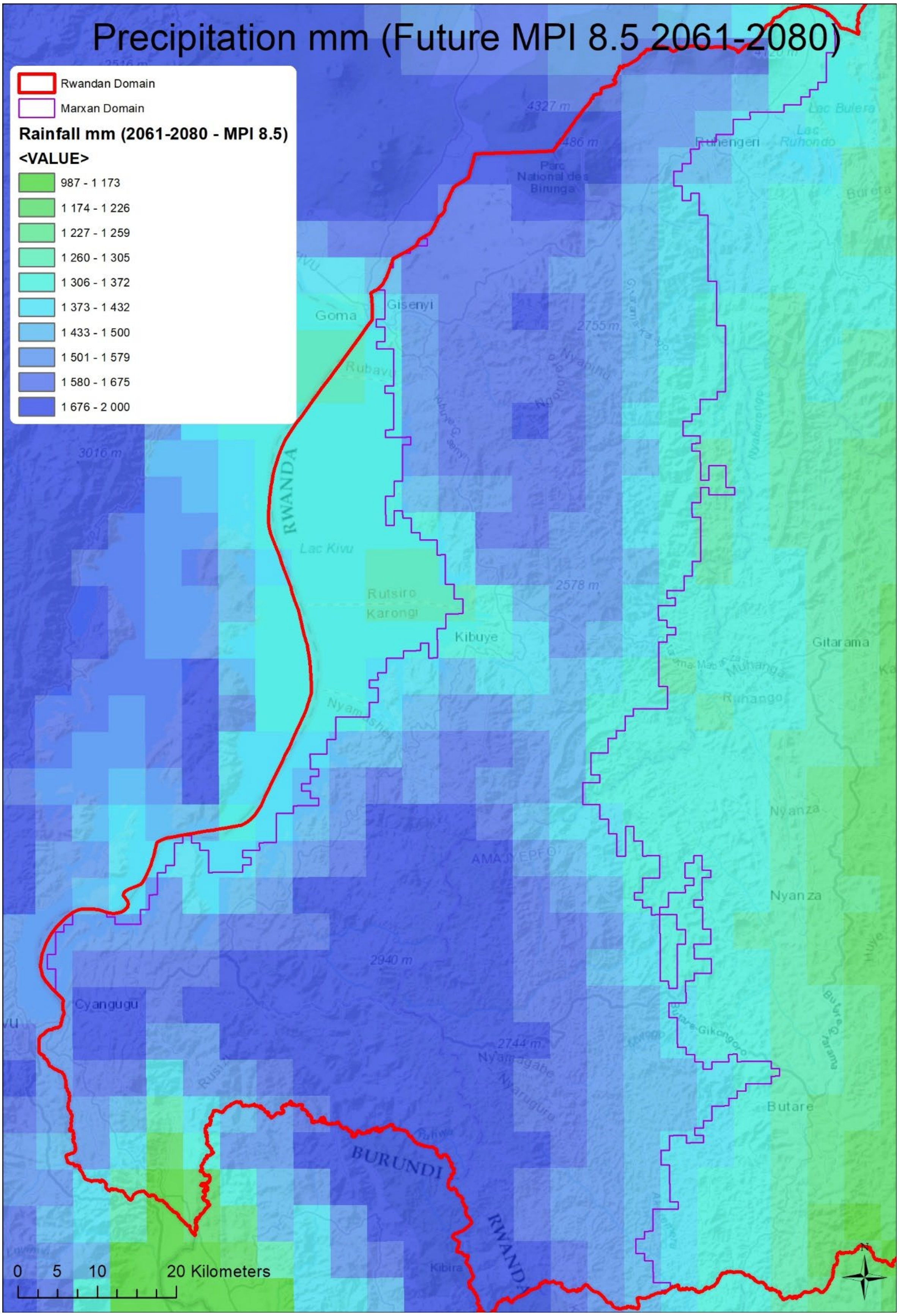

Figure 33: Future precipitation (mm/ annum) modelled for an extreme (RCP 8.5) climate change scenario (for 2061-2080), in the Congo Nile Divide. This is an <u>example</u> from the MPI model of one of the modelled layers included for RCP 8.5.

Precipitation (primarily in the form of rainfall) delivers much needed water to the region's rural communities and is a key ecosystem service for the Congo Nile Divide going forward, in the face of climate change. Additionally, part of the underlying rationale for the CND project relates to the interaction of increasing rainfall intensity and shorter rainfall periods, which results in landslides. Understanding current and future trends in precipitation is therefore key.

Current climate change data suggests that by 2050, annual rainfall may increase by up to 5% to 10%, combined with a temperature increase of 1.4°C to 2.3°C (Ministry of Environment, 2020b). Seimon (2022) reports changes in both precipitation seasonality and intensity. Seasonal changes will upend annual climatological patterns that have the potential to disrupt biodiversity, environmental systems and agricultural practices. Although further investigation is required, novel rainfall simulations performed for the EAGLE project show the total disappearance of the mid-year dry season by 2055-64, and onwards. A warming climate will definitively increase short-period rainfall rates and storm events, especially the fraction of higher-end events that can cause flash flooding and landslides (Seimon, 2022).

Current precipitation and examples of future precipitation from selected models for a moderate (RCP 2.6) and extreme (RCP 8.5) climate change scenario (for 2061-2080) are shown in **Figure 31** to **Figure 33** respectively.

It is straightforward to include current precipitation is straightforward to include. The approach for this assessment was to use current precipitation from Worldclim 2, which provides climate surface data at a 1 km spatial resolution (Fick and Hijmans, 2017). This is shown in **Figure 31**.

Precipitation under future conditions is much more difficult to incorporate. The models are much less robust than temperature models, and can vary significantly.

We used an ensemble approach to future precipitation. We used the data collated by Worldclim 2 project which are downscaled future climate projections derived from the Coupled Model Intercomparison Project, Phase 6 (CMIP6)[3]. The downscaling and calibration was done with WorldClim v2.1, as the baseline climate. The Worlclim project collated monthly values of precipitation for a range of global climate models (GCMs) for the moderate RCP 26 and the more extreme RCP 85 pathways. The data are annual totals based on monthly averages over 20-year periods (2061-2080). The data are at a 2.5 minute spatial resolution.

We used an ensemble approach based on 7 precipitation models for the region for each of the moderate and extreme scenarios to cover the range of plausible future precipitation outcomes. The models for the used for each of the scenarios were included:

- ACCESS-ESM1-5
- BCC-CSM2-MR
- CMCC-ESM2
- CNRM-CM6-1
- HadGEM3-GC31-LL
- MIROC6 (this is the example shown in **Figure 32** for the moderate RCP2.6)
- MPI-ESM1-2-HR (this is the example shown in **Figure 33** for the more extreme RCP8.5).

[3] The World Climate Research Programme is acknowledged, which, through its Working Group on Coupled Modelling, coordinated and promoted CMIP6. Thanks are also extended to the climate modelling groups for producing and making available their model output, the Earth System Grid Federation (ESGF) for archiving the data and providing access, and the multiple funding agencies who support CMIP6 and ESGF.

Note that the maps in **Figure 32** and **Figure 33** are examples. The analysis used all 7 models for each of RCP 2.6 and RCP 8.5, but we have not mapped them all as this would dominate the report, and the outcomes look broadly similar.

For the current and each of the future scenarios, targets were set at 30% of the total aggregated rainfall in millimetres across the domain. This ensures that the analysis targets the areas of consistently rainfall on which the forests of the CND depend, both under current and a full range of potential future scenarios.

The current and 14 future scenarios were incorporated into the systematic conservation plan as process areas with a target as described in the targets section (**Table 3**).

4.1.6 Marxan Cost Surface

Socio-economic and land use components were incorporated into the conservation planning process via a cost surface approach. A cost surface is required in the MARXAN analysis in order to ensure an efficient landscape solution and to avoid areas that are in **poor ecological condition** (e.g. transformed landcover classes, such as urban or arable fields), are **used intensively by incompatible activities** (i.e. incompatible for conservation land uses) or **have high socio-economic** cost (e.g. areas with high population densities). A cost surface (**Figure 36**) was used in the MARXAN analysis in order to focus on (select) intact natural ecosystems, thus avoiding areas that are in a poor ecological condition or areas that are used intensively by activities that are largely conservation-incompatible, at least at higher intensities. This is done to ensure a spatially efficient solution that retains natural or semi-natural areas; and avoids areas with the highest population densities.

The cost surface was built up of the following elements:

- **Area of the planning unit in hectares.** Since all planning units are equal, this value is 100 for each planning unit. This is necessary to ensure MARXAN is spatially efficient and does not add in any zero cost units.
- **Percentage of natural and near-natural landcover classes.** This was calculated based on the average coverage of natural and near-natural landcover classes i.e. “known natural” (127 400 ha) and “possibly natural” (85 938 ha) from the ecological condition map. These classes were scored as 100 and the remaining classes scored as a zero. A summary of the average value of the 10 m pixels was done for each 1 km^2 planning unit. This provides a score of percentage natural for each unit. It is shown in **Figure 34**. Refer to the Section 3.1 regarding the land use / landcover classes that were used to generate the ecological condition map.
- **Population density.** The population density, in individuals / km^2, was used to ensure highest density areas were avoided where possible. This is shown in **Figure 35**. Population density data from WorldPop (2020).

A variety of cost surface weightings were explored, with the final cost surface being calculated using the formula:

- Area in hectares + (100 - Percentage of natural and near-natural landcover classes) + 10*(Population density in individuals/km^2).

The final cost surfaces are shown in **Figure 36**. The highest cost is shown in red, which represents the high intensity land uses (e.g. cultivated pastures, urban) and areas of high population density. The lowest cost is presented in green, which is predominantly landcover in a natural or semi-natural state, and with low population density.

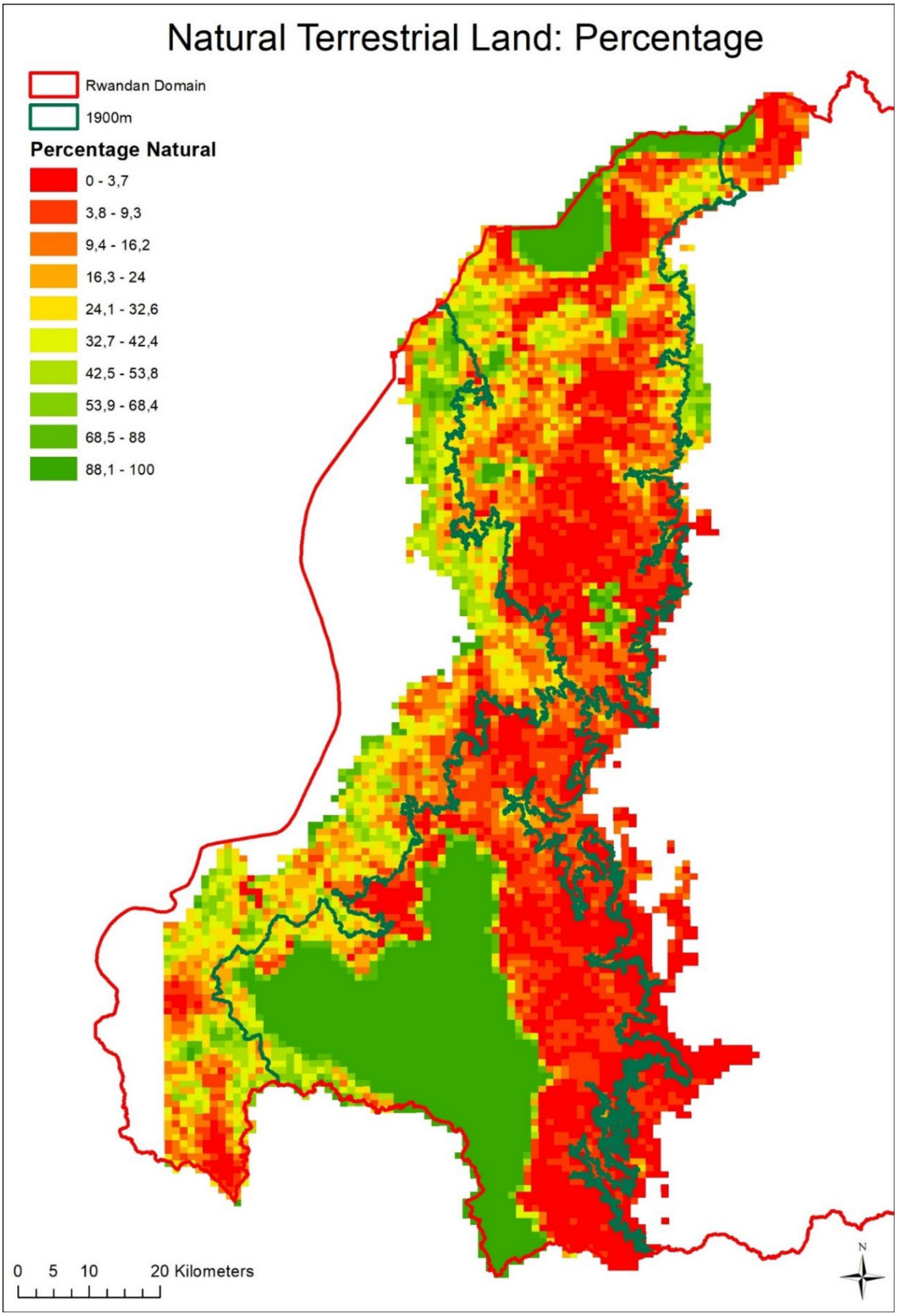

Figure 34: The natural land percentage derived from the ecological condition map for the Congo Nile Divide.

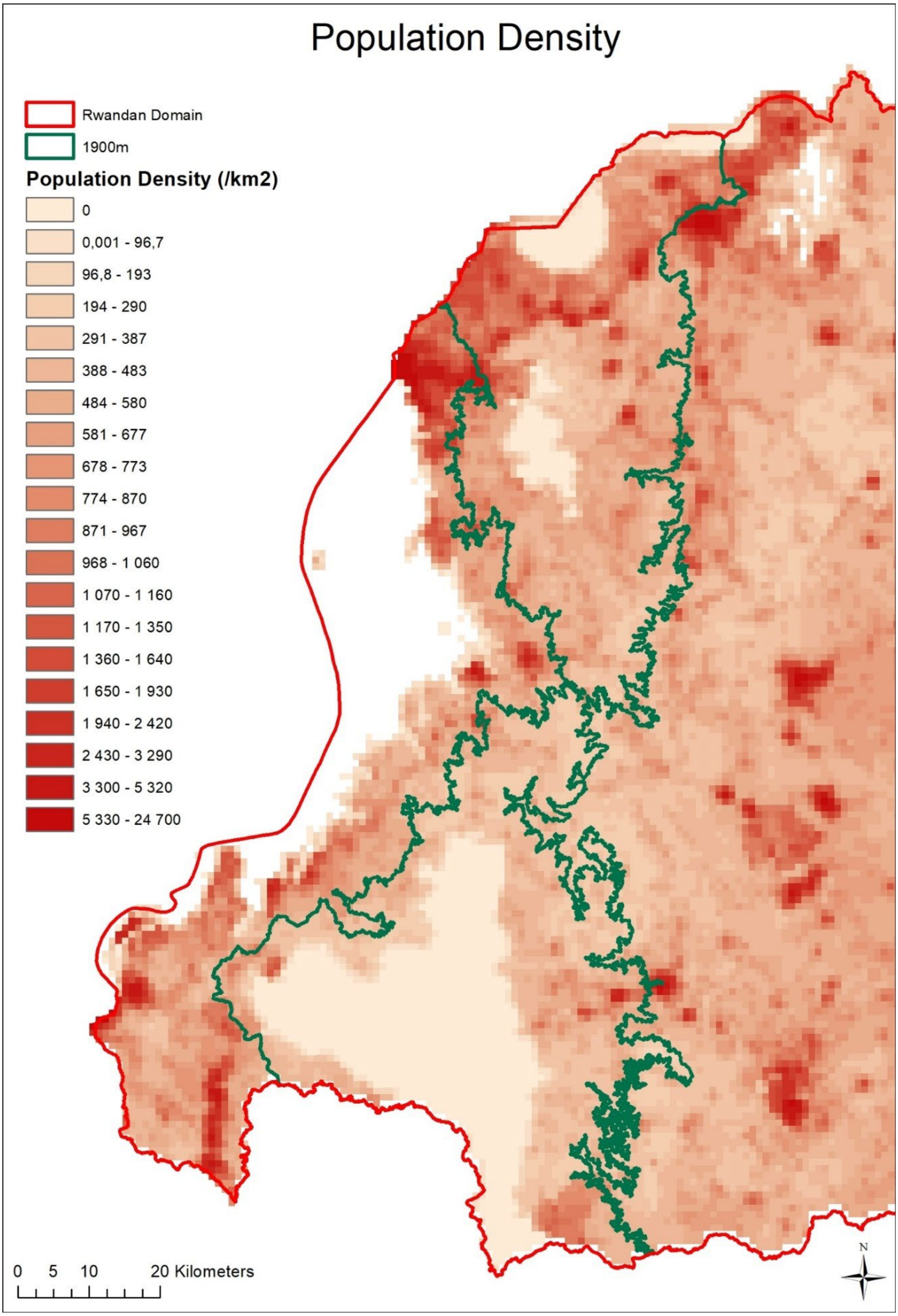

Figure 35. Population density per square kilometre for the Congo Nile Divide. Data sourced from the (WorldPop, 2020).

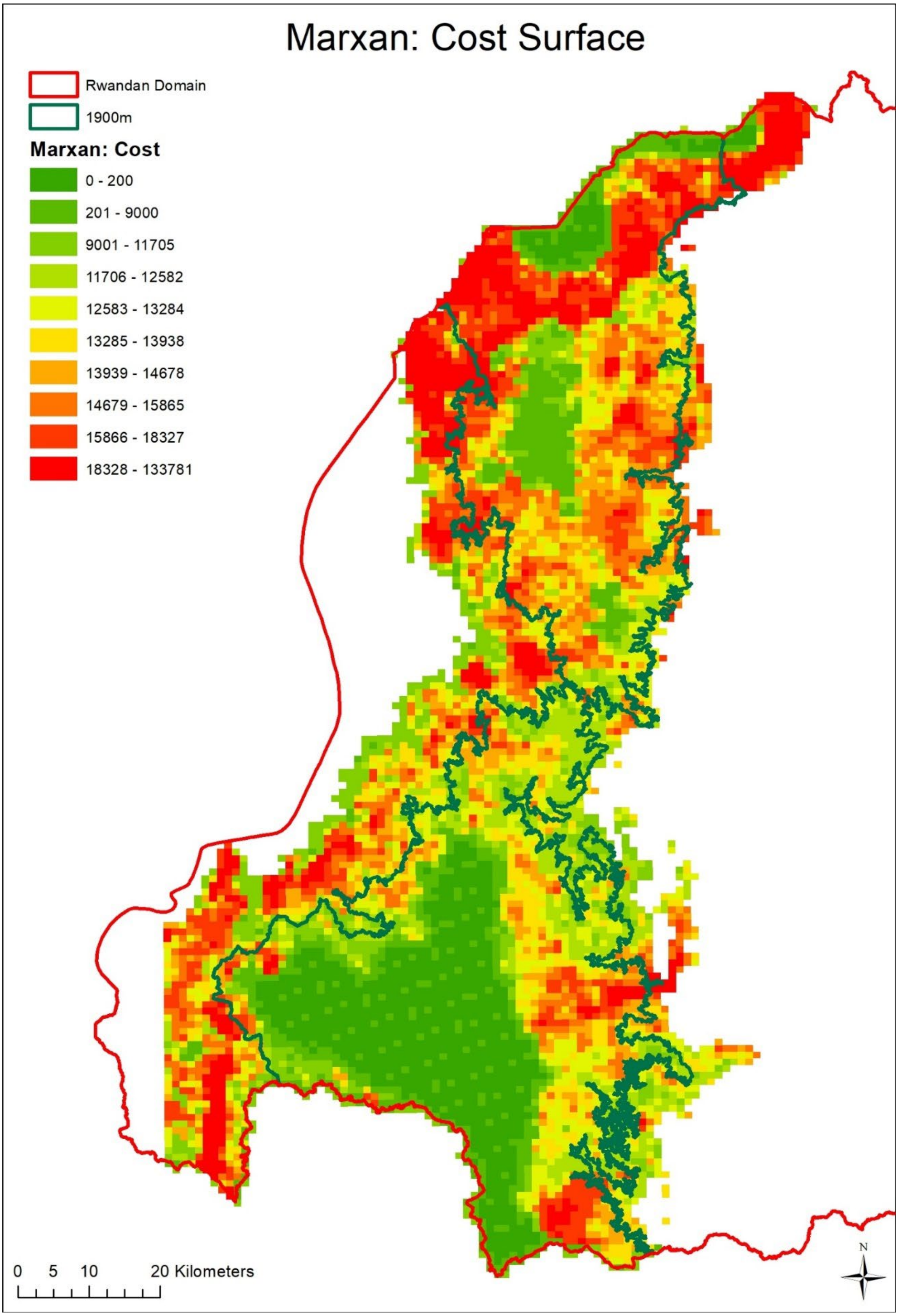

Figure 36: The overall cost surface layer used in the MARXAN analysis for the Congo Nile Divide landscape. The highest costs are in red and the lowest in green.

5 Spatial Prioritization Results

The key spatial results that are outlined in this section include:

- The **MARXAN landscape prioritization**, which builds in landscape connectivity, climate change refugia, biodiversity values, and social costs (in terms of avoiding, where possible, high-density people, agriculture etc) (**Figure 37**).
- The four key **landscape categories** that splits the Congo Nile Divide into current land use activities for appropriate conservation-oriented measures (**Figure 38**).
- A **spatial characterisation** of each land use sector (i.e. conservation, agroforestry and livestock agriculture) to prioritize activities (**Figure 39**).

The key ecological analyses, as outlined in **Section 3**, that contributed data inputs to generate the key spatial prioritization results, included:

- **Ecological Condition (Section 3.1)**: The ecological condition map (**Figure 8**), derived from the composite land use/ land cover map (**Figure 7**), which determined remaining intact areas of natural forest and other ecosystems.
- **Climate Change Refugia (Section 3.2)**: The climate change refugia (**Figure 15**), which represents areas where the core forest types will persist under future climate scenarios. The climate change scenarios were derived using a Global Environmental Stratification (GEnS) process; and included a moderate (RCP 2.6) scenario (for 2060-2080) (**Figure 12**) and an extreme (RCP 8.5) scenario (for 2060-2080) (**Figure 13**).
- **Condatis Connectivity Analysis (Section 3.3)**: The Condatis connectivity analysis (**Figure 18**), which evaluated the connectivity of the existing habitat network and prioritised potential restoration opportunities by identifying bottleneck areas (**Figure 17**).
- **Ecosystem and Forest Mapping (Section 3.4):** An ecosystems type or vegetation map was developed, based on the draft ecosystem map for the country (**Figure 21**). The map was further analysed based on ecological condition to determine, more importantly, remaining intact areas, ecosystem threat status (**Figure 23**) and protection levels (**Figure 25**). Remaining natural patches of montane forest types (**Figure 26**), from Rwanda's national forest map, were additional inputs into the MARXAN analysis.

In addition, data were included on:

- **The Protected Areas and Other Effective Place Based Conservation Measures (OECM) (Section 4.1.1):** These include the three National Parks, their buffers, two Protected Forests and 14 Protected Wetlands, shown in **Figure 27**. All the identified ecosystems found in the CND to be gazetted for protection are included (Rwanda Environment Management Authority, 2015), as were the Fully Protected Wetlands (Rwanda Water Resources Board, 2016).
- **Ecological process areas – Rivers and Streams (Section 4.1.2):** Rivers and streams, including their buffers. These are shown in **Figure 28**.
- **Ecological process areas – Wetlands and Lakes (Section 4.1.3):** Wetlands and lakes, including their buffers. These are shown in **Figure 29**.

- **Ecosystem services – Steep slopes (Section 4.1.4):** Steep slopes over 55% were included to identify areas at high risk of landslides and soil erosion. These are shown in **Figure 30**.
- **Ecosystem services – Precipitation (Section 4.1.5):** Precipitation, under current and a range of moderate and more extreme climate scenarios, was included to ensure that this key driver of montane forest distribution was directly targeted. These are shown from **Figure 31** to **Figure 33.**

The analysis avoided unsuitable and high socio-economic cost areas by incorporating a cost surface:

- **MARXAN Cost Surface (Section 4.1.6):** A cost surface is required in the MARXAN analysis in order to ensure an efficient landscape solution and to avoid areas that are in poor ecological condition (e.g. transformed landcover classes, such as urban or arable fields), are used intensively by incompatible activities (i.e. incompatible for conservation land uses) or have high socio-economic cost (e.g. areas with high population densities). A cost surface (**Figure 36**) was used in the MARXAN analysis in order to focus on intact natural ecosystems, thus avoiding areas that are in a poor ecological condition or areas that are used intensively by activities that are largely conservation-incompatible, at least at higher intensities.

5.1 MARXAN Analysis

The MARXAN irreplaceability analysis for the Congo Nile Divide identifies areas of higher conservation importance (Score close to 10) to areas of lower importance for conservation (Scores closer to 0) (**Figure 37**). The areas of highest importance (red) are largely driven by climate change refugia, the connectivity analysis, the presence of natural forest patches, wetlands and rivers. The analysis identifies a key high-altitude linkage that connects the National Parks, which support the majority of the remaining montane forest, via smaller isolated forest patches and riparian corridors. As result, the areas of highest elevation, which link the three National Parks and remaining forest patches (beyond the Parks), are clearly the highest conservation priority.

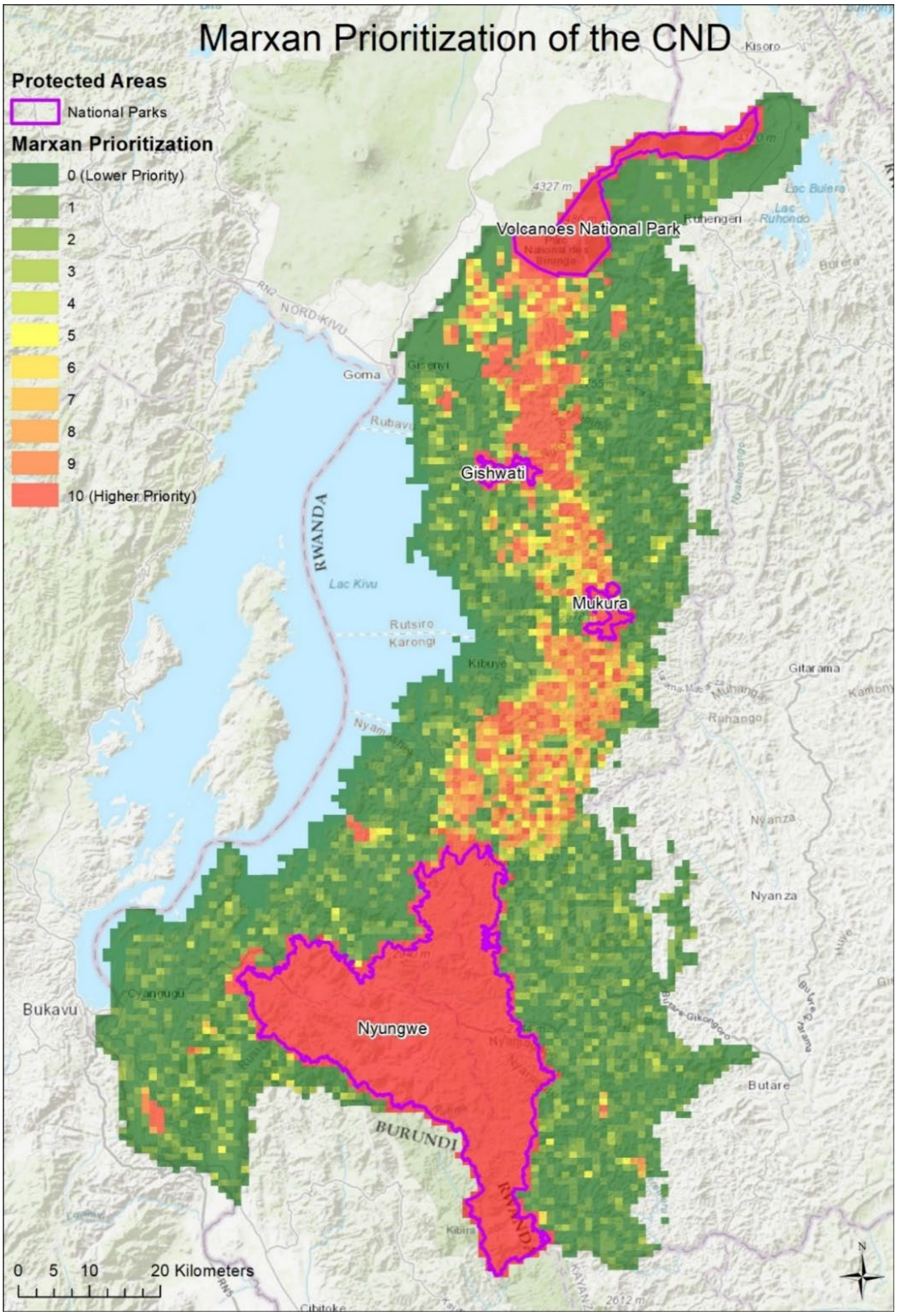

Figure 37: MARXAN irreplaceability analysis for the Congo Nile Divide, Rwanda.

5.2 Priority Landscapes for Interventions

5.2.1 Landscape Categories and Specific Implementation Areas

Based on the Condatis connectivity study **(Section 3.3)** and the MARXAN results **(Section 5.1)**, the Congo Nile Divide was divided into four major landscape categories (**Figure 38**), each with their own project interventions **(Section 6)**. Each of the spatial planning categories were further split into areas referred to as "Landscape Implementation Sectors" (**Figure 39**). The landscape categories and implementation areas (sectors) are defined and explained in the following sections.

The four major landscape categories were:

Core Protected Area (PA) Nodes and their Buffers:

- National Parks comprise the "Core PA Nodes" that need to be secured and well managed, which include Volcanoes, Gishwati-Mukura and Nyungwe National Parks. Priority activities include strengthening PA management and sustainability, rehabilitation and restoration of natural forests, other conservation-oriented land use activities that reduce stress on PAs and natural forests (e.g. improved wood stove efficiency to reduce pressure on natural forests) and supporting sustainable biodiversity compatible activities (e.g. improved beekeeping). These nodes also include buffer areas around the National Parks.

Stepping Stones:

- These are priority nodes outside of the current National Parks that are critical for maintaining landscape connectivity, comprising of small, isolated patches of forest, at Dutake and Karehe-Gatuntu Protected Forests and the extensive Gishwati Pastures. These areas would be a sensible focus for some (patches of) forest restoration and protection, beekeeping and energy efficient stoves. The Gishwati Pastures are a focus for agroforestry on pastoral land to increase the coverage of native trees to secure reasonable landscape connectivity for forest species.

Landscape linkages:

- These are key landscape linkages and knickpoints in the farming landscape that require afforestation on steep slopes and riparian areas to link the CND at a landscape scale. Compatible land use activities include agroforestry, increasing the use of native species, reforesting steep slopes, beekeeping and energy efficient stoves.

Broader Farming Mosaic:

- These are broader areas of moderate priority where conservation interventions can support broader sustainable landscapes and ecosystem service delivery but are likely to be beyond the scope of most project interventions except for those linked to land use planning.

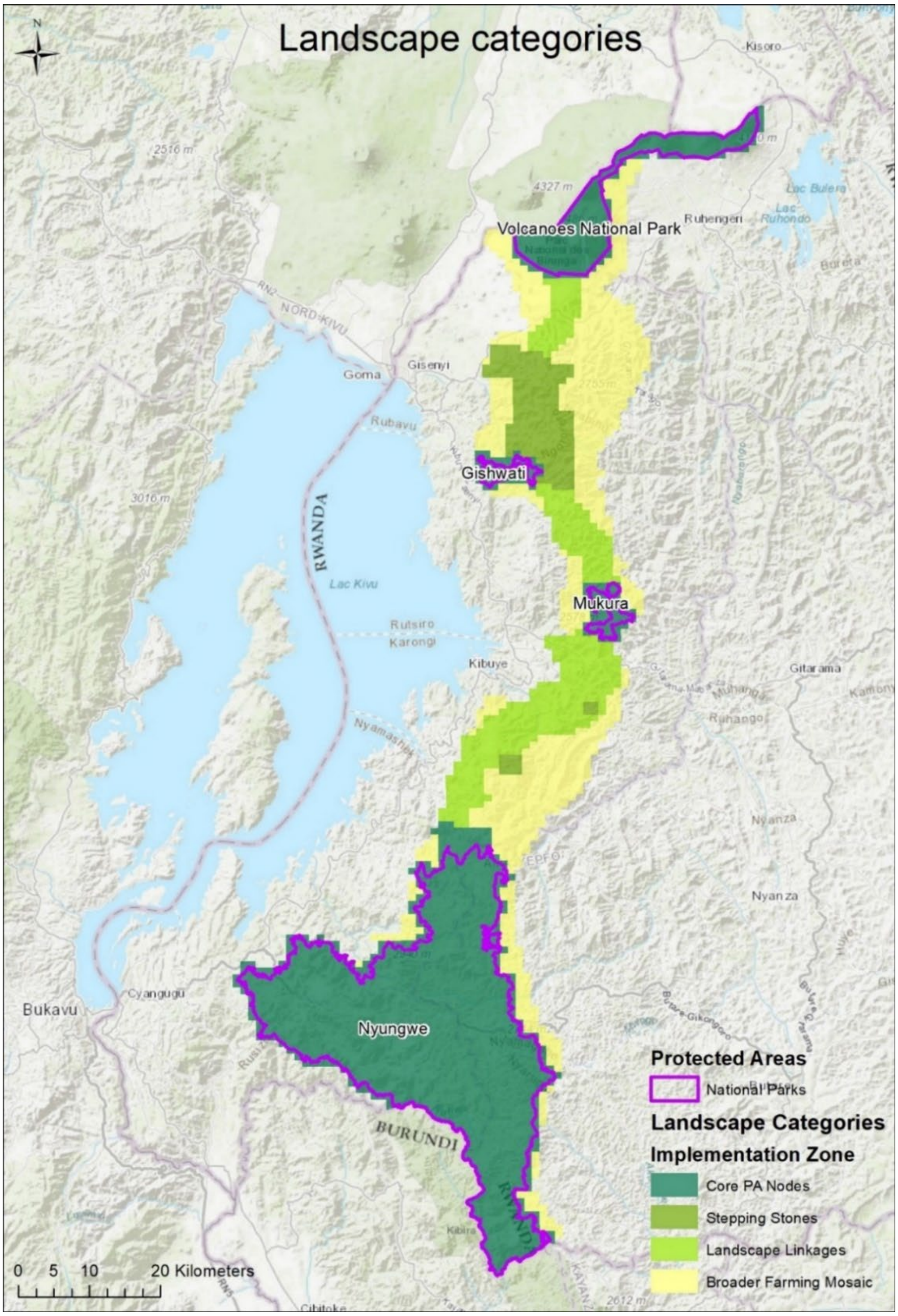

Figure 38: The Congo Nile Divide was divided into landscape categories based on the Condatis connectivity study and the MARXAN results.

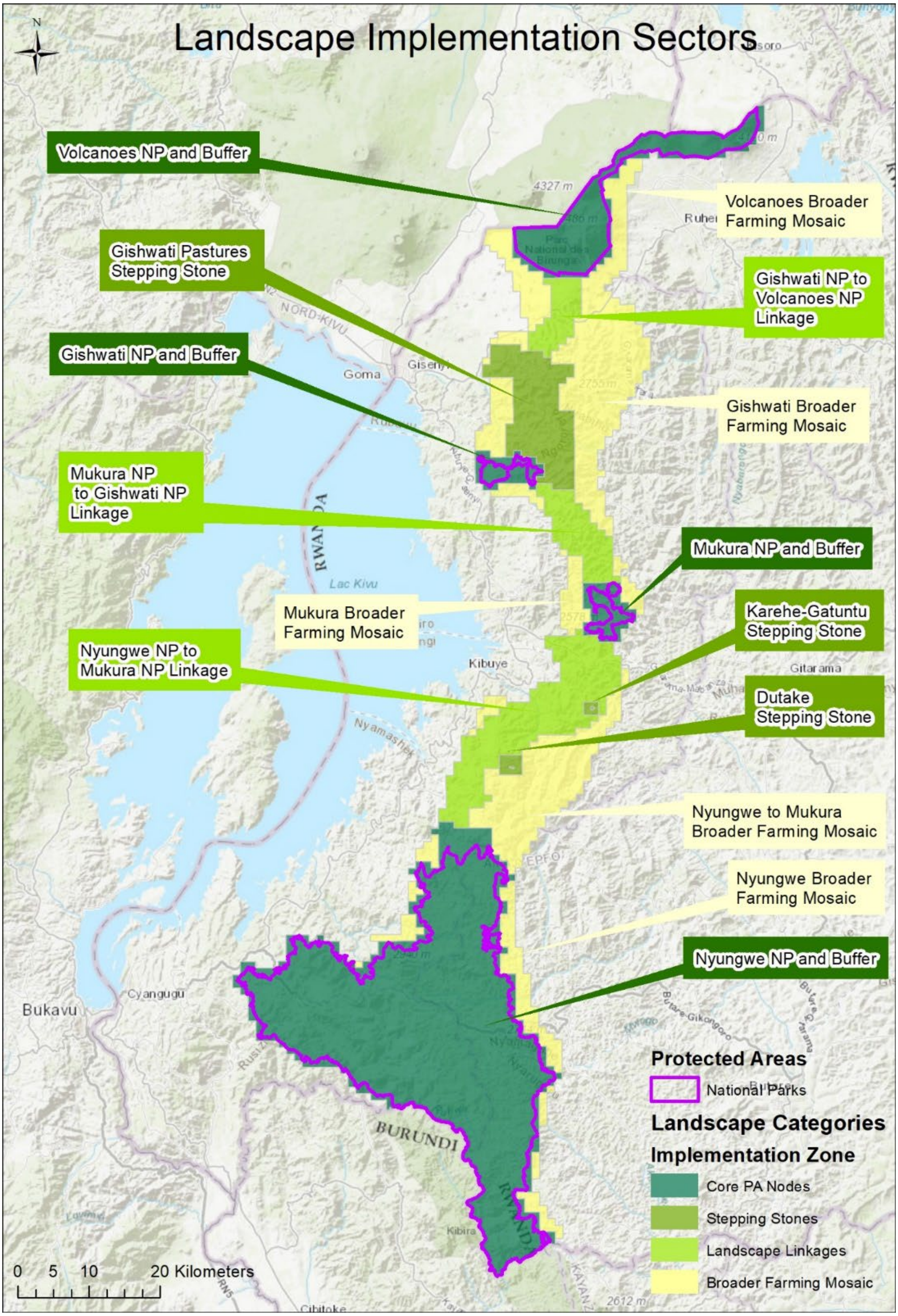

Figure 39: The four major landscape categories (Core PA Nodes, Stepping Stones, Landscape Linkages and the Broader Farming Mosaic) were split into specific areas to aid prioritization and description.

Landscape Implementation Sectors

To aid prioritization and description of the landscape categories above, the four categories were further split into specific areas within the CND, referred to as "Landscape Implementation Sectors" (**Figure 39**). These are presented in **Table 11** below.

The four Core PA Node implementation areas focus on the National Parks, and include buffers around the Park boundaries. Although Volcanoes NP does not have a legally designated buffer, the term "Buffer" refers to areas adjacent to the park which need to be managed.

Three Stepping Stone and three Landscape Linkage implementation areas were identified, with Gishwati Pastures representing the largest Stepping Stone (15 547 ha) and the highest MARXAN score (value of 9). The Nyungwe NP to Mukura NP Linkage represents the largest of the connections (23 375 ha) and a relatively high MARXAN score (value of 7.78).

The Broader Farming Mosaic comprises of five implementation areas; and is the second largest landscape category, after the Core PA Nodes category.

Table 11: Summary of area and overall MARXAN score (irreplaceability values) for each landscape category and specific sectors. MARXAN scores range from 10 (Highest irreplaceability) to 0 (Lowest irreplaceability).

Landscape Category	Landscape Implementation Sector	Area (ha)	Marxan Score (Mean)
Core PA Nodes	Volcanoes NP and Buffer	19 487,0	10,00
	Nyungwe NP and Buffer	116 794,9	9,93
	Mukura NP and Buffer	4 713,5	9,57
	Gishwati NP and Buffer	4 013,7	9,38
Stepping Stones	Gishwati Pastures Stepping Stone	15 547,4	9,00
	Karehe-Gatuntu Stepping Stone	401,1	8,75
	Dutake Stepping Stone	903,0	6,67
Landscape Linkages	Nyungwe NP to Mukura NP Linkage	23 375,4	7,78
	Gishwati NP to Volcanoes NP Linkage	5 014,8	7,64
	Mukura N to Gishwati NP Linkage	7 823,7	6,91
Broader Farming Mosaic	Nyungwe to Mukura Broader Farming Mosaic	21 164,4	5,55
	Volcanoes Broader Farming Mosaic	11 694,4	2,90
	Mukura Broader Farming Mosaic	4 814,0	2,56
	Gishwati Broader Farming Mosaic	28 433,2	1,88
	Nyungwe Broader Farming Mosaic	11 437,0	0,84

Table 12 below presents a summary of the landscape categories, along with the associated ideas, required outcomes, core benefits and associated benefits.

Table 12. A description of the four key landscape planning categories and associated ideas, required outcomes, core benefits and associated benefits.

Landscape Component	Core PA Nodes The National Parks	Stepping Stones Priority nodes outside of current PAs	Landscape linkages Key landscape linkages and knickpoints in the farming landscape	Broader Farming Mosaic The broader landscape mosaic	Institutional issues
Description	The current core national parks and protected forests.	Critical pieces of biodiversity outside of the PAs required for landscape connectivity, maintenance of biodiversity and delivery of ecosystem services.	The parts of landscape within identified key corridors, where functional connectivity and ability to deliver ecosystem services needs to be urgently maintained or improved.	Remaining farmland areas of the CND.	The non-geographic specific elements of the CND system
Key ideas	Protect and manage for climate resilience.	Restore and protect to ensure landscape connectivity and ecosystem service delivery.	Functional linked farming landscapes delivering ecosystem services.	Diverse climate change resilient farmland delivering ecosystem services.	Strong, well-capacitated and equitable environmental governance and land use planning.
Required Outcome	PAs effectively protect and manage natural forests improving resilience to climate change impacts and risks. Natural forests protected, connected, more resilient to climate change impacts and risks.	Critical landscape nodes / stepping- stones are secured and where necessary restored to a natural state.	Priority portions of the farming landscape are specifically managed to improve overall connectivity and ecosystem service delivery.	Sustainably managed farmland landscape is more biodiverse, supports delivery of ecosystem services and is resilient to climate risk.	Government and civil society are well capacitated to ensure robust landscape planning that supports climate resilience.
Core benefit	Maintain globally significant, species-rich natural forests. Core areas secure best possible source and/or refuge areas for species under climate change.	Biodiversity value of critical landscape nodes is maintained. Landscape connectivity supported through retention of key stepping- stones for species movement across the landscape.	Improved connectivity of the landscape ensures long term climate resilience. Value of core PAs and priority nodes is retained (i.e. the inevitable degradation of sites due to isolation is avoided).	Generally improved farmland management ensures rural sustainability and supports livelihoods.	Integrated land use plans, with community participation and spatial planning tools/ monitoring
Associated benefits	Improved delivery of ecosystem services (especially water) and support of rural economies and livelihoods.	Improved delivery of ecosystem services (especially water) and support of rural economies and livelihoods.	Improved delivery of ecosystem services (especially water) and support of rural economies and livelihoods.	Improved delivery of ecosystem services (especially water) and support of rural economies and livelihoods.	Cross sectoral planning and management.

6 Priority Areas for Implementation Activities

6.1 Natural Forest Restoration

Forest ecosystems play a vital role in capturing, storing and releasing water required for rainfed agriculture in the CND. The National Parks support most of the remaining montane rain forest in Rwanda, with the most extensive within the NNP. However, species composition and wildfire regimes have already been altered due to climate change, reducing the delivery of ecosystem services. Additionally, transformation and degradation of forest due to agriculture has resulted in recurring landslides, soil erosion and downstream flooding, which is exacerbated by the steep and mountainous landscape. Target restoration areas will be within the Parks, including within Park buffer zones and the highland corridor to the GMNP. The forest restoration programme will require fern clearing operations to facilitate natural forest regeneration. A community participatory approach will be adopted, with an emphasis on women, which will build on the World Bank's Landscape Approach to Forest Restoration and Conservation (LAFREC) project in the GMNP.

The aim is to implement a forest restoration programme that will include rehabilitating 6 000 ha of indigenous forest in the Nyungwe National Park (NNP), restoring 500 ha in the Gishwati-Mukura National Park (GMNP) and restoring isolated forest patches outside of the PAs to promote connectivity between the Parks. We have used rehabilitation to refer primarily to the removal invasive plant species to allow for natural forest growth to re-establish native forest. This is primarily in areas which have been burnt and subsequently invaded by ferns. The more active / intensive forest restoration process involves the active planting / establishment of native forest. In both cases, the actions explicitly mean rehabilitating or restoring to a natural state, rather than agroforestry or improved plantations.

6.1.1 Rehabilitation of Natural Forest within National Parks

The focus of the restoration programme in the National Parks (**Figure 40**) should consider:

- Degraded forest areas due to alien plant infestation or species loss are not shown or delineated within the National Parks. "Sparse forest" from the landcover data could potentially be used, however, this is probably not a valid assumption and is not recommended.
- The assumption is that 6 000 ha of rehabilitation through fern clearing is confirmed as reasonable from park management.
- The proposal should be flexible and not site specific to allow activities to be conducted in any of the core NPs, as well as the other small Protected Forests i.e. Dutake and Karehe-Gatuntu.

The three National Parks cover a combined area of 120 803 ha, with Nyungwe NP protecting the largest area of montane rain forest habitat. The Protected Forests, Dutake and Karehe-Gatuntu, represent an area of 30 ha (**Table 13**).

Table 13: Summary table of the extent (ha) of formal Protected Areas in the Congo Nile Divide. Degraded areas within the various National Parks and Protected Forests should be cleared of alien and/or invasive species to allow natural processes to restore native forest. The available datasets do not allow the mapping of precise areas in each PA. This requires a combination of high-resolution remote sensing and ground-truthing.

Protected Areas	Area (ha)
Core PA Nodes	**120 803,6**
Gishwati NP	1 456,2
Mukura NP	1 995,3
Nyungwe NP	101 347,8
Volcanoes NP	16 004,2
Stepping Stones	**30,0**
Dutake Protected Forest	10,8
Karehe-Gatuntu Protected Forest	19,2
Grand Total	**120 833,6**

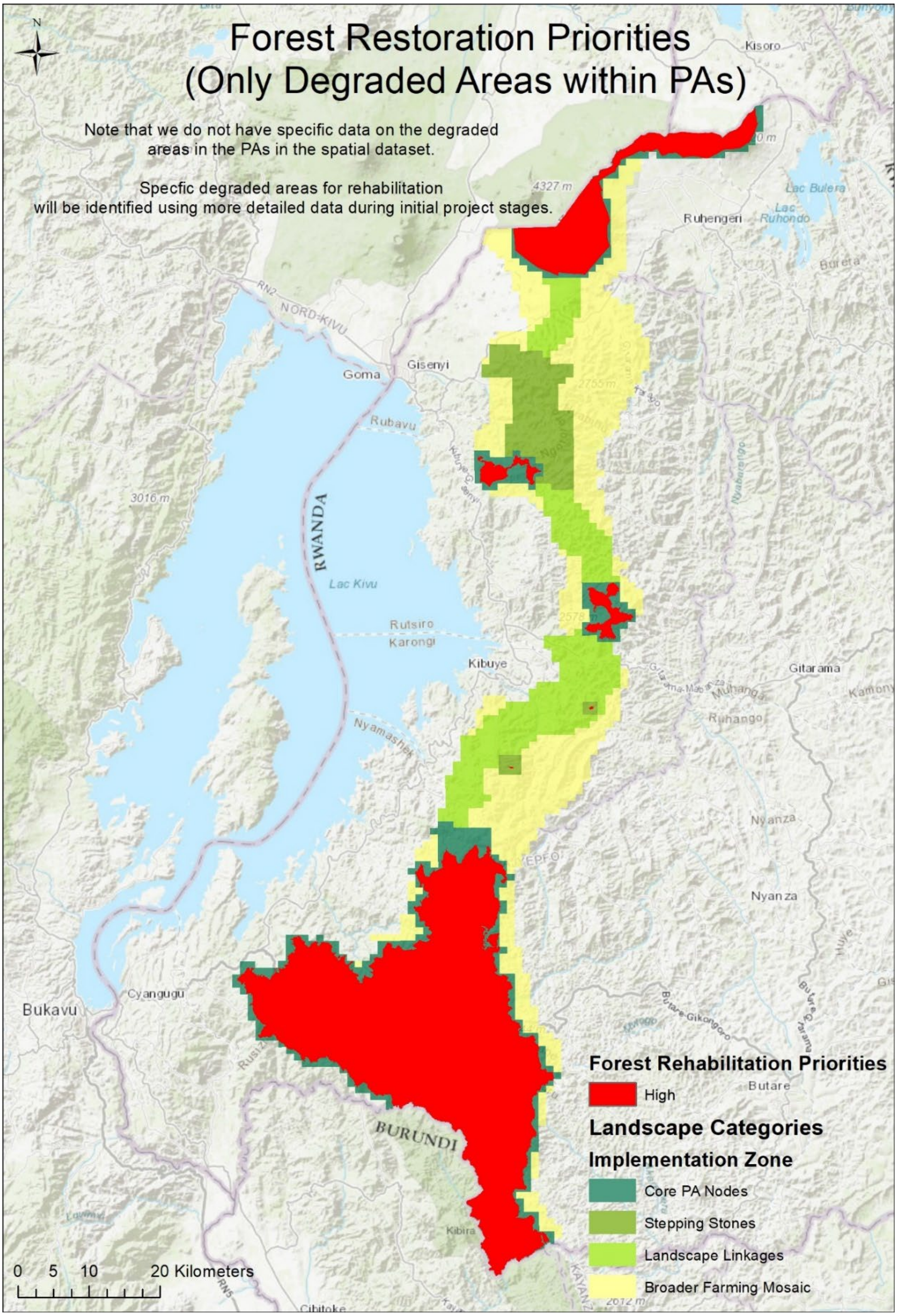

Figure 40: Map showing the extent of high priority areas for natural forest rehabilitation within National Parks and Stepping Stones in the Congo Nile Divide.

6.1.2 Restoration of Natural Forest within National Park Buffers and Stepping Stones

The focus of the restoration programme in the Park Buffers and Stepping Stones (**Figure 41**) should consider:

- The original project proposal aimed for 500 ha of forest restoration around Gishwati-Mukura National Park (GMNP). The spatial analysis confirms that most of the areas suitable for forest restoration are around GMNP (**Table 14**).
- An attempt has been made to prioritise the degraded, steep slopes in the park buffers and the Stepping Stones areas. The Gishwati Pastures Stepping Stone has been excluded as it is the focus of other interventions and does not have a core PA around which to focus the forest restoration.
- A total area of 2 492 ha is likely to be available for restoration. It is recommended to target as much of this as possible. This would help ensure the viability of the Protected Areas, important for the major core areas, such as Volcanoes NP[4] and Nyungwe NP; the critical smaller core areas of Gishwati and Mukura NP; and the very small pockets of Dutake and Karehe-Gatuntu Protected Forests.

Table 14: Priority areas for forest restoration. These areas focus on degraded and steep slopes in the buffers around the Core PA Nodes and in the Stepping Stones. The Gishwati Pastures Stepping Stone is excluded as it is targeted for other interventions.

Sector	Area (ha)
Core PA Nodes - Buffer Areas Only	**2 340,0**
Gishwati NP Buffer	795,7
Mukura NP Buffer	1 444,3
Nyungwe NP Buffer	85,9
Volcanoes NP “Buffer”	14,1
Stepping Stones	**152,9**
Dutake Stepping Stone	151,4
Karehe-Gatuntu Stepping Stone	1,4
Grand Total	**2 492,9**

[4] *Although Volcanoes NP does not have a legally designated buffer, the term “Buffer” refers to areas adjacent to the park which need to be managed.*

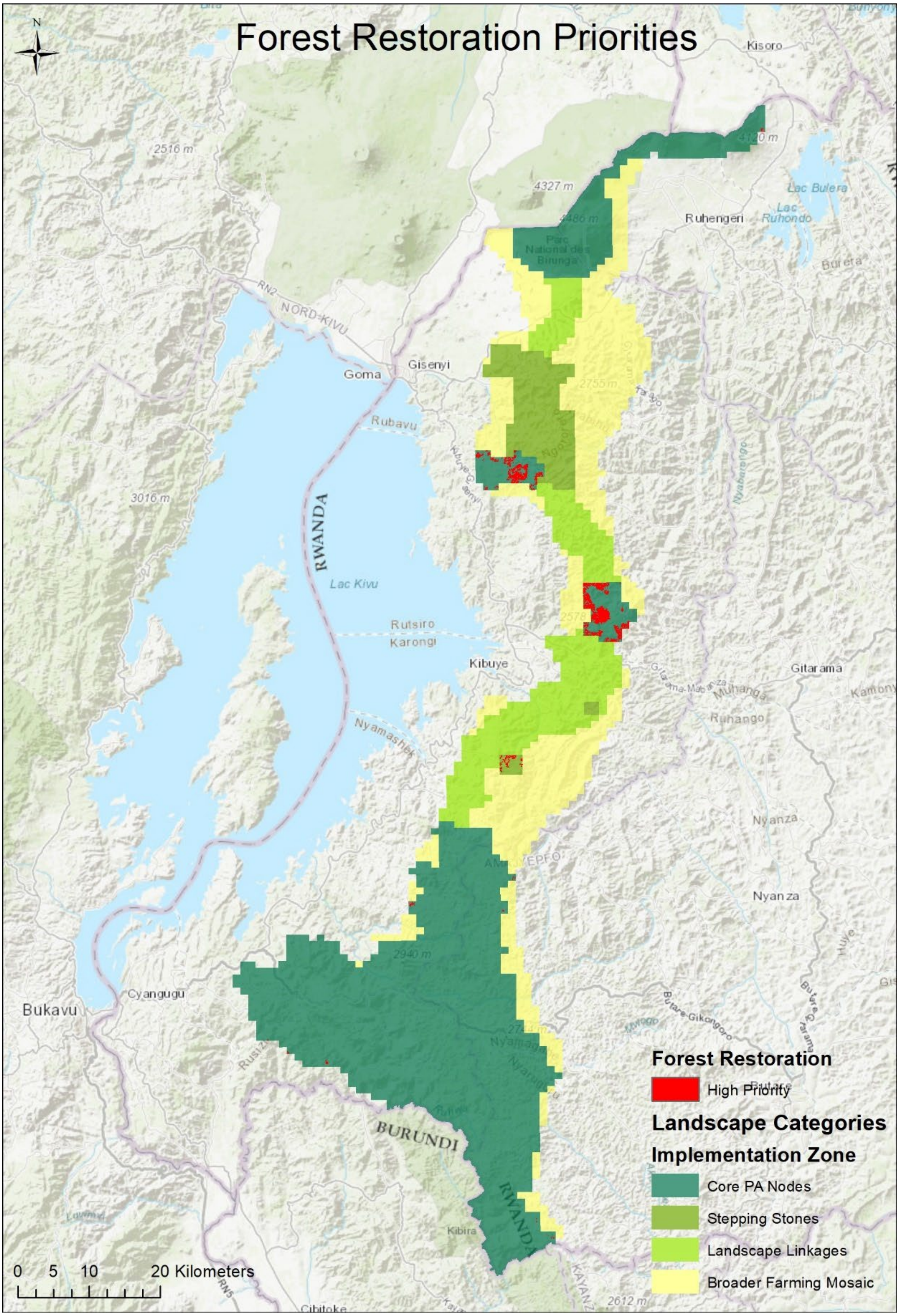

Figure 41: Map showing the extent of high priority areas for natural forest restoration within National Park buffers and Stepping Stones in the Congo Nile Divide.

6.2 Protective Forests and Riparian Land Interventions

The aim is to restore **13 000 ha** of protective forests on slopes > 55% by promoting indigenous tree planting on farms and along altitudinal and riparian linkages to reduce landslides, soil erosion and downstream flooding. In addition, to increase the supply of fuelwood for cooking and to reduce the time woman allocate to collecting wood. In Rwanda, most protective forests comprise exotic species, including Eucalyptus and Pine. Thus, the project intervention is to facilitate the planting of indigenous species, where feasible. This shall be weighed against community needs for faster growing exotics and the higher cost of indigenous trees. Restoration will be conducted on public land, private land (community cooperatives) and public private partnerships (forest plantations) where food production is not taking place and agreements are signed.

6.2.1 Restoration of Protective Forests on Steep Slopes (> 55%)

The focus of the protective forest restoration programme on steep slopes in the Park Buffers, Stepping Stones and Landscape Linkages (**Figure 42**) should consider:

- Steep land (over 55%) are the focus in priority sections of the landscape, namely Core PA Node Buffers, Stepping Stones and Landscape Linkages. A total of 17 637 ha is highlighted for potential protective afforestation (**Table 15**).
- The focus is on agricultural land, cultivated pasture and plantations which are likely to be the most suitable land use classes for protective forest restoration on steep slopes. There are likely to be additional areas outside of these land use classes.
- Further, should resources be available for additional slopes to be afforested to protect against erosion and landslides, this could include an additional 6 947 ha of eroded low angle slopes in the three landscape categories / priority sectors.
- In addition, a very large area, measuring more than 16 550 ha of steep land exists within these three land cover classes in the Broader farming Mosaic.

Landscape Linkages areas includes the bulk of the slopes targeted for restoration at 9 620 ha, whereas the Park Buffers and Stepping Stones amount to 4 896 ha and 3 119ha respectively (**Table 15)**.

Table 15: Steep land (over 55%) in priority sections of the three landscape categories and land use classes. The Core PA Node Buffers, Stepping Stones, and Landscape Linkages form the priorities for protective forests.

Sector	Agriculture (ha)	Cultivated Pasture (ha)	Plantations (ha)	Grand Total (ha)
Core PA Nodes - Buffer Areas Only	**1 151,7**	**101,9**	**3 643,1**	**4 896,8**
Gishwati NP Buffer	271,7	36,5	248,6	556,8
Mukura NP Buffer	449,0	42,9	229,7	721,6
Nyungwe NP Buffer	392,2	13,6	3 127,2	3 533,0
Volcanoes NP Buffer	38,8	9,0	37,6	85,4
Stepping Stones	**575,1**	**1 061,6**	**1 483,2**	**3 119,9**
Dutake Stepping Stone	138,2	5,9	134,3	278,4
Gishwati Pastures Stepping Stone	420,4	1 055,4	1 294,5	2 770,3
Karehe-Gatuntu Stepping Stone	16,5	0,3	54,3	71,2
Landscape Linkages	**3 901,2**	**370,6**	**5 348,9**	**9 620,8**
Gishwati NP to Volcanoes NP Linkage	256,4	32,9	112,7	402,0
Mukura NP to Gishwati NP Linkage	1 067,1	267,4	1 107,8	2 442,4
Nyungwe NP to Mukura NP Linkage	2 577,7	70,3	4 128,5	6 776,4
Grand Total	**5 628,0**	**1 534,2**	**10 475,2**	**17 637,4**

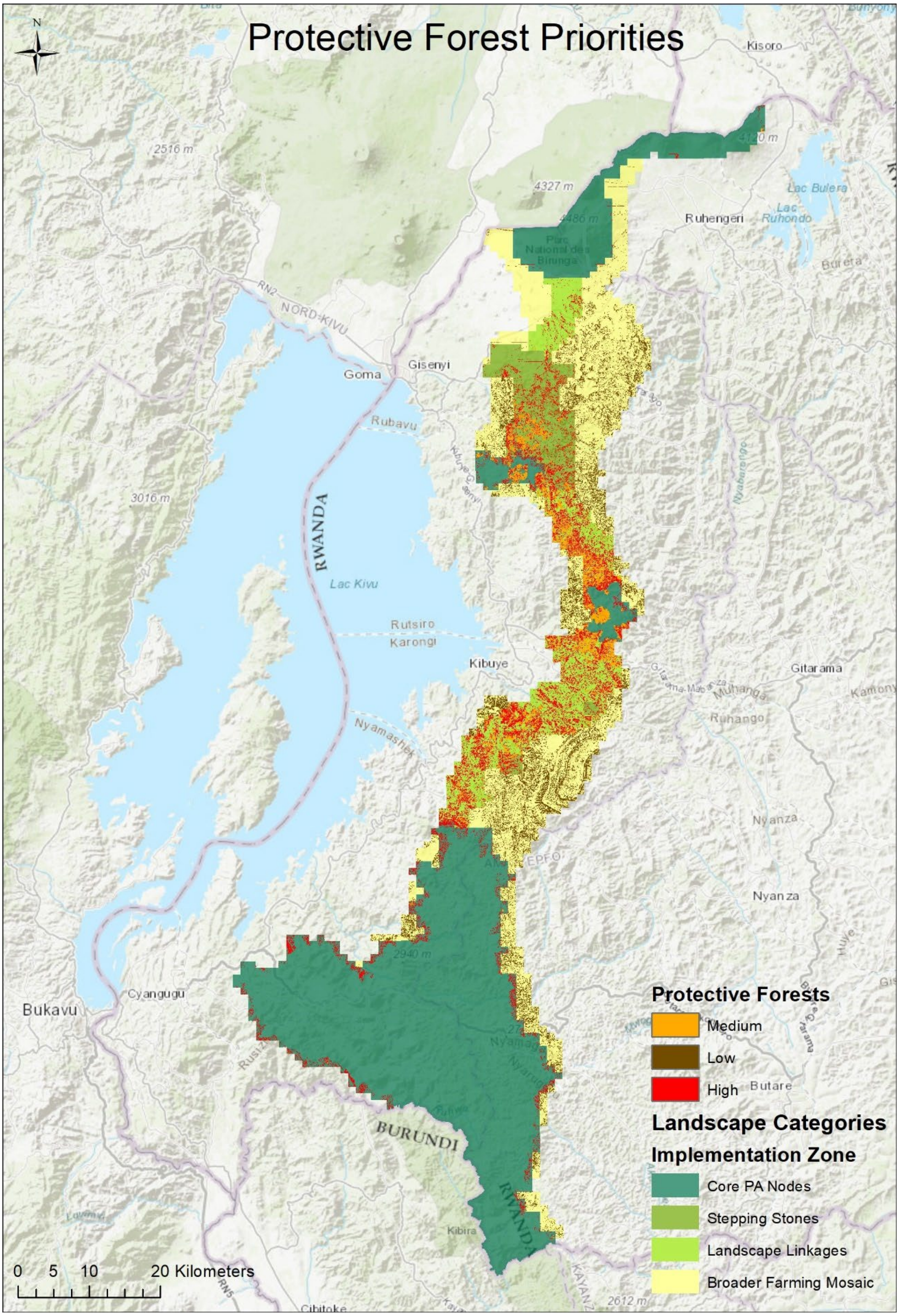

Figure 42: Map showing the extent of priority areas (High, Medium, Low) for protective forest restoration on steep slopes (>55%) in the Congo Nile Divide.

6.2.2 Restoration of Protective Forests on Riparian Land

The focus of the protective forest restoration programme along riparian lands in the Park Buffers, Stepping Stones and Landscape Linkages (**Figure 43**) should consider:

- Riparian areas are both valuable in their own right and provide a key opportunity to link landscapes at a medium scale.
- Two options are suggested:
    - The first (**Table 16**) highlights the highest priority areas in the Core PA Nodes, Stepping Stones and Landscape Linkages. There are approximately 1 566 ha within this category.
    - The second (**Table 17**) includes an additional 2 051 ha of riparian areas within the Broader Farming Mosaics, which would increase the potential footprint within which implementation could occur to 3 618 ha.
- Given the extremely high value of riparian areas for supporting ecosystem services, ideally, wetlands throughout the area would be improved. However, the 1 566 ha wetlands in the Core PA Nodes, Stepping Stones and Landscape Linkages are of much higher overall priority as they contribute significantly more to overall landscape connectivity.

Table 16: Riparian areas in Core PA Node Buffers, Stepping Stones and Landscape Linkages within impacted landscapes only (agriculture, grassland pastures, plantations etc).

Sector	River and Buffer (ha)	Wetland and Buffer (ha)	Grand Total (ha)
Core PA Nodes - Buffer Areas Only	**178,4**	**181,9**	**360,3**
Gishwati NP Buffer	21,9	23,4	45,4
Mukura NP Buffer	18,4	59,0	77,5
Nyungwe NP Buffer	120,0	99,4	219,5
Volcanoes NP Buffer	18,0	0	18,0
Stepping Stones	**133,6**	**135,5**	**269,1**
Dutake Stepping Stone	18,9	22,9	41,9
Gishwati Pastures Stepping Stone	113,8	81,6	195,4
Karehe-Gatuntu Stepping Stone	0,9	31,0	31,8
Landscape Linkages	**447,9**	**489,2**	**937,1**
Gishwati NP to Volcanoes NP Linkage	16,5	63,8	80,3
Mukura NP to Gishwati NP Linkage	117,3	41,1	158,4
Nyungwe NP to Mukura NP Linkage	314,2	384,3	698,5
Grand Total	**760,0**	**806,6**	**1 566,6**

Table 17: Riparian areas in Core PA Node Buffers, Stepping Stones, Landscape Linkages and Broader Farming Mosaics within impacted landscapes only (agriculture, grassland pastures, plantations etc).

Sector	River and Buffer (ha)	Wetland and Buffer (ha)	Grand Total (ha)
Core PA Nodes (Buffer areas only)	**178,4**	**181,9**	**360,3**
Gishwati NP Buffer	21,9	23,4	45,4
Mukura NP Buffer	18,4	59,0	77,5
Nyungwe NP Buffer	120,0	99,4	219,5
Volcanoes NP Buffer	18,0	0	18,0
Stepping Stones	**133,6**	**135,5**	**269,1**
Dutake Stepping Stone	18,9	22,9	41,9
Gishwati Pastures Stepping Stone	113,8	81,6	195,4
Karehe-Gatuntu Stepping Stone	0,9	31,0	31,8
Landscape Linkages	**447,9**	**489,2**	**937,1**
Gishwati NP to Volcanoes NP Linkage	16,5	63,8	80,3
Mukura NP to Gishwati NP Linkage	117,3	41,1	158,4
Nyungwe NP to Mukura NP Linkage	314,2	384,3	698,5
Broader Farming Mosaic	**1 038,3**	**1 013,4**	**2 051,7**
Gishwati Broader Farming Mosaic	377,7	650,3	1 028,0
Mukura Broader Farming Mosaic	54,2	50,4	104,6
Nyugwe to Mukura Broader Farming Mosaic	403,9	155,5	559,3
Nyungwe Broader Farming Mosaic	175,9	144,7	320,6
Volcanoes Broader Farming Mosaic	26,6	12,5	39,1
Grand Total	**1 798,3**	**1 820,0**	**3 618,2**

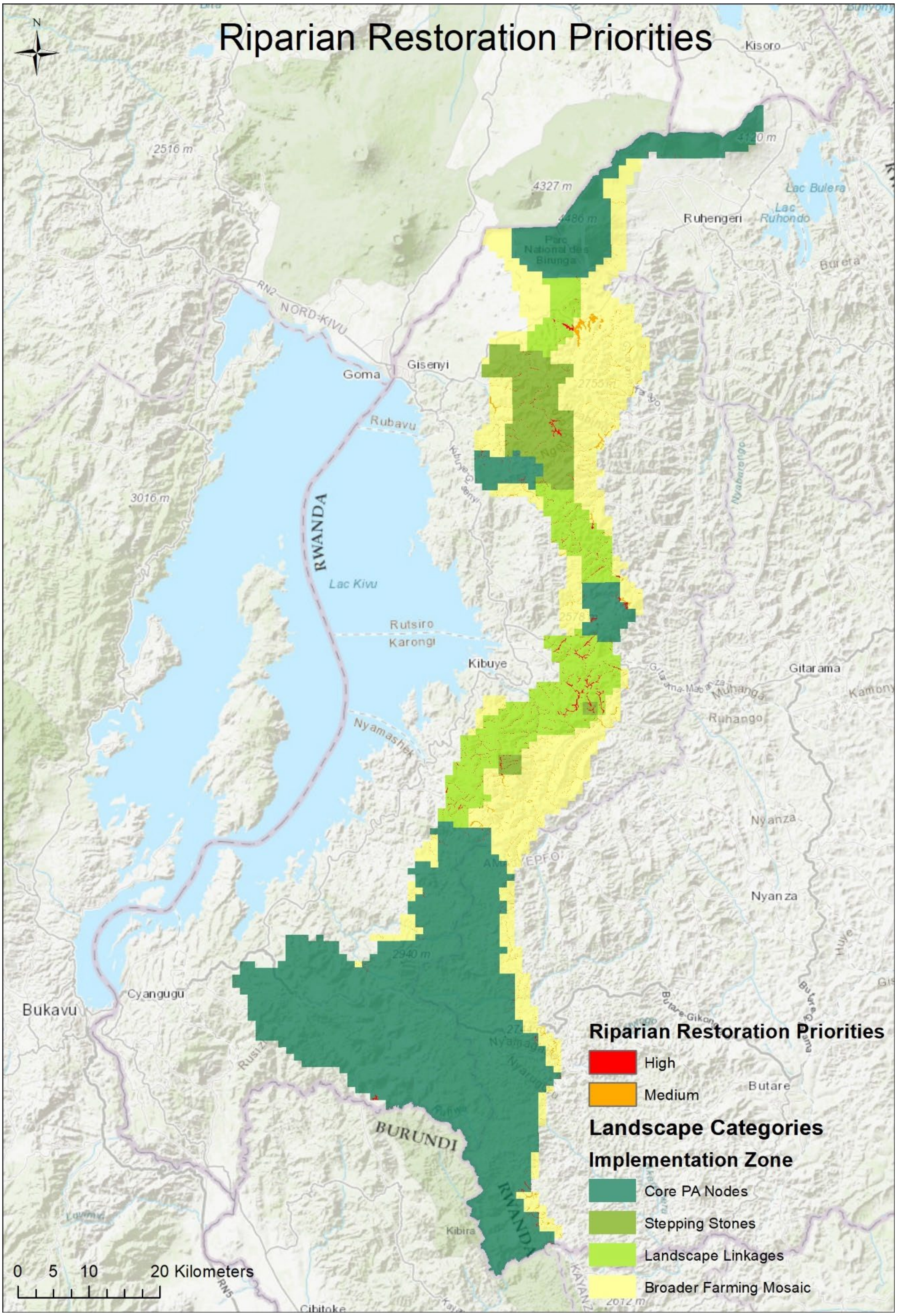

Figure 43:Map showing the extent of priority areas for protective forest restoration along riparian areas in the Congo Nile Divide.

6.3 Agroforestry Interventions

The aim is to establish biodiversity-friendly agroforestry practices in existing agricultural lands located within Park Buffers, Stepping Stones and Landscape Linkages. This will be achieved through several mechanisms and/ or project activities, including the promotion of silvo-pastoral systems to increase biodiversity on pasture lands in Gishwati areas, agroforestry interventions on 2 500 ha of farmland, and the introduction of shade indigenous trees in tea and coffee plantations,

6.3.1 Agroforestry in Key Highland Linkages

The focus of the agroforestry programme in key highland linkages in the Park Buffers, Stepping Stones and Landscape Linkages (**Figure 44**) should consider:

- Agroforestry interventions focus on existing agricultural land within the priority landscape sectors (i.e. in the buffers around the Core PA Nodes, the areas around the Protected Forests in the Stepping Stones and in the key Landscape Linkages) (**Error! Reference source not found.**). A total of 24 216 ha has been identified.
- The Gishwati Pastures Stepping Stone is dealt with separately as it is the focus of a different implementation activity, i.e. agroforestry on pastoral land (silvo-pastoral practices).
- The areas of agricultural land which would significantly benefit from agroforestry interventions substantially exceed potential project interventions. Therefore, the focus should be on:
    - Priorities around the Core PA Nodes and the Protected Forests in the Stepping Stones, and then in the Landscape Linkages.
    - Areas where landscape degradation has occurred (i.e. 2 198 ha of steep, eroded areas and 5 013 ha of eroded areas that are not steep, which together total 7 211 ha) or is a high risk (i.e. steep but not eroded, which include an addition 3 009 ha).

Table 18: Existing agricultural land in key highland linkages are the focus areas for agroforestry interventions.

Sector	Eroded and Steep (ha)	Eroded but Not Steep (ha)	Steep but Not Eroded (ha)	Not Eroded or Steep (ha)	Total (ha)
Core PA Nodes - Buffer Areas Only	**546,7**	**1 351,5**	**605,0**	**3 509,3**	**6 012,5**
Gishwati NP Buffer	176,5	518,0	95,2	469,4	1 259,1
Mukura NP Buffer	344,2	785,5	104,8	322,8	1 557,3
Nyungwe NP Buffer	25,9	43,7	366,3	1 082,2	1 518,1
Volcanoes NP Buffer	0,1	4,3	38,7	1 634,9	1 678,0
Stepping Stones	**38,8**	**79,3**	**115,9**	**440,8**	**674,7**
Dutake Stepping Stone	38,3	78,5	99,8	262,6	479,3
Karehe-Gatuntu Stepping Stone	0,5	0,7	16,0	178,2	195,5
Landscape Linkages	**1 612,5**	**3 582,2**	**2 288,6**	**10 045,6**	**17 529,0**
Gishwati NP to Volcanoes NP Linkage	0,1	4,9	256,2	2 036,0	2 297,2
Mukura NP to Gishwati NP Linkage	553,5	1 173,4	513,7	1 534,7	3 775,3
Nyungwe NP to Mukura NP Linkage	1 058,9	2 403,9	1 518,7	6 474,8	11 456,4
Grand Total	**2 198,1**	**5 013,0**	**3 009,5**	**13 995,7**	**24 216,2**

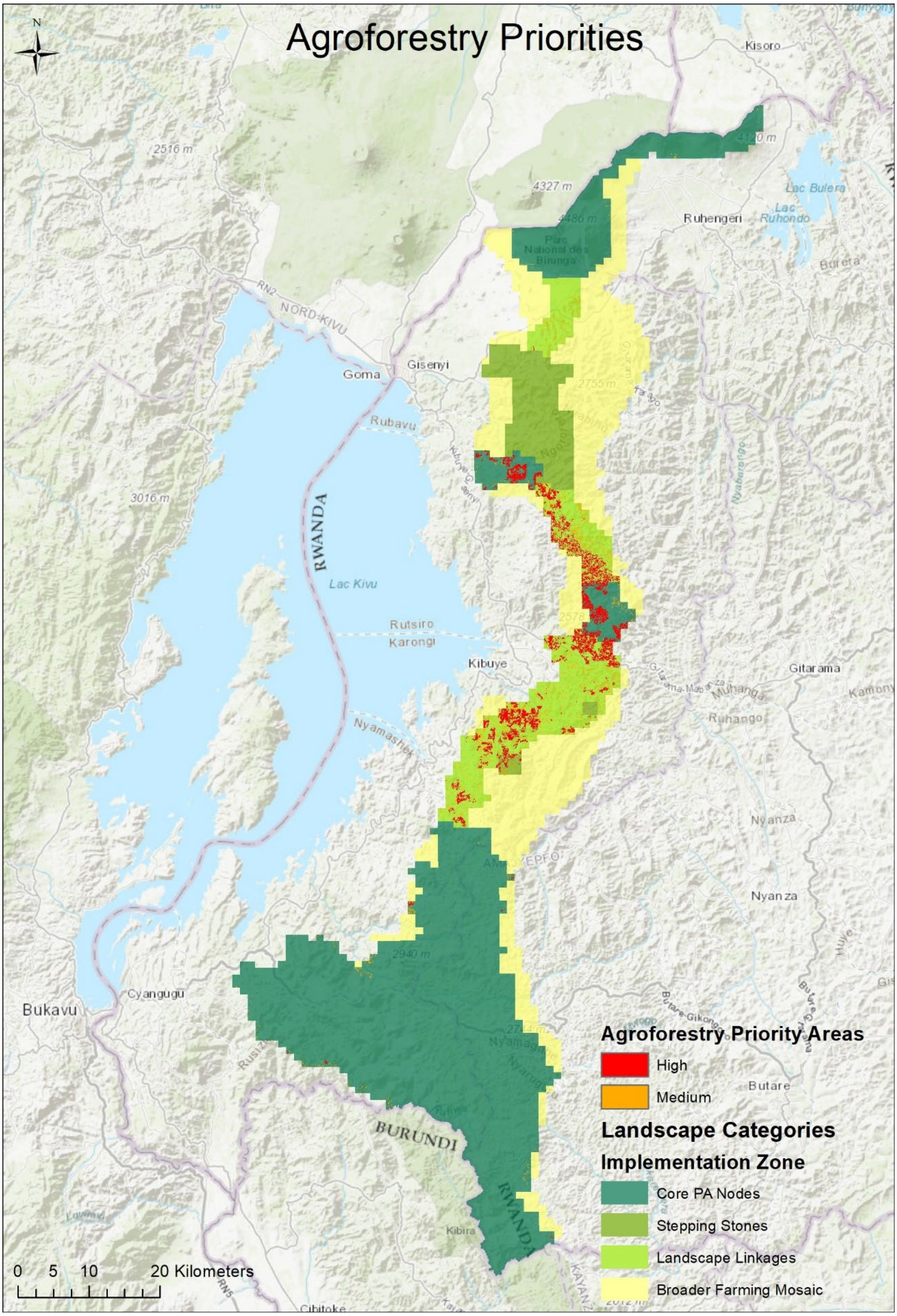

Figure 44: Map showing the extent of agroforestry priority areas (high and medium) in key highland linkages of the Congo Nile Divide.

6.3.2 Gishwati Pastures Stepping Stone – Agroforestry on Pastoral Land (Silvo-Pastoral Practices)

The Gishwati Pastures Stepping Stone is an identified key focus area for pasture focussed agroforestry interventions (**Figure 45**). Interventions should be prioritised in the following areas:

- The potential implementation area is classified as "Cultivated Pasture" for cattle farming, "Possibly Natural" and interspersed "Plantation" areas. These areas total 11 932 ha.
- There should be a particular focus on the 1 224 ha which known to be in an eroded or degraded state (**Table 19**).

Table 19: Areas identified for the Gishwati agroforestry on pastoral land intervention.

Sector	Possibly Natural (ha)	Cultivated Pasture (ha)	Plantations (ha)	Grand Total (ha)
Gishwati Pastures Stepping Stone	**2 475,4**	**6 228,7**	**3 228,5**	**11 932,6**
Eroded	173,7	1 007,0	44,0	1 224,7
Not Eroded	2 301,7	5 221,7	3 184,6	10 707,9
Grand Total	**2 475,4**	**6 228,7**	**3 228,5**	**11 932,6**

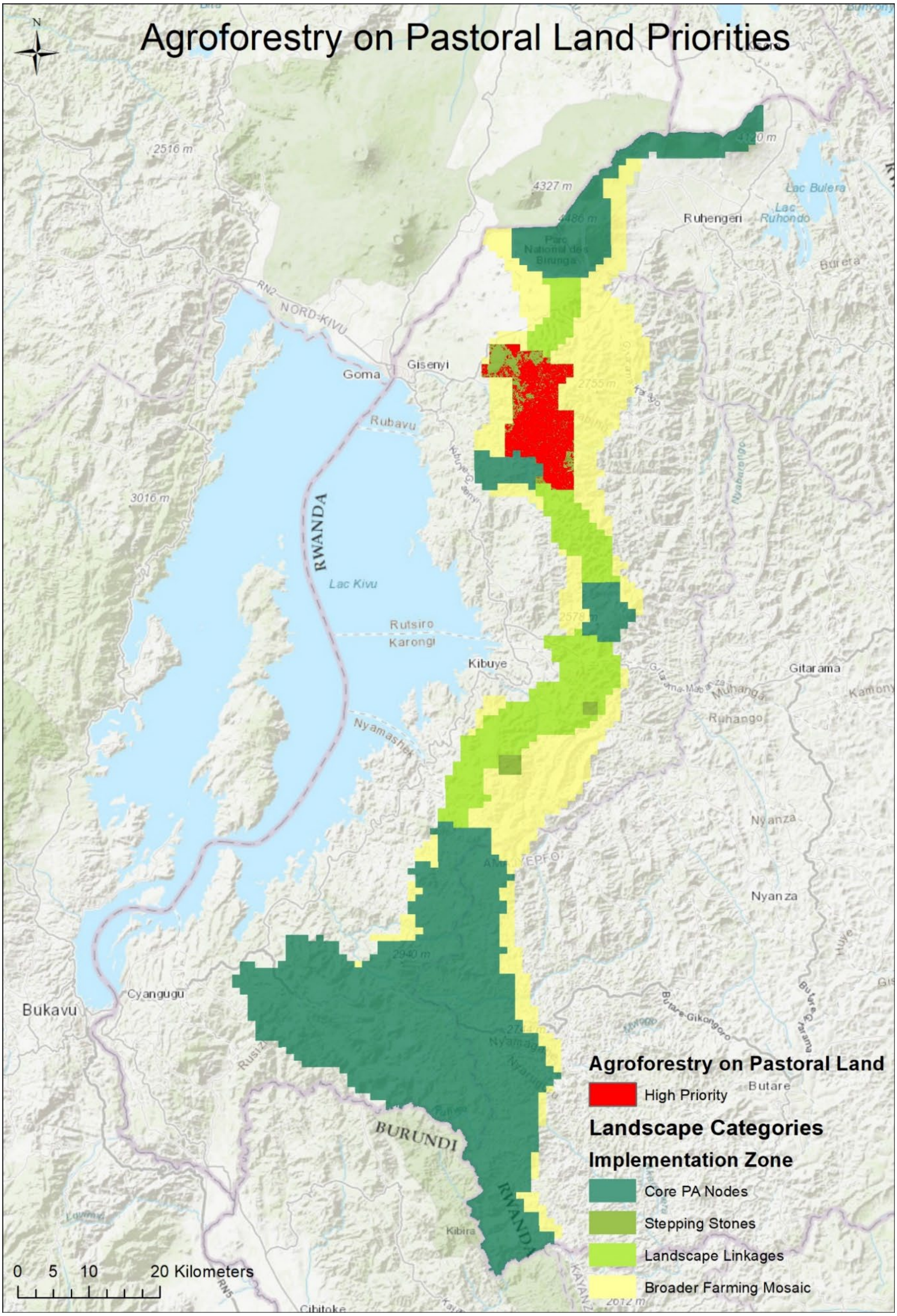

Figure 45: High priority agroforestry intervention areas on pastoral land in the Congo Nile Divide.

6.3.3 Indigenous Shade Trees for Coffee and Tea

The focus of agroforestry interventions in the coffee and tea plantations (**Figure 46**) should focus on:

- Tea and coffee plantations in the buffers of the Core PA Nodes (1 362 ha), in the buffers around the Protected Forests and elsewhere in the Stepping Stones (122 ha) and within the Landscape Linkages (883 ha) are a sensible focus for improving landscape biodiversity value through the introduction of indigenous shade trees (**Table 20**).
- The intervention could be extended to the Broader Farming Mosaic (5 818 ha) if project budgets allow.

This would bring the total intervention area to 8 186 ha.

Table 20: Areas of identified tea and coffee plantations for potential promotion of the use of indigenous shade tree species to improve overall biodiversity value.

Sector	Tea (ha)	Coffee (ha)	Grand Total (ha)
Core PA Nodes - Buffer Areas Only	**1 362,8**	**0**	**1 362,8**
Gishwati NP Buffer	33,4	0	33,4
Mukura NP Buffer	20,3	0	20,3
Nyungwe NP Buffer	1 309,1	0	1 309,1
Stepping Stones	**122,4**	**0**	**122,4**
Dutake Stepping Stone	105,1	0	105,1
Gishwati Pastures Stepping Stone	4,2	0	4,2
Karehe-Gatuntu Stepping Stone	13,1	0	13,1
Landscape Linkages	**881,6**	**1,7**	**883,3**
Gishwati NP to Volcanoes NP Linkage	51,6	0	51,6
Mukura NP to Gishwati NP Linkage	123,2	0	123,2
Nyungwe NP to Mukura NP Linkage	706,8	1,7	708,5
Broader Farming Mosaic	**5 818,2**	**0**	**5 818,2**
Gishwati Broader Farming Mosaic	2 066,8	0	2 066,8
Mukura Broader Farming Mosaic	53,4	0	53,4
Nyugwe to Mukura Broader Farming Mosaic	1 341,1	0	1 341,1
Nyungwe Broader Farming Mosaic	2 348,5	0	2 348,5
Volcanoes Broader Farming Mosaic	8,5	0	8,5
Grand Total	**8 185,0**	**1,7**	**8 186,6**

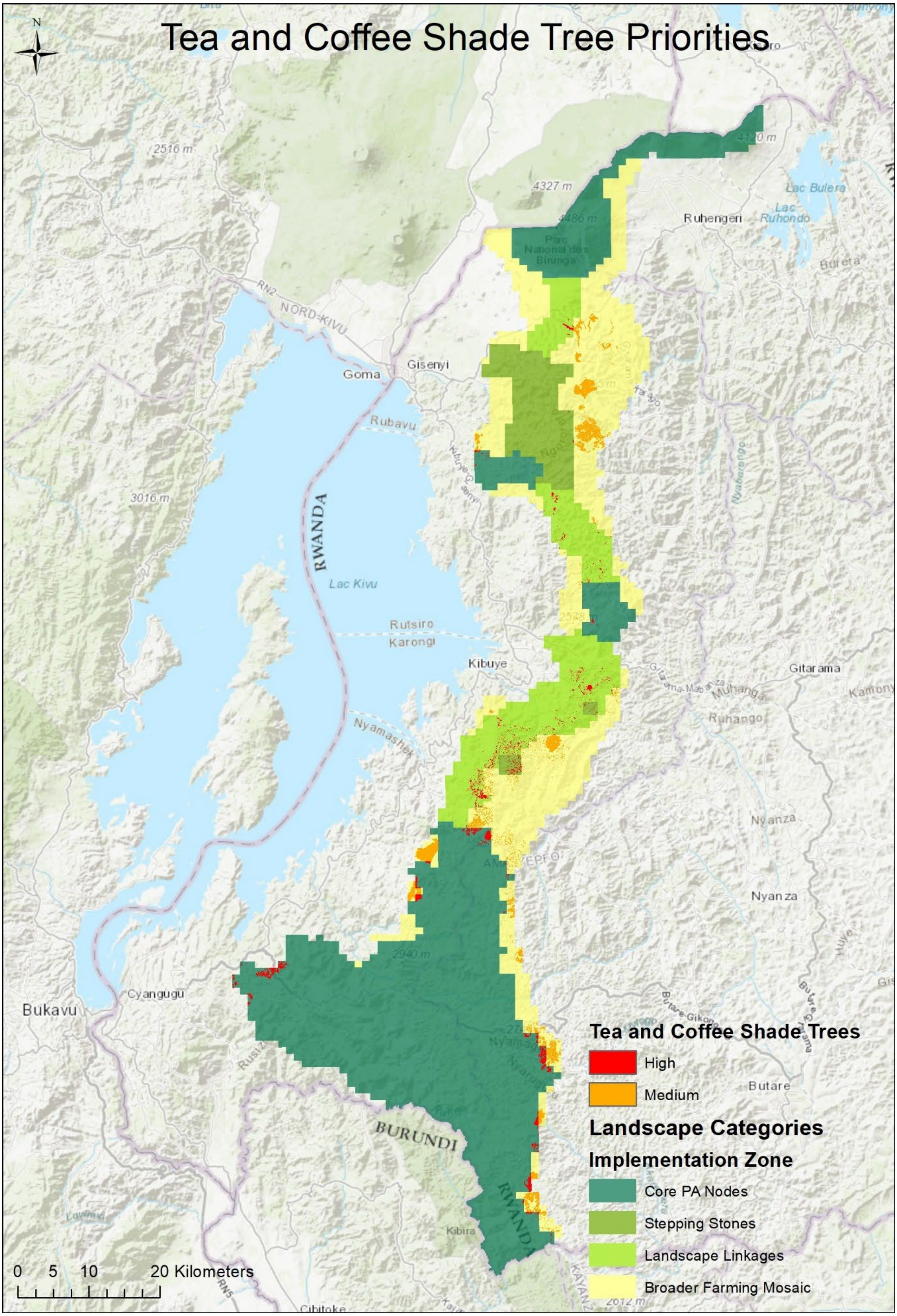

Figure 46: Map showing the extent of agroforestry priority areas (high and medium) for tea and coffee plantations in the Congo Nile Divide.

6.4 Beekeeping Interventions

The aim is to promote modern beekeeping among 4 000 farmers surrounding the Core PA Nodes to reduce the risk of fires that threaten forest habitat, especially due to illegal honey harvesting in forests.

A community participation approach will be adopted, with a focus on woman, youth and gender equality. Promoting fire management by park managers will also be an intervention through capacity building.

6.4.1 Beekeeping in Park Buffers and Stepping Stone Buffers

The focus of activities to support beekeeping in Park Buffers and Stepping Stone Buffers (**Figure 47**) should consider:

- Focusing on natural forest and possibly natural areas in the buffer areas around the Core PA Nodes, and the buffer areas around the Protected Forests in the Dutake and Karehe-Gatunu Stepping Stones. These areas total 5 555 ha, with the largest and highest priority areas being around Nyungwe NP (3 955 ha) (**Table 21**).
- Plantation areas in these buffers could also form part of the priority areas[5].
- Together these present a potential working footprint of 15 375 ha.
- Gishwati Pastures Stepping Stone was not included as it is the focus for a separate intervention.

Table 21: Beekeeping priority areas in the Buffers of the Core PA Nodes and Stepping Stones.

Sector	Known Natural (Ha)	Possibly Natural (Ha)	Plantations (ha)	Grand Total (ha)
Core PA Nodes - Buffer Areas Only	**3 730,2**	**1 729,4**	**9 521,2**	**14 980,8**
Gishwati NP Buffer	172,4	235,6	617,2	1 025,2
Mukura NP Buffer	308,1	77,2	387,7	772,9
Nyungwe NP Buffer	2 864,9	1 090,5	8 035,7	11 991,0
Volcanoes NP Buffer	384,9	326,2	480,6	1 191,7
Stepping Stones - Buffer Areas Only		**95,2**	**299,1**	**394,2**
Dutake Stepping Stone		47,9	198,4	246,2
Karehe-Gatuntu Stepping Stone		47,3	100,7	148,0
Grand Total	**3 730,2**	**1 824,6**	**9 820,2**	**15 375,1**

[5] *It is assumed plantation areas are also suitable, as fires would also have impacts on forest habitat.*

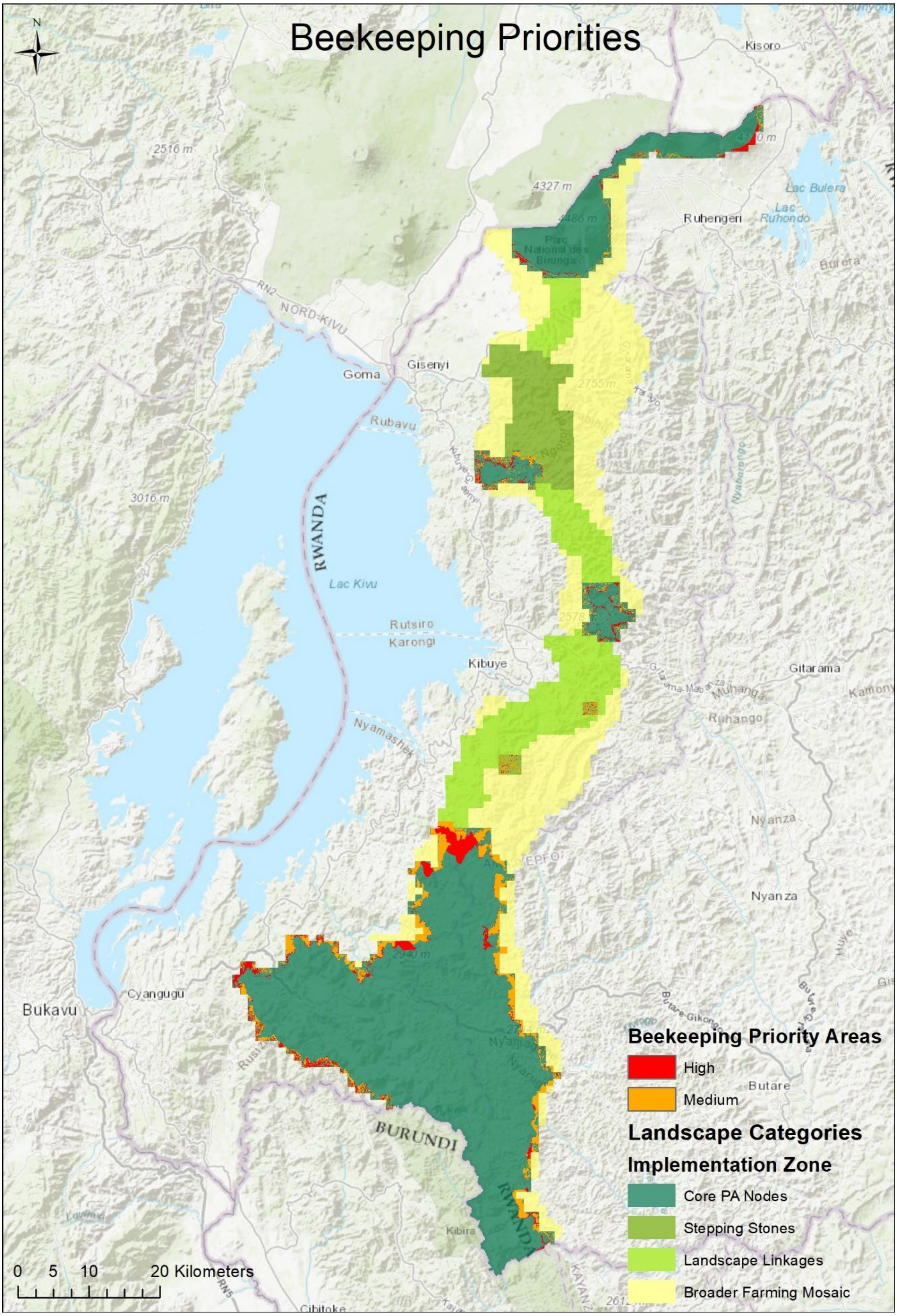

Figure 47: Map showing the extent of beekeeping priority areas (high and medium) for interventions in buffer areas around the National Parks and Protected Forests in the Congo Nile Divide.

6.5 Summary of Project Activities across the Congo Nile Divide Landscape

Table 22 below presents a geographical summary of the project activities that will be implemented in the Congo Nile Divide landscape. The project activities are either a primary, secondary or tertiary focus based on the relative importance of these activities in each area as set out in the previous sections.

Many project activities are not place-based and would occur across the entire CND domain. These include land use planning, developing a forest monitoring system, developing and operationalizing a new fire management curriculum, facilitating access to finance and private sector investments, and facilitating learning and knowledge sharing.

Table 22: Summary of project activities (place based and non-place based) to be implemented across the Congo Nile Divide.

	Core PA Nodes				Stepping Stones			Landscape Linkages			Broader Farming Mosaic					Across the CND
	Volcanoes NP and Buffer	Nyungwe NP and Buffer	Mukura NP and Buffer	Gishwati NP and Buffer	Gishwati Pastures Stepping Stone	Karehe-Gatuntu Stepping Stone	Dutake Stepping Stone	Nyungwe NP to Mukura NP Linkage	Gishwati NP to Volcanoes NP Linkage	Mukura NP to Gishwati NP Linkage	Nyungwe to Mukura Broader Farming Mosaic	Volcanoes Broader Farming Mosaic	Mukura Broader Farming Mosaic	Gishwati Broader Farming Mosaic	Nyungwe Broader Farming Mosaic	
1.1.1 Synthesize & disseminate information on value of natural forests & ecosystem services																Primary
1.1.2 Develop climate-resilient landscape land-use plan																Primary
1.2.1 Create interagency taskforce institutionalizing integrated landscape planning & policy																Primary
1.2.2 Build capacity for spatial planning in national agencies re climate change																Primary
1.2.3 Develop an effective forest monitoring system to underpin forest management decisions	Primary	Primary	Primary	Primary	Primary	Primary	Primary									
2.1.1 Facilitate revision of PA management plans to address climate risks	Primary	Primary	Primary	Primary												
2.1.2 Establish long-term plans for CND financial sustainability post-GCF	Primary	Primary	Primary	Primary												
2.1.3 New fire management curriculum developed and operationalized in PAs and adjacent landscapes	Primary	Primary	Primary	Primary												
2.2.1 Secure key remaining natural areas outside PAs	Primary	Primary	Primary	Primary	Primary	Primary	Primary	Secondary	Secondary	Secondary	Some activity	Some activity	Some activity	Some activity	Some activity	
2.2.2 Restore natural forest cover in & outside PAs including riparian linkages	Secondary	Primary	Primary	Primary	Secondary	Secondary	Secondary	Some activity	Some activity	Some activity						
2.2.3 Promote silvo-pastoralism with indigenous trees in Gishwati Pasture Stepping Stone areas					Primary											
3.1.1 Restore high slope areas (>55%) as protective forests	Secondary	Secondary	Secondary	Secondary	Primary	Primary	Primary	Primary	Primary	Primary						
3.1.2 Develop on-farm agroforestry for high caloric and indigenous tree species	Secondary	Secondary	Secondary	Secondary	Primary	Primary	Primary	Primary	Primary	Primary	Some activity	Some activity	Some activity	Some activity	Some activity	
3.2.1 Develop agroforestry related value chain for markets access	Secondary	Secondary	Secondary	Secondary	Primary	Primary	Primary	Primary	Primary	Primary	Some activity	Some activity	Some activity	Some activity	Some activity	
3.2.2 Facilitate & scale up capacity, value addition & marketing of select climate-resilient value chain products																Primary
3.2.3 Facilitate access to input & output markets for vulnerable farmers																Primary
3.2.4 Scale up marketing, production, sales, use of fuel-efficient cookstoves																Primary
3.3.1 Facilitate access to finance & private sector investments																Primary
3.3.2 Set up & support savings & loan groups, enhance asset-building																Primary
3.3.3 Build capacity of financial institutions to serve targeted value chains & communities																Primary
3.3.4 Facilitate learning & knowledge sharing																Primary
4.1 - Performance monitoring plan developed																Primary
4.2 - Project monitored and evaluated; lessons learnt integrated into adaptive management processes																Primary

Primary Focus
Secondary Focus
Some activity

7 Conclusions

The Congo Nile Divide (CND) region of Rwanda sustains the country's last remaining montane forests. The Afromontane Rain Forests are Endangered, and along with smaller areas of other montane and alpine ecosystem types, are habitat for a host of threatened and endemic species. Most of these forests are in the three National Parks, Volcanoes National Park, Gishwati-Mukura National Park and Nyungwe National Park, with a few isolated forest patches located beyond the park boundaries. The region is a complex topography, with steep, mountainous slopes, degraded landcover and an extensive rural agricultural economy. Combined with climate change impacts, these factors threaten forest integrity and its delivery of critical ecosystem services to the region's rural communities.

Consequently, this rapid systematic conservation plan for the Congo Nile Divide region was needed to identify priority areas for landscape interventions to ensure the long-term conservation of montane forests and ensure the ongoing delivery of ecosystem services which they provide to the people of the region. The analysis had a strong climate change focus, which included the identification of climate change refugia using a Global Environmental Stratification (GEnS) process, a Condatis landscape analysis to identify key areas to secure and restore for landscape connectivity and to identify key knickpoints, and a MARXAN systematic conservation planning process to integrate all these elements. The analysis produced a set of landscape categories to aid planning and implementation. These included four planning categories: Core Protected Area (PA) Nodes, Stepping Stones, Landscape Linkages and the Broader Farming Mosaic. Within each category, priority areas for intervention were spatially delineated.

The Core PA Nodes consist of the National Parks and associated buffers, which cover 52.6% of the CND landscape. The Stepping Stones represent 6.1% of the CND landscape, and includes key forest and wetland patches outside of the Parks. The Landscape Linkages are the critical joins and knickpoints connecting the CND landscape, which cover only 13.1% of the landscape but are central to its long-term persistence. The Core PA Nodes, Stepping Stones and Landscape Linkages represent the clear priorities for landscape interventions. The Broader Farming Mosaic comprises the remaining 28.1% of the CND, is dominated by agricultural activities, and represents a significantly lower priority for intervention.

Place-bound project implementation activities across the planning categories involve forest restoration in Core PA Nodes, Park Buffers and Stepping Stones, as well as beekeeping interventions in the buffers of the Parks and Stepping Stones. The Park Buffers, Stepping Stones and Landscape Linkages will be subject to protective forest restoration on steep slopes (> 55%) and along riparian areas, as well as agroforestry best practice interventions. Biodiversity-friendly agroforestry will be a priority intervention in the Landscape Linkages and the pasture areas of the Gishwati Stepping Stone.

These place bound activities are supported by a range of non-place bound interventions, which will be implemented across the four planning categories. These interventions include, for example, land use planning, building capacity and governance in forest management, opening market opportunities and financial investments for climate resilience value chain products and facilitating knowledge sharing.

Rwanda's Congo Nile Divide rapid systematic conservation plan provides a critical landscape corridor linking the National Parks, stretching from the north to the south of the region. The overall aim of place-bound project interventions is to aid in the prevention of landslides, erosion, flooding and fire hazards through forest conservation, restoration and biodiversity-friendly agricultural practises, which will ultimately bolster the long-term sustainability of rural livelihoods. In so doing, climate change resilience of vulnerable rural communities will be promoted and montane rain forests conserved and restored.

Limitations of the current Study:

Importantly, this study is a rapid assessment to support project proposal development and does not replace a full conservation planning process. There are significant additional steps which are required to develop a product that is useful for land use planning. These changes include:

- A robust stakeholder engagement process, at a national, district and local scale.
- Incorporation of issues relating to land use rights, both of landowners and farm tenants.
- Incorporation of issues relating to social safeguards, especially for marginalized groups.
- Inclusion of issues related to planning processes and strategies, at a national and local scale.
- Finer scale planning (ideally at a 1:50 000 scale).
- Improved biodiversity data, including revised data on forest degradation, validation of the ecological condition map, and specific species data where possible.

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