November 2024

Strategic Environmental Assessment for the Cuando River Basin

VOLUME 4

Systematic Conservation Plan

Suggested reference:

Southern African Institute for Environmental Assessment for WWF-Namibia on behalf of ZAMCOM, 2024, Rapid Systematic Conservation Plan for the Cuando River Basin – prepared as part of the Strategic Environmental Assessment for the Cuando River Basin

Authors, data gathering, analysis and writing:

Dr Stephen Holness, Southern Connections NPC and Nelson Mandela University

Data sources:

WWF US – Freshwater modelling and species data.

The Nature Conservancy – Terrestrial species modelling.

Foreword

The Cuando River Basin, shared by Angola, Botswana, Namibia, and Zambia, is a vital sub-basin of the greater Zambezi Watercourse, supporting diverse ecosystems, livelihoods, and economic activities across the region. As riparian states strive to harness the basin's potential for sustainable development, it is imperative to balance socio-economic progress with environmental stewardship.

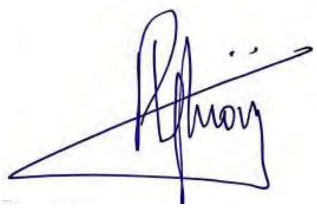
The Strategic Environmental Assessment (SEA) of the Cuando River Basin reinforces our shared vision of fostering resilient ecosystems, securing water resources for present and future generations, and promoting transboundary collaboration. From a strategic point of view, the SEA's alignment to the Strategic Plan of the Zambezi Watercourse (ZSP 2018 – 2040) is critical in ensuring sustainable environment and water resources management. It serves as a crucial tool in ensuring that environmental, social, and economic considerations are integrated into decision-making processes.

The Zambezi Watercourse Commission (ZAMCOM) remains committed to fostering cooperation among riparian states in promoting the sustainable and equitable utilization of shared water resources. This SEA aligns with our collective vision of strengthening resilience, enhancing livelihoods, and safeguarding biodiversity in the region. It provides a science-based assessment of potential impacts, mitigating measures, and opportunities for sustainable development. Importantly, it also provides recommendations for implementation.

I commend the governments of the Republic of Angola, Republic of Botswana, Republic of Namibia, and the Republic of Zambia for their commitment to this important initiative. I also extend my gratitude to our partners, the Kavango-Zambezi Trans-frontier Conservation Area (KAZA TFCA) Secretariat for their technical support and the World Wildlife Fund (WWF), whose financial and technical support has been invaluable in making this initiative a reality.

Through enhanced collaboration, data-driven decision-making, and strategic investments, we can ensure that the Cuando River Basin remains a source of prosperity and environmental integrity for present and future generations.

On behalf of ZAMCOM, I encourage all stakeholders to actively engage with the insights provided in this assessment and to work together toward a sustainable and resilient future for the Cuando River Basin.



Felix M. Ngamlagosi

ZAMCOM EXECUTIVE SECRETARY

Executive Summary

This rapid Systematic Conservation Plan (SCP) for the Cuando River Basin is part of the Strategic Environmental Assessment undertaken for the basin by the Southern African Institute for Environmental Assessment for WWF-Namibia on behalf of ZAMCOM. The purpose of the Systematic Conservation Plan (SCP) is to guide zonation of key and important biodiversity areas and ecological corridors in the basin. The goal is to ensure that the Valued Ecosystem Components (VECs) identified as a core step of the SEA (SAIEA, 2024) are integrated into a single spatial product which highlights where these VECs and the landscapes and ecological processes supporting them are located with the Cuando River Basin to ensure that they are adequately represented in protected areas, and highlight complementary areas (outside of existing protected areas) that require better protection and management.

The planning area covers the Cuando River Basin of around 12,25 million ha which stretches across four countries. The upper reaches include large portions of the Angolan Highlands Water Tower and the proposed Lisima Water Tower (Lisima Lya Mwono) Ramsar site; the mid reaches are primarily in Angola, with some smaller areas in Zambia, as the river enters the Kavango Zambezi (KAZA) Transfrontier Conservation Area (TFCA); and finally the lower reaches are in Namibia and Botswana where the Cuando discharges into the Linyati Swamps and the Savuti Marsh, and portions of the Okavango Delta System Ramsar site. The SCP included an additional 15km buffer area around the catchment that extends the core domain to just over 16 million hectares, while data were collected over a somewhat broader area to allow for connectivity analyses.

The SCP was designed to integrate the Valued Ecosystem Components (VECs) identified as a core step of SEA:

- **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** This supply is fundamental to the structure, functioning and value of the entire river basin.
- **VEC 2 – The immense area of swamp or reedbeds**. The Cuando includes some of the largest expanses of reeds, papyrus and sedges in Africa. The reedbeds are hydrologically important, support important biodiversity, and may include significant carbon storage in peat beds.
- **VEC 3 – Linyanti Swamps and Savuti area.** The Cuando feeds water, dissolved minerals and suspended solids into the Linyanti Swamps, the Savuti River and Savuti Marsh where the water disappears, and the minerals and sediments remain trapped to feed concentrations of plants and wildlife; which in turn support the livelihoods of local residents and a tourism industry that contributes much to the economy of northern Botswana and Namibia's Zambezi region.
- **VEC 4 – Western flanks of the Cuando.** The areas west of the Cuando River once supported an abundance of wildlife as a result of supplies of surface water in the Cuando and its ephemeral tributaries and the area's diverse habitats and relatively fertile soils. Wildlife numbers are likely to recover if the area is managed for conservation.
- **VEC 5 – Wildlife corridors and ecological connectivity.** Landscape connectivity - particularly for plains game, elephants, buffalo, and predators – is crucial for the health of wildlife populations by facilitating genetic exchange and expansion. Maintaining these corridors is vital for the entire KAZA landscape.
- **VEC 6 - Cuando aquifers**. Groundwater is a poorly known resource in the Cuando Basin, but is still an important resource for rural people who live some distance from available surface water.

This rapid Systematic Conservation Plan integrates available spatial biodiversity and socio-economic data to identify a robust set of spatial priorities for the Cuando River Basin (CURB), which integrate and support the VECS as well as other important biodiversity and socio-economic features of the basin. Whilst the VECs are ecological, most have profound implications for ecosystem services, the livelihoods of the people dependent on them, and the broader economy. They all contribute to maintaining the functioning and integrity of the Cuando Basin and supporting the small but very important tourism industry.

A key purpose of the SCP was to integrate the available/emerging broader scale planning e.g. TNC has undertaken terrestrial focussed planning on the Cubango Okavango (TNC, 2024) and WWF-US is completing a freshwater/hydrology focussed SCP in South East Angola (WWF, 2023); and the finer scale planning undertaken for areas overlapping various parts of the Cuando Basin (e.g. the WWF Zambezi and Kavango East rapid SCP (WWF Namibia, 2022) and the NatGeo / Wild Bird Trust focussed planning for the Okavango Zambezi Water Tower (Wild Bird Trust, 2022; Wild Bird Trust National Geographic Okavango Wilderness Project, 2024). Available SEA project data, suitable additional global data, and useful raw data and priority area outputs from this range of planning projects with various purposes and outcomes need to be aligned in a single coherent spatial product for the Cuando River Basin which supports the VECs identified in the SEA. The current Systematic Conservation Plan attempts to bridge these scales and integrate this range of plans, and add in elements of landscape function and connectivity.

<u>The programme of work for the Systematic Conservation Plan covered the following:</u>

- Integration of available spatial data (socio-economic and biodiversity, including key landcover change datasets) relevant for the Valued Ecosystem Components (VECs), into MARXAN conservation planning software.
- Integration of data and results from recent broader scale WWF analyses on aquatic features and TNC analyses of terrestrial features.
- Integrate priority area outputs from the finer scale planning undertaken for areas overlapping various parts of the Cuando Basin (especially the WWF Zambezi and Kavango East rapid SCP and the NatGeo / Wild Bird Trust focussed planning for the Okavango Zambezi Water Tower.
- Review of potential additional datasets for inclusion into the analysis.
- A connectivity analysis for the area.
- Systematic Conservation Planning analysis using MARXAN.
- Identification of key areas supporting the VECs inside and outside of existing protected areas, which should be appropriately protected, managed and monitored.

MARXAN analysis

<u>The SCP analyses comprised key biodiversity features (set out in Table 1), including:</u>

- Ecosystems (vegetation types) – terrestrial and aquatic.
- Wilderness areas – core and broader areas.
- Ramsar Sites – Proposed Lisima Water Tower (Lisima Lya Mwono) and Okavango Delta System Ramsar Site
- Priority areas from other fine scale analyses (e.g. WWF Zambezi and Kavango East areas of Namibia, Nat Geo/Wild Bird Trust Okavango Zambezi Water Tower).

- Aquatic and hydrological features:
  - Wetland and peat accumulations – from a range of global and regional products.
  - Key catchment areas – especially the Angola Highlands Water Tower
  - Source lakes for the Cuando (and their surrounding landscape)
  - River systems and associated hydrological processes (discharge and floodplains)
  - Groundwater priority areas.
- Connectivity and process areas:
  - Priority areas for wildlife west of the Cuando mainstem
  - KAZA wildlife dispersal areas.
  - Landscape linkages from a new Condatis landscape connectivity analysis.
- Species distribution and priority data:
  - WWF Integrated ecosystem value data for grouped taxa of aquatic birds, aquatic mammals and fish.
  - WWF Integrated ecosystem value data for 11 aquatic bird species.
  - WWF Integrated ecosystem value data for 8 aquatic mammals.
  - WWF Integrated ecosystem value data for 14 fish species.
  - TNC models for 24 individual mammal species.
  - TNC models for 21 individual bird species.
- Protected areas and conservation areas.
- Areas which are in the best ecological condition based on landcover.

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. In total, 8 socio-economic cost features were used. These are set out in the Cost Surface Section on page 75. Socio-economic or cost related features that were included in the analysis were:

- Proximity to larger roads
- Accessibility to any route
- Average distance to roads (i.e. not just to the larger roads)
- Croplands (including mapped cleared and fallow areas)
- Settlements
- Areas with the lowest wilderness characteristics
- Access to urban centres
- Density of buildings

We deliberately used a multivariate approach to socio-economic cost features / human impacts in order to get an overall/aggregated picture of human footprint, and would not be excessively impacted by errors in one layer. Note that these layers do co-vary, but that this is accommodated for in the analysis weighting.

Table 1: Summary of biodiversity data included in the SCP analysis.

Ecosystems	Aquatic features	Species	Connectivity and process	Other
• Wet Miombo • Dry Miombo • Baikiaea Woodland & Savanna • Gabono-Congolian Mesic Woodland & Grassland • Dry Acacia - Terminalia - Combretum Woodland & Savanna • Zambezi Mopane • Etosha Salt Pan • Kalahari Salt Pan • African Tropical Freshwater Marsh (Dembos) • Zambesian Cryptosepalum Dry Forest • Okavango-Cuvelai Phreatophyte Vegetation • Open Water	• Wetlands and peat accumulations • Key catchment areas - the Angola Highlands Water Tower • Source lakes for the Cuando (and their surrounding landscape) • River systems and associated hydrological processes (discharge and floodplains) • Goundwater priorities	• WWF Integrated ecosystem value data for grouped taxa of aquatic birds, aquatic mammals and fish. • WWF Integrated ecosystem value data for 11 aquatic bird species. • WWF Integrated ecosystem value data for 8 aquatic mammals. • WWF Integrated ecosystem value data for 14 fish species. • TNC models for 24 individual mammal species. • TNC models for 21 individual bird species.	• Wildlife Concentrations and Dispersal Areas • Condatis analysis of landscape linkages and knickpoints • Core Wilderness Areas • Broader Wilderness Areas	• Ramsar Sites - Lisima Water Tower (Lisima Lya Mwono) and Okavango Delta System Ramsar Site • Priority areas from other fine scale analyses (WWF Zambezi and Kavango East areas of Namibia, Nat Geo/Wild Bird Trust Okavango Zambezi Water Tower) • Protected Areas • Other Conservation Areas: Community Forests, Communal Conservancies and Game Management Areas

MARXAN results

The MARXAN analysis was used to produce **seven main conservation prioritizations** for the Cuando Basin. The prioritizations were differentiated by varying targets for biodiversity features and the cost surface values (which impact the level of avoidance of socio-economic activity and impacts). The seven main prioritizations were as follows:

- **<u>Base Case (Run 17c):</u>** Targets of 30-50% were used for most biodiversity features, with higher targets for high conservation value special features (e.g. wetlands, peat wetlands), process areas (e.g. key landscape linkages, floodplains) with lower targets for ecosystem types, species, and areas with wilderness characteristics.
- **<u>Base with reduced sustainable management focus (Run 30c):</u>** This was as for the base case, but with reduced targets for existing conservation management areas (e.g. the game management area) to avoid forcing selection into some "sustainable management" areas which actually have relatively high levels of human impact.
- **<u>Areas outside existing Protected Areas (Run 31):</u>** Targets and cost surfaces were as per the base case, but formal Protected Areas were hardwired into the results. This run allowed us to identify features of high importance that were largely outside of the PA network. It however deprioritizes the portions of features that are outside of PAs, where large areas are already inside PAs, even if these features are important.

- **Species focused scenario (Run 28C):** Higher conservation targets for identified priorities for species.
- **Hydrologically Focused Scenario (Run 25C):** Higher targets for hydrological linked features – wetlands, rivers, discharge, important catchment areas etc.
- **Natural Landscape Focused Scenario (Run 49):** Targets as for the base case, but significantly higher cost values, and consequently with much stronger avoidance of human impacted landscapes.
- **Wilderness and connectivity (Run 27b):** Higher targets for wilderness and connectivity linked features, with strong avoidance of human impacted landscapes Existing Protected Areas were also strongly favoured.

The various conservation planning runs showed strong overall patterns / similarities. Key differences included the level of focus on wetlands and wilderness areas. However, given that the overall scenarios had strong similarities in selection areas, we have developed an integrated layer based on the mean selection frequency for individual planning units across the seven scenarios. The **Integrated Marxan Results Layer** was recommended for the final conservation prioritization plan for the region (Figure 1).

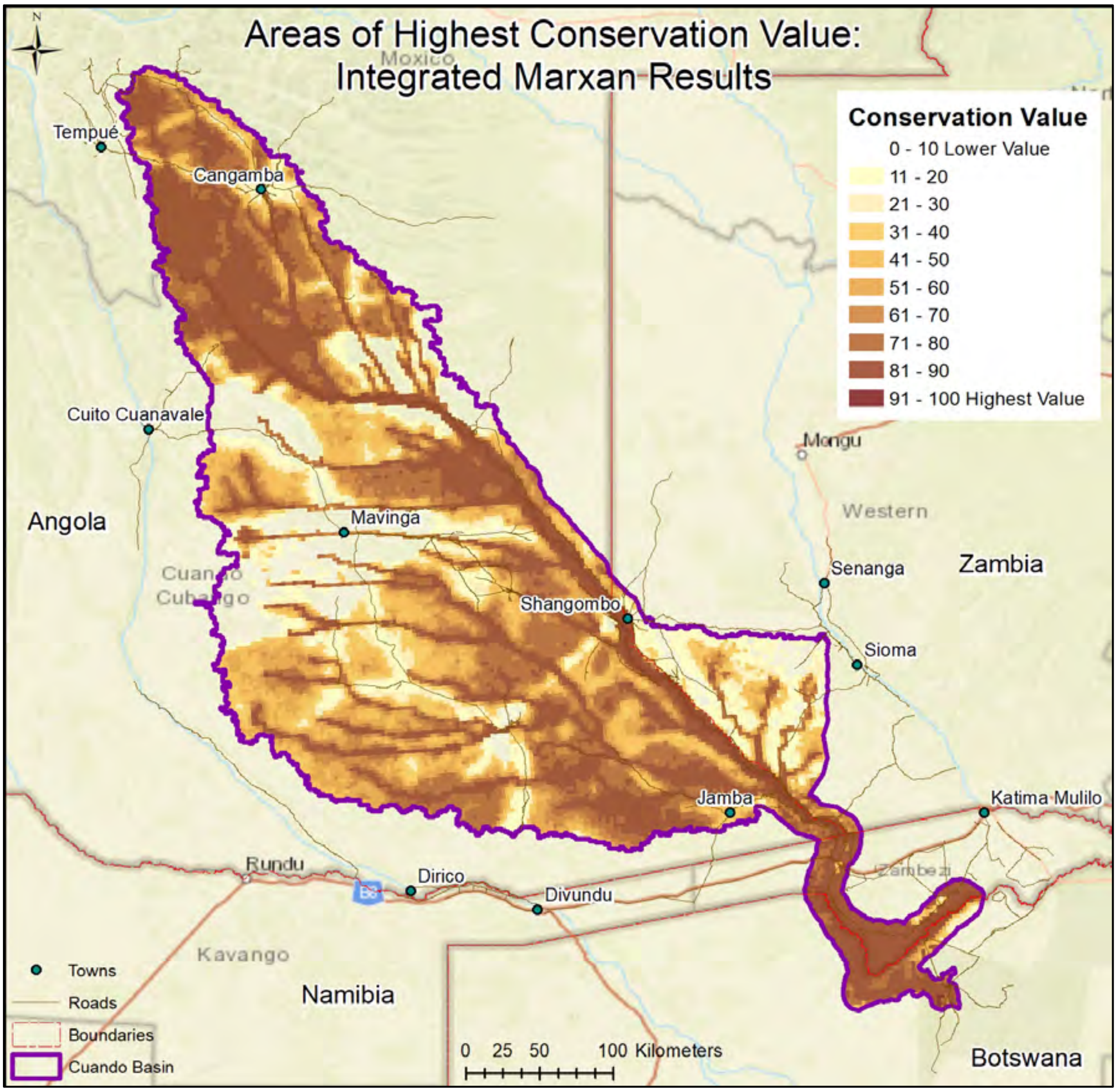


Figure 1: Areas of Highest Conservation Value were identified based on the mean selection frequency across the seven favoured Marxan scenarios. This integrated prioritization was used as the basis for identifying landscape categories for inclusion into the SEA, and guide catchment sustainability and conservation actions.

Areas of Highest Sustainable Management and Conservation Value

The rapid Systematic Conservation Plan (SCP) for the Cuando River Basin was used to identify areas of highest value for sustainable management and conservation actions aligned with the VECs identified in the SEA (SAIEA, 2024). The landscape was categorised into four categories (Figure 2 and Table 2):

- **Critical Areas** – These areas are irreplaceable or practically irreplaceable (i.e. required to meet targets under almost all circumstances and scenarios). These sites had mean Marxan irreplaceability values (or selection frequencies) across the seven scenarios of 90%-100%, which means that they are almost always required to meet targets. These areas are most strongly linked to the VECs.
- **High Value Areas** – These areas have mean selection frequencies of between 70% and <90%. Although it may still be possible to meet targets if some of these areas are lost, in practice these area areas of very high value. If some of these areas are lost then alternate spatial scenarios are likely to be much less efficient. Even limited losses of these areas are likely to

result in other sites with similar features immediately becoming "irreplaceable", as they would be identified as being required to meet targets if a new Marxan planning process was undertaken. These areas are strongly linked to the VECs.

- **Medium Value Areas** – These areas have irreplaceability values of between 30% and <70%. They include many high value areas for ecosystem targets, landscape connectivity and wilderness characteristics. Although some specific areas could be lost without necessarily compromising the ability to meet targets, a key issue is the pattern of loss. Fragmentation of these areas could rapidly reduce their value for supporting landscape processes, and could undermine the integrity of linked Critical and High Value Landscape Areas. These areas can be considered to be "ecological support areas" and are important for the overall function of landscape processes which underpin the VECs.
- **Lower Value Areas**- These areas have lower selection frequency of < 30%. However, given the high overall value of the Cuando River Basin, they are still of significant value for supporting overall landscape function and integrity. Significant portions of these areas are directly required to meet targets, but there is some flexibility in the landscape about where the targets are met.

Critical Areas cover 4 492 405ha or 36.7% of the Cuando River Basin. Importantly, almost exactly half of these Critical Areas are outside of existing Protected Areas. **High Value Areas** cover an additional 1 856 976ha or 15.2% of the Cuando River Basin. Together, the **Critical Areas** and the **High Value Areas**, include the most important VECs and areas supporting VECs, and should be a clear focus of conservation and landscape management practices supporting sustainability. Combined, these areas are of highest value as potential protected areas sites for conserving biological diversity and are highlighted as the most important for immediate conservation actions. The **Medium Value Areas** cover 3 281 823ha or 26.8% of the basin. They are generally less fragmented, have overall higher irreplaceability values than the remainder of the basin, and represent areas with strong wilderness and connectivity characteristics (where these have not already been included in the Critical or High Value categories). These areas are important for overall landscape linkages. Their loss would result in a significant decrease in landscape connectivity. Retaining the overall connectivity and function of these areas should be a focus for landscape management activities. The remaining **Lower Value Areas** cover 21,4% of the basin. These areas are of significantly lower value (relative to the rest of the basin) for supporting VECs than the other landscape categories. However, given the high value of the basin as a whole, on a national or regional scale these sites would undoubtedly be identified as valuable. Significant loss of these areas could undermine the overall integrity of the Cuando River Basin and its VECs. Key tools and mechanisms to achieve landscape sustainability and conservation outcomes are highlighted for each landscape category, and guidance is provided incorporation into the Draft Strategic Environmental Monitoring Framework (SEMF) for the Cuando River Basin (CURB) set out in the SEA (SAIEA, 2024).

Table 2: The MARXAN irreplaceability analysis for the Cuando River Basin was used to identify areas of highest value for sustainable management and conservation actions aligned with the VECs identified in the SEA. The basin was divided into four categories, which were also stratified according to their location inside or outside of Protected Areas.

Landscape Category	Inside Protected Areas		Outside Protected Areas		Cuando Basin Total	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Critical Areas	2 233 833	18.2%	2 258 572	18.4%	4 492 405	36.7%
High Value Areas	1 101 578	9.0%	755 399	6.2%	1 856 976	15.2%
Medium Value Areas	2 044 634	16.7%	1 237 189	10.1%	3 281 823	26.8%
Lower Value Areas	1 387 156	11.3%	1 236 873	10.1%	2 624 030	21.4%
Grand Total	**6 767 200**	**55.2%**	**5 488 033**	**44.8%**	**12 255 234**	**100.0%**

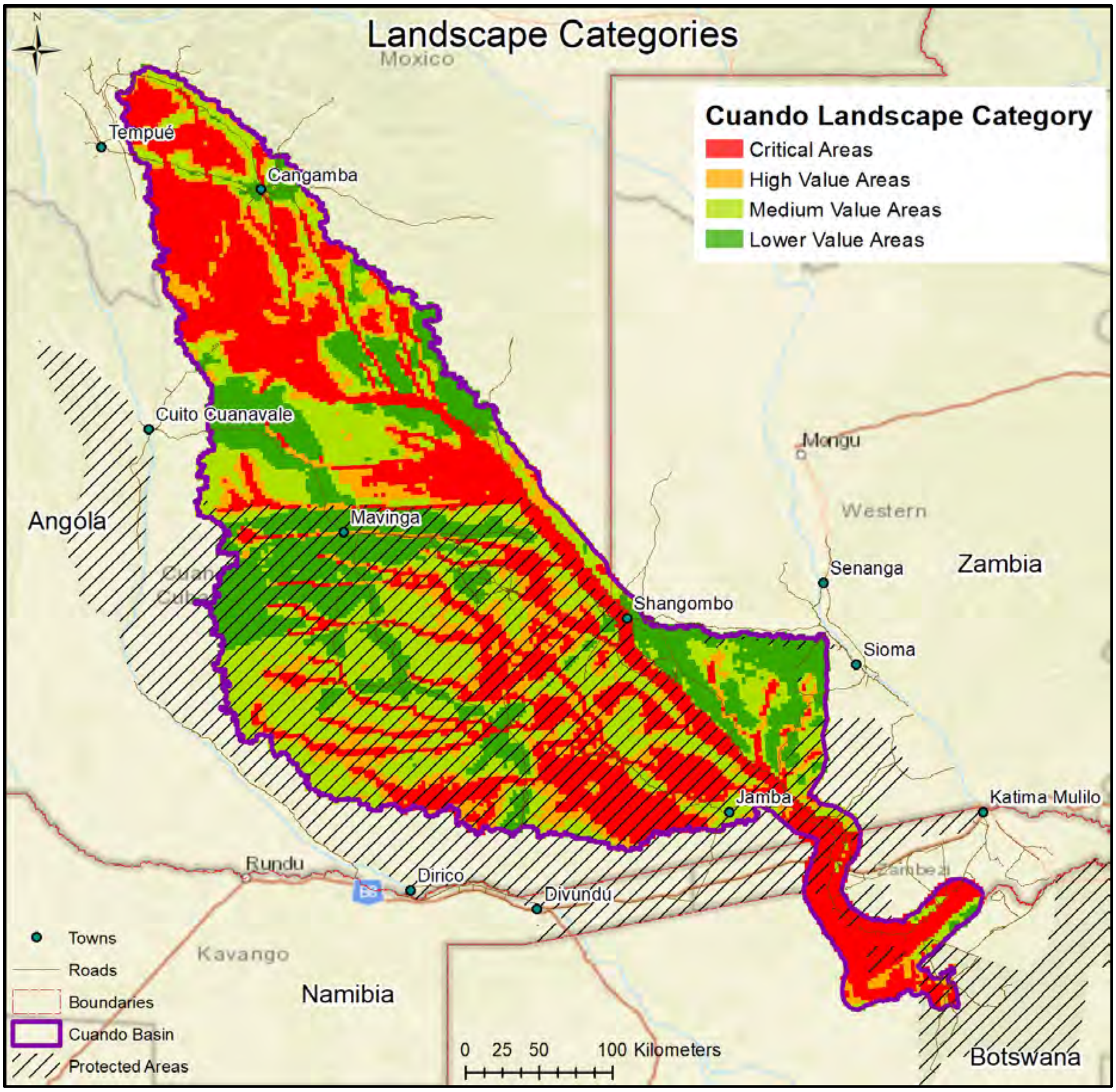


Figure 2: Map of the four landscape categories for sustainable management and conservation actions aligned with the VECs identified in the SEA identified in the MARXAN analysis.

Contents

List of Figures

List of Tables

Acronyms and Abbreviations

BLM	Boundary Length modifier
CBD	Convention on Biological Diversity
CIFOR	Centre for International Forestry Research
COP	Conference of the Parties
CURB	Cuando River Basin
FR	Forest Reserve
IUCN	International Union for Conservation of Nature
NGOs	Non-Governmental Organizations
NP	National Park
PA	Protected Area
SCP	Systematic Conservation Planning
SEA	Strategic Environmental Assessment
SPF	Species Penalty Factor
UNEP	United Nations Environment Programme

Introduction

This rapid Systematic Conservation Plan (SCP) for the Cuando River Basin is part of the Strategic Environmental Assessment undertaken for the basin by the Southern African Institute for Environmental Assessment for WWF-Namibia on behalf of ZAMCOM. The purpose of the Systematic Conservation Plan (SCP) is to guide zonation of key and important biodiversity areas and ecological corridors in the basin. The goal is to ensure that the Valued Ecosystem Components (VECs) identified as a core step of the SEA are integrated into a single spatial product which highlights where these VECs and the landscapes and ecological processes supporting them are located with the Cuando River Basin to ensure that they are adequately represented in protected areas, and highlight complementary areas (outside of existing protected areas) that require better protection and management.

The planning area covers the Cuando River Basin of around 12,25 million ha which stretches across four countries (Figure 5). The upper reaches include large portions of the Angolan Highlands Water Tower and the proposed Lisima Water Tower (Lisima Lya Mwono) Ramsar site; the mid reaches are primarily in Angola, with some smaller areas in Zambia, as the river enters the Kavango Zambezi (KAZA) Transfrontier Conservation Area (TFCA); and finally the lower reaches are in Namibia and Botswana where the Cuando discharges into the Linyati Swamps and the Savuti Marsh, and portions of the Okavango Delta System Ramsar site. The SCP included an additional 15km buffer area around the catchment that extends the core domain to just over 16 million hectares, while data was collected over a somewhat broader area to allow for connectivity analyses.

The SCP was designed to integrate the Valued Ecosystem Components (VECs) identified as a core step of the SEA:

- **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** This supply is fundamental to the structure, functioning and value of the entire river basin.
- **VEC 2 – The immense area of swamp or reedbeds**. The Cuando includes some of the largest expanses of reeds, papyrus and sedges in Africa. The reedbeds are hydrologically important, support important biodiversity, and include significant carbon storage in peat beds.
- **VEC 3 – Linyanti Swamps and Savuti area.** The Cuando feeds water, dissolved minerals and suspended solids into the Linyanti Swamps, the Savuti River and Savuti Marsh where the water disappears, and the minerals and sediments remain trapped to feed concentrations of plants and wildlife; which in turn support the livelihoods of local residents and a tourism industry that contributes much to the economy of northern Botswana and Namibia's Zambezi region.
- **VEC 4 – Western flanks of the Cuando.** The areas west of the Cuando River once supported an abundance of wildlife as a result of supplies of surface water in the Cuando and its ephemeral tributaries and the area's diverse habitats and relatively fertile soils. Wildlife numbers are likely to recover if the area is managed for conservation.
- **VEC 5 – Wildlife corridors and ecological connectivity.** Landscape connectivity - particularly for plains game, elephants, buffalo, and predators – is crucial for the health of wildlife populations by facilitating genetic exchange and expansion. Maintaining these corridors is vital for the entire KAZA landscape.
- **VEC 6 - Cuando aquifers**. Groundwater is a poorly known resource in the Cuando Basin, but is still an important resource for rural people who live some distance from available surface water.

This rapid Systematic Conservation Plan integrates available spatial biodiversity and socio-economic data to identify a robust set of spatial priorities for the Cuando River Basin (CURB), which integrate and support the VECS as well as other important biodiversity and socio-economic features of the basin. Whilst the VECs are ecological, most have profound implications for ecosystem services, the livelihoods of the people dependent on them, and the broader economy. They all contribute to maintaining the functioning and integrity of the Cuando Basin and supporting the small but very important tourism industry.

Planning objectives and project scope

The purpose of the rapid Systematic Conservation Plan (SCP) for the Cuando River Basin is to integrate the Valued Ecosystem Components (VECs) and areas supporting the VECs into a single spatial analysis to guide zonation, protection, management and monitoring of important biodiversity areas and ecological corridors in the basin.

A key purpose of the SCP was to integrate the available/emerging broader scale planning e.g. TNC has undertaken terrestrial focussed planning on the Cubango Okavango and WWF-US is completing a freshwater/hydrology focussed SCP in South East Angola (WWF, 2023); and the finer scale planning undertaken for areas overlapping various parts of the Cuando Basin (e.g. the WWF Zambezi and Kavango East rapid SCP (WWF Namibia, 2022) and the NatGeo / Wild Bird Trust focussed planning for the Okavango Zambezi Water Tower and Ramsar site (Wild Bird Trust, 2022; Wild Bird Trust National Geographic Okavango Wilderness Project, 2024). Available SEA project data, suitable additional global data, and useful raw data and priority area outputs from this range of planning projects with various purposes and outcomes need to be aligned in a single coherent spatial product for the Cuando River Basin which supports the VECs identified in the SEA. The projects attempts to bridge these scales and integrate this range of plans, and add in elements of landscape function and connectivity.

This rapid Systematic Conservation Plan integrated available spatial biodiversity and socio-economic data to identify a robust set of spatial priorities for the project area.

Specific Scope of Work to achieve the planning objectives:

- Integration of available spatial data (socio-economic and biodiversity, including key landcover change datasets) relevant for the Valued Ecosystem Components (VECs), into MARXAN conservation planning software.
- Integration of data and results from recent broader scale WWF analyses on aquatic features and TNC analyses of terrestrial features.
- Integrate priority area outputs from the finer scale planning undertaken for areas overlapping various parts of the Cuando Basin (especially the WWF Zambezi and Kavango East rapid SCP and the NatGeo / Wild Bird Trust focussed planning for the Okavango Zambezi Water Tower and Ramsar site.
- Review of potential additional datasets for inclusion into the analysis.
- A connectivity analysis for the area.
- Systematic Conservation Planning analysis using MARXAN.
- Identification of key areas supporting the VECs inside and outside of existing protected areas, which should be appropriately protected, managed and monitored.

Planning Approach

Systematic conservation planning concept

This assessment is based on a Systematic Conservation Planning (SCP) approach. 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 3 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 3: Systematic Conservation Planning process summary.

The rapid Systematic Conservation Plan is based on existing datasets, supplemented with some additional analyses on wilderness characteristics and landscape connectivity. Figure 4 below provides details on data review and the dataset building stages of the planning process.

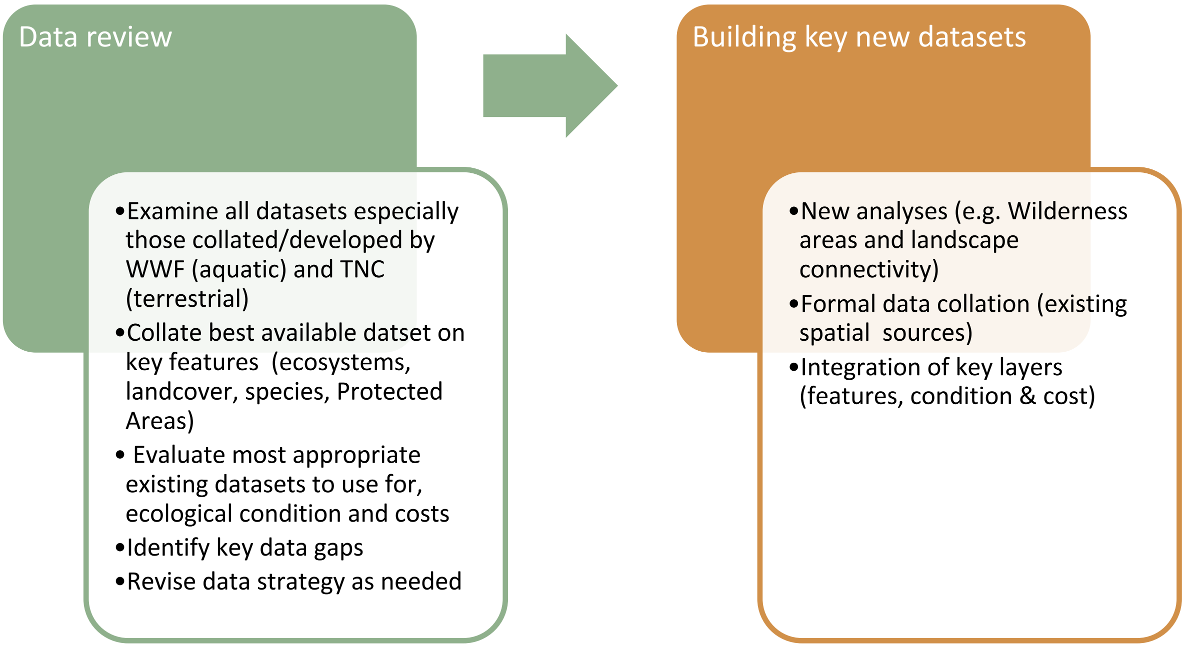


Figure 4: Additional details on data review and dataset building stages of the planning process.

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 planning area covers the Cuando River Basin of around 12,25 million ha which stretches across four countries (Figure 5). The upper reaches include large portions of the Angolan Highlands Water Tower and Okavango Zambezi Ramsar site; the mid reaches are primarily in Angola, with some smaller areas in Zambia, as the river enters the Kavango Zambezi (KAZA) Transfrontier Conservation Area (TFCA); and finally the lower reaches are in Namibia and Botswana where the Cuando discharges into the Linyati Swamps and the Savuti Marsh. The SCP included an additional 15km buffer area around the catchment that extends the core domain to just over 16 million hectares, while data was collected over a somewhat broader area which must be considered when building a systematic conservation plan (e.g. major socio-economic patterns, such as population centres and land use, ecological process priorities, protected area linkages and landscape connectivity that should be aligned).

Figure 5: Map of the planning domain, which incorporates the full Cuando River Basin along with a 15km buffer.

Planning units

To facilitate data collection and analysis, the planning domain was divided into 35 999 2.5x2.5-km planning units (Figure 6). This was done 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 usable units.
- Provide required units for the Systematic Conservation Planning software MARXAN (Ball et al., 2009).
- Provide a basis for sharing datasets used in the assessment that cannot be shared in their original form due to data ownership or publication issues. This allows the project to share the digested values that were incorporated into the planning process and reference the original source.

<u>The 625 ha unit size was chosen because:</u>

- This planning unit size had successfully been used in previous successful mapping processes in the region.
- It was reasonably matched to the range of resolutions of different spatial data inputs.
- It provides a manageable number of planning units given the size of the planning domain. Too many units complicates the analyses, and slows down key steps such as calibration of MARXAN outputs.

Figure 6: Map showing the 2.5x2.5-km planning units used for the assessment. These units were used for data collection, data integration and for the conservation planning analyses.

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 several steps. 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.

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

- The assessment intended to meet targets (see Target setting on page 10) for all features while reducing conflict with other competing activities. 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 (e.g. 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.
- The assessment aimed to avoid a fragmented set of priority areas as far as possible. This issue was addressed using three approaches:
    - The analysis focussed on areas with the strongest wilderness characteristics. We identified areas with the lowest levels of human impact, which are generally least fragmented.
    - The analysis focused on areas that are most connected in the landscape, and undertook a dedicated analysis of landscape connectivity using Condatis (Computational Biology Facility, University of Liverpool, 2022; Wallis and Hodgson, 2015).
    - 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.

- The assessment aimed to meet all targets as far as possible but did not force the selection of poor condition with high levels of human impact. This balance was obtained by an iterative calibration of the MARXAN input variables. Areas with low levels of conflicting human activity that are 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).

A set of Focus Areas for conservation actions were identified using the following method:

- Data layers were prepared using ESRI ArcGIS 10.6.
- The analyses used 625ha or 2.5 x 2.5km grids for the spatial prioritization.
- 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/).
- 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 on Costs surfaces (Sections from page 75).
- 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 for **seven different conservation prioritizations**. 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 of the seven different conservation prioritizations were combined into a single integrated prioritization using a mean value of the selection frequencies for each scenario. This was done as there were strong spatial overlaps between runs.
- The results of the integrated prioritization was used to split the Cuando River Basin into **four landscape categories** based on selection frequency. The focus areas were then split into a number of **spatial scenarios for landscape conservation**. The categorisation of the landscape was done on the basis of the integrated summary of conservation priority (i.e. the mean selection frequency across the seven favoured Marxan scenarios). An iterative approach was used to allow the identification of thresholds for categories. The categories are aligned to their importance as VECs or where they are required to support the VECs. The categories were **Critical Areas**, **High Value Areas**, **Medium Value Areas** and **Lower Value Areas**. These priority areas and categories aid in understanding the spatial prioritization, are useful for describing selected areas, and are

easier to include in monitoring and implementation actions (Table 4). A range of implementation actions for each landscape category were set out to provide guidance on inclusion of these areas into the Strategic Environmental Framework of the SEA (SAIEA, 2024).

Table 3: Seven main conservation prioritizations were run using MARXAN.

Scenario	Features / Definitions
Base Case (Run 17c)	Targets of 30-50% were used for most biodiversity features, with higher targets for high conservation value special features (e.g. wetlands, peat wetlands), process areas (e.g. key landscape linkages, floodplains) with lower targets for ecosystem types, species, and areas with wilderness characteristics.
Base with reduced sustainable management focus (Run 30c)	This was as for the base case, but with reduced targets for existing conservation management areas (e.g. the game management area) to avoid forcing selection into some "sustainable management" areas which actually have relatively high levels of human impact.
Areas outside existing Protected Areas (Run 31)	Targets and cost surfaces were as per the base case, but formal Protected Areas were hardwired into the results. This run allowed us to identify features of high importance that were largely outside of the PA network. It however deprioritizes the portions of features that are outside of PAs, where large areas are already inside PAs, even if these features are important.
Species focused scenario (Run 28C):	Higher conservation targets for identified priorities for species.
Hydrologically Focused Scenario (Run 25C):	Higher targets for hydrological linked features – wetlands, rivers, discharge, important catchment areas etc.
Natural Landscape Focused Scenario (Run 49):	Targets as for the base case, but significantly higher cost values, and consequently with much stronger avoidance of human impacted landscapes.
Wilderness and connectivity (Run 27b):	Higher targets for wilderness and connectivity linked features, with strong avoidance of human impacted landscapes Existing Protected Areas were also strongly favoured.

Table 4: The analysis split the Cuando Basin into several planning categories. The categorisation of the landscape was done on the basis of the integrated summary of conservation priority (i.e. the mean selection frequency across the seven favoured Marxan scenarios). An iterative approach was used to allow the identification of thresholds for categories. The categories are aligned to their importance as VECs or where they are required to support the VECs.

Category	Description
Critical Areas	These areas are irreplaceable or practically irreplaceable (i.e. required to meet targets under almost all circumstances and scenarios). These sites had mean Marxan irreplaceability values (or selection frequencies) across the seven scenarios of 90%-100%, which means that they are almost always required to meet targets. These areas are most strongly linked to the VECs.
High Value Areas	These areas have mean selection frequencies of between 70% and <90%. Although it may still be possible to meet targets if some of these areas are lost, in practice these area areas of very high value. If some of these areas are lost then alternate spatial scenarios are likely to be much less efficient. Even limited losses of these areas are likely to result in other sites with similar features immediately becoming "irreplaceable", as they would be identified as being required to meet targets if a new Marxan planning process was undertaken. These areas are strongly linked to the VECs.
Medium Value Areas	These areas have irreplaceability values of between 30% and <70%. They include many high value areas for ecosystem targets, landscape connectivity and wilderness characteristics. Although some specific areas could be lost without necessarily compromising the ability to meet targets, a key issue is the pattern of loss. Fragmentation of these areas could rapidly reduce their value for supporting landscape processes, and could undermine the integrity of linked Critical and High Value Landscape Areas. These areas can be considered to be "ecological support areas" and are important for the overall function of landscape processes which underpin the VECs.
Lower Value Areas	These areas have lower selection frequency of < 30%. However, given the high overall value of the Cuando River Basin, they are still of significant value for supporting overall landscape function and integrity. Significant portions of these areas are directly required to meet targets, but there is some flexibility in the landscape about where the targets are met.

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 to safeguard a representative portion of that feature such that it will persist in the future (see Table 5).

Targets were set for the range of biodiversity features used in the planning process (Table 5). 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 the link to VECs identified in the SEA, conservation value, threat status or rarity of features, or on the objectives of a conservation prioritization.

Targets (along with varying the cost surface, see MARXAN Cost Layer on page 86) were the main tool used to define the seven main conservation prioritizations for the Cuando Basin planning domain.

Table 5: Targets (percentage values) used in the rapid systematic conservation plan. Targets were used to help identify priority areas using MARXAN. Together with using different cost surface options, these targets were used to create seven different conservation prioritizations.

Type	Feature	ID	Base Case (Run 17c)	Base with reduced sustainable management focus (Run 30c)	Areas outside existing Protected Areas (Run 31)	Species focused scenario (Run 28C):	Hydrologically Focused Scenario (Run 25C):	Natural Landscape Focused Scenario (Run 26d):	Wilderness and connectivity (Run 27b):
Ecosystems (vegetation types)	Wet Miombo	1	30	30	30	30	30	30	30
	Dry Miombo	2	30	30	30	30	30	30	30
	Baikiaea Woodland & Savanna	3	30	30	30	30	30	30	30
	Gabono-Congolian Mesic Woodland & Grassland	4	30	30	30	30	30	30	30
	Dry Acacia - Terminalia - Combretum Woodland & Savanna	5	30	30	30	30	30	30	30
	Zambezi Mopane	6	30	30	30	30	30	30	30
	Etosha Salt Pan	7	30	30	30	30	30	30	30
	Kalahari Salt Pan	8	30	30	30	30	30	30	30
	African Tropical Freshwater Marsh (Dembos)	9	75	75	75	75	75	75	75
	Zambesian Cryptosepalum Dry Forest	10	30	30	30	30	30	30	30
	Okavango-Cuvelai Phreatophyte Vegetation	11	75	75	75	75	75	75	75
	Open Water	12	75	75	75	75	75	75	75
Wilderness Areas	Broader Wilderness	95	40	40	40	40	40	40	70
	Core Wilderness	96	40	40	40	40	40	40	70
Priority areas from other analyses	Core areas from SCP for the Okavango Zambezi Water Tower (OZWT)	29	80	80	80	80	80	80	80
	Priority Areas from SCP for the Zambezi and Kavango East Regions of Namibia	85	80	80	80	80	80	80	80
	Proposed Ramsar site: Lisima Water Tower (Lisima Lya Mwono)	26	75	75	75	75	75	75	75
	Okavango Delta System Ramsar Site	30	80	80	80	80	80	80	80
River systems and associated	All rivers	16	30	30	30	30	45	30	30
	Main rivers (WWF dataset)	18	75	75	75	75	85	75	75
	Raw discharge of rivers	14	30	30	30	30	40	30	30

Type	Feature	ID	Base Case (Run 17c)	Base with reduced sustainable management focus (Run 30c)	Areas outside existing Protected Areas (Run 31)	Species focused scenario (Run 28C):	Hydrologically Focused Scenario (Run 25C):	Natural Landscape Focused Scenario (Run 26d):	Wilderness and connectivity (Run 27b):
hydrological processes	Normalized discharge values	15	30	30	30	30	40	30	30
	Cuando river discharge highest categories	17	80	80	80	80	40	80	80
	Hydrological process areas 100 yr	25	75	75	75	75	90	75	75
Wetlands	Wetlands - Reedbeds on the Cuando	19	75	75	75	75	80	75	75
	Wetlands - Linyati and Savuti Wetlands	20	75	75	75	75	75	75	75
	Wetlands - Global subtropical wetlands	21	75	75	75	75	90	75	75
	Wetlands - Global subtropical wetlands (Cuando only)	22	75	75	75	75	90	75	75
Catchments	Key catchments: Angola Highlands Water Tower	27	75	75	75	75	75	75	75
	Key Catchments: Cuando Source Lakes landscape and 5km buffer	28	75	75	75	75	75	75	75
Groundwater	Groundwater High Value Areas	24	30	30	30	30	30	30	30
Connectivity and process areas	Priority areas for wildlife west of the Cuando mainstem	23	60	60	60	60	60	60	60
	KAZA Wildlife dispersal areas	80	40	40	40	40	40	40	50
	Condatis Corridors - North	86	60	60	60	60	60	60	70
	Condatis Corridors - Zambia Mavinga	87	60	60	60	60	60	60	70
	Condatis Corridors - Marginal Central	88	60	60	60	60	60	60	70
	Condatis Corridors - Chobe to Bwabwata	89	60	60	60	60	60	60	70
	Condatis Corridors - Main NW NE corridor	90	60	60	60	60	60	60	70
	Condatis Corridors - Marginal Central Corridor W E	91	60	60	60	60	60	60	70
	Condatis Corridors - West East	92	60	60	60	60	60	60	70
	Condatis Corridors - Source to sink	93	60	60	60	60	60	60	70
	Condatis Bottlenecks	94	60	60	60	60	60	60	70
Species group models	WWF Wetland species model priorities	76	40	40	40	45	60	40	40
	WWF Aquatic Bird Priorities	77	40	40	40	45	45	40	40

Type	Feature	ID	Base Case (Run 17c)	Base with reduced sustainable management focus (Run 30c)	Areas outside existing Protected Areas (Run 31)	Species focused scenario (Run 28C):	Hydrologically Focused Scenario (Run 25C):	Natural Landscape Focused Scenario (Run 26d):	Wilderness and connectivity (Run 27b):
	WWF Aquatic Mammal Priorities	78	40	40	40	45	45	40	40
	WWF Fish Priorities	79	40	40	40	45	45	40	40
Species Distributions - TNC Mammals	Acinonyx jubatus	31	30	30	30	45	30	30	30
	Canis adustus	32	30	30	30	45	30	30	30
	Caracal caracal	33	30	30	30	45	30	30	30
	Chlorocebus pygerythrus	34	30	30	30	45	30	30	30
	Civettictis civetta	35	30	30	30	45	30	30	30
	Crocuta crocuta	36	30	30	30	45	30	30	30
	Diceros bicornis	37	30	30	30	45	30	30	30
	Equus quagga	38	30	30	30	45	30	30	30
	Giraffa camelopardalis	39	30	30	30	45	30	30	30
	Hippopotamus amphibius	40	30	30	30	45	30	30	30
	Hippotragus equinus	41	30	30	30	45	30	30	30
	Hippotragus niger	42	30	30	30	45	30	30	30
	Kobus leche	43	30	30	30	45	30	30	30
	Kobus vardonii	44	30	30	30	45	30	30	30
	Loxodonta africana	45	30	30	30	45	30	30	30
	Lycaon pictus	46	30	30	30	45	30	30	30
	Mellivora capensis	47	30	30	30	45	30	30	30
	Panthera leo	48	30	30	30	45	30	30	30
	Panthera pardus	49	30	30	30	45	30	30	30
	Raphicerus campestris	50	30	30	30	45	30	30	30
	Sylvicapra grimmia	51	30	30	30	45	30	30	30

Type	Feature	ID	Base Case (Run 17c)	Base with reduced sustainable management focus (Run 30c)	Areas outside existing Protected Areas (Run 31)	Species focused scenario (Run 28C):	Hydrologically Focused Scenario (Run 25C):	Natural Landscape Focused Scenario (Run 26d):	Wilderness and connectivity (Run 27b):
	Syncerus caffer	52	30	30	30	45	30	30	30
	Tragelaphus oryx	53	30	30	30	45	30	30	30
	Tragelaphus strepsiceros	54	30	30	30	45	30	30	30
Species Distributions - TNC Birds	Aquila nipalensis	55	30	30	30	45	30	30	30
	Aquila rapax	56	30	30	30	45	30	30	30
	Ardeotis kori	57	30	30	30	45	30	30	30
	Balearica regulorum	58	30	30	30	45	30	30	30
	Bucorvus leadbeateri	59	30	30	30	45	30	30	30
	Bugeranus carunculatus	60	30	30	30	45	30	30	30
	Calidris ferruginea	61	30	30	30	45	30	30	30
	Circus macrourus	62	30	30	30	45	30	30	30
	Egretta vinaceigula	63	30	30	30	45	30	30	30
	Falco vespertinus	64	30	30	30	45	30	30	30
	Glareola nordmanni	65	30	30	30	45	30	30	30
	Gyps africanus	66	30	30	30	45	30	30	30
	Gyps coprotheres	67	30	30	30	45	30	30	30
	Necrosyrtes monachus	68	30	30	30	45	30	30	30
	Phoeniconaias minor	69	30	30	30	45	30	30	30
	Polemaetus bellicosus	70	30	30	30	45	30	30	30
	Rynchops flavirostris	71	30	30	30	45	30	30	30
	Sagittarius serpentarius	72	30	30	30	45	30	30	30
	Terathopius ecaudatus	73	30	30	30	45	30	30	30
	Torgos tracheliotos	74	30	30	30	45	30	30	30

Type	Feature	ID	Base Case (Run 17c)	Base with reduced sustainable management focus (Run 30c)	Areas outside existing Protected Areas (Run 31)	Species focused scenario (Run 28C):	Hydrologically Focused Scenario (Run 25C):	Natural Landscape Focused Scenario (Run 26d):	Wilderness and connectivity (Run 27b):
	Trigonoceps occipitalis	75	30	30	30	45	30	30	30
Conservation and Sustainable Management	Protected Areas (All Reserves)	81	40	40	40	40	40	40	50
	Protected Areas (Smaller Reserves)	82	40	40	40	40	40	40	50
	Community Conservation Areas	83	50	10	50	50	20	50	50
	Game Management Areas	84	50	10	50	50	20	50	50

Spatial Biodiversity Data

Ecosystem Types

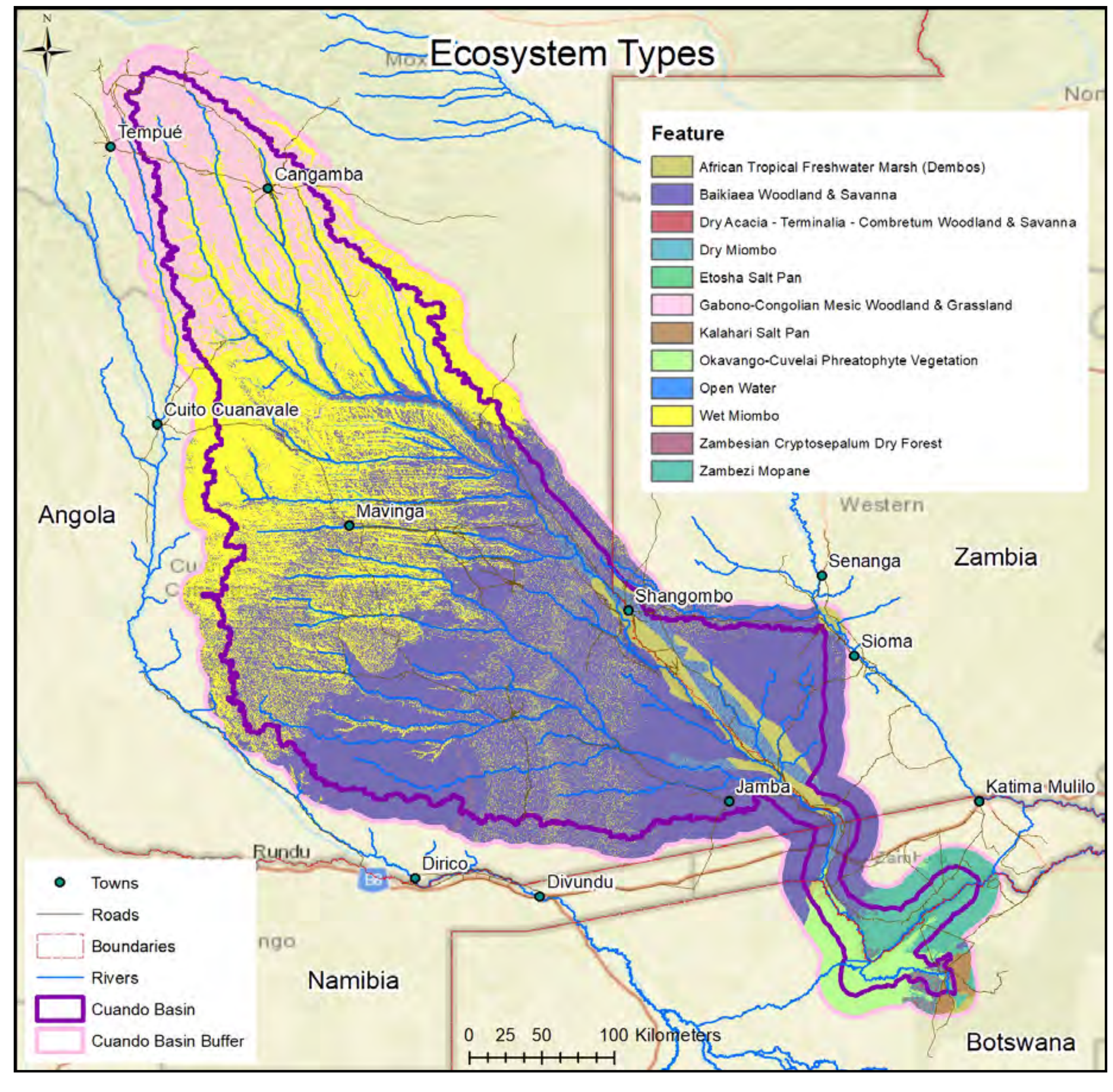


Figure 7: The broad-scale ecosystem map for the Cuando Basin planning domain, from United States Geological Survey "A new map of standardized terrestrial ecosystems of Africa" (Sayre et al., 2020b, 2020a, 2013).

Description

For this analysis we used the "A new map of standardized terrestrial ecosystems of Africa" (Sayre et al., 2020b, 2020a, 2013). This aligns with the maps chosen for the WWF Angolan terrestrial analysis. Although more detailed ecosystem/ vegetation maps are available for specific areas (e.g. the East Zambezi and Caprivi strip in Namibia), this represents the best published map the basin as a whole.

The Cuando River Basin is characterized by a reasonably diverse array of terrestrial ecosystems, each contributing uniquely to the region's ecological complexity (Figure 7 and Table 6). The area is dominated by extensive Baikiaea Woodland and Savanna, and wet and dry Miombo. Intact Miombo woodlands dominate these highlands above the peat lands and open floodplains. The sands are relatively infertile as a result of excessive leaching and the inert nature of the quartz-dominated substrates, while soils in the floodplains are acidic due to the peat in surrounding seepages and wetlands. Soils are thus generally not arable outside of the floodplains, and the region, therefore, supports very few people (Wild Bird Trust, 2022).

Table 6. Summary of area and percentage coverage of the broad-scale ecosystem types for the planning domain, from the United States Geological Survey "A new map of standardized terrestrial ecosystems of Africa" (Sayre et al., 2020b, 2020a, 2013). Note that the figures are for the planning domain, which is the Cuando Basin with a 15km buffer, and hence the total area exceeds that of the basin itself.

Broad Vegetation Type	ID	Area (Hectares)	Area (%)
Wet Miombo	1	4 483 270	28.0
Dry Miombo	2	322 728	2.0
Baikiaea Woodland & Savanna	3	7 435 871	46.4
Gabono-Congolian Mesic Woodland & Grassland	4	2 017 799	12.6
Dry Acacia - Terminalia - Combretum Woodland & Savanna	5	16 896	Under <0.1
Zambezi Mopane	6	565 075	3.5
Etosha Salt Pan	7	12	Almost 0
Kalahari Salt Pan	8	65 058	0.4
African Tropical Freshwater Marsh (Dembos)	9	614 532	3.8
Zambesian Cryptosepalum Dry Forest	10	81 576	0.5
Okavango-Cuvelai Phreatophyte Vegetation	11	415 999	2.6
Open Water	12	3 561	Under <0.1
		16 022 377	

Overview of mapping methods and layer incorporation

A map of ecosystem types is a fundamental building block for most Systemic Conservation Planning processes. The best available ecosystem map for the planning domain was "A new map of standardized terrestrial ecosystems of Africa" (Sayre et al., 2020b, 2020a, 2013). This map used for the WWF Angolan terrestrial analysis. Although more detailed ecosystem/ vegetation maps are available for specific areas (e.g. the East Zambezi and Caprivi strip in Namibia), this represents the best published map the basin as a whole.

<u>There are some issues linked to the ecosystem map:</u>

- The map of ecosystem types is based on remote sensing and landscape units (geology, soil, and topography). The map is effectively a map of original or potential ecosystem types and is ideal for Systematic Conservation Planning as it shows the historical extent of each natural ecosystem type, which allows for comprehensive planning and setting targets (Botts et al., 2016).
- Targets for these features are examined in the Target Setting section on page 10.

Link to Valued Ecosystem Components (VECs)

The SCP was designed to integrate the Valued Ecosystem Components (VECs) identified as a core step of SEA. Ensuring sufficient representation of natural and near natural areas of each of the of the basin's ecosystem types is fundamental to securing the overall biodiversity and functioning of **all the VECs**. Specific direct links to the VECs include incorporation of the diversity of ecosystems of the area which supports the wildlife populations of **VEC 4 – Western flanks of the Cuando**, and the underlying intact natural areas that make up the corridor and dispersal areas critical for **VEC 5 – Wildlife corridors and ecological connectivity**.

Data providers

Data are published and freely available.

Wilderness Areas

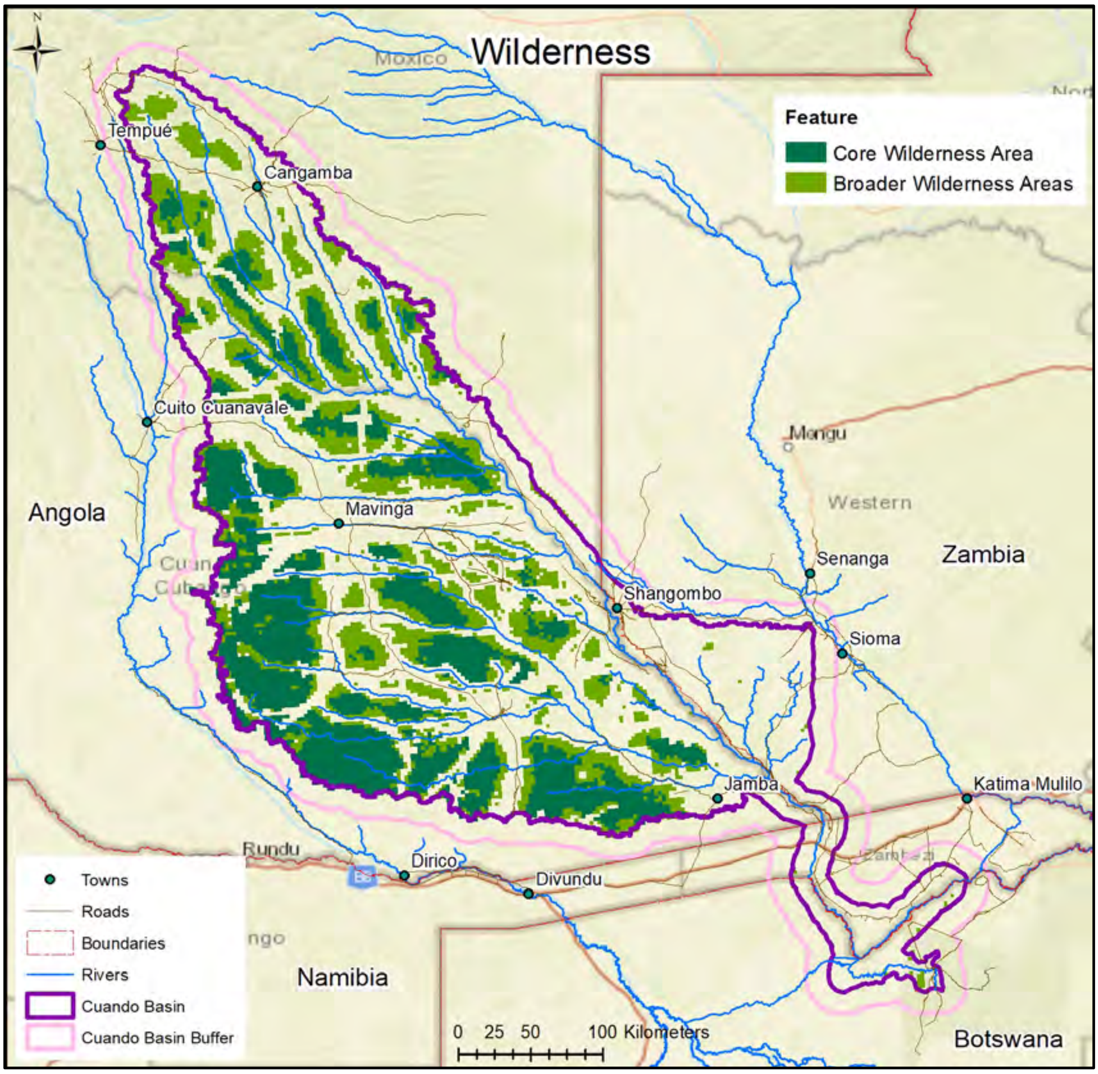


Figure 8: The project undertook an analysis of areas with the strongest wilderness characteristics.

Description

Wilderness areas are expansive, untouched landscapes with minimal human impact, fostering biodiversity, scenic beauty, and natural processes. These regions, free from significant development, serve as crucial habitats for diverse plant and animal species. Offering recreational opportunities, they also hold cultural significance and contribute to conservation efforts. Preserving these areas is essential for maintaining ecological balance and providing a sanctuary for nature to thrive undisturbed. As humanity faces environmental challenges, the protection of wilderness areas becomes increasingly vital for a sustainable and harmonious relationship with the natural world.

One of the key features of the planning domain is that it is one of the few areas remaining where there are large areas with strong wilderness characteristics. The sandy soils are relatively infertile due to leaching, while floodplain soils are acidic because of surrounding peat. Consequently, arable land is limited, and the area supports a sparse population.

Further, these wilderness characteristics provide one of the last opportunities for developing wilderness focussed land uses without disrupting large existing resident populations.

We therefore identified two categories of "areas with wilderness characteristics" across the landscape using a quantitative approach (Figure 8). The two categories were:

- **Core Wilderness Areas:** these areas have the lowest levels of human impact and are extremely remote and inaccessible.
- **Broader Wilderness Areas:** these areas have slightly higher levels of human impact and may be more accessible.

The analysis was based on the following variables:

- **Transformed / human dominated landcover classes:** Areas with the greatest coverage of cultivated areas and urban areas were avoided.
- **Proximity to and density of settlements:** Areas near the densest settlements and buildings were avoided.
- **Proximity to larger roads:** Areas near larger roads were avoided.
- **Areas accessible by any road or track:** Areas with higher accessibility were avoided.
- **Access:** Areas with greatest level of accessibility to major centres were avoided.
- **Proximity of population centres:** Areas closets to the larger villages were avoided.

Link to Valued Ecosystem Components (VECs)

Although the Wilderness Areas are valuable to the VECs of the Cuando River Basin as a whole, the Wilderness areas are of particular importance to **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River** as significant portions of the Water Tower have retained their wilderness characteristics (and are included in this feature); the areas are likely to be important for supporting current and future wildlife populations of **VEC 4 – Western flanks of the Cuando**; and the underlying wilderness areas are critical for **VEC 5 – Wildlife corridors and ecological connectivity**.

Overview of mapping methods and incorporation into planning

The following are key points in the mapping methodology:

- The data used and the specific analysis for each variable are set out in the costs surface section on page 75.
- Variables were normalized to the same range (0-100) and then an equal weighted summary value for each planning unit was calculated.
- Values for units within the planning domain were split into five quantiles.
- The top quantile, in terms of wilderness characteristics, was defined as "Core Wilderness Areas".
- The next quantile, in terms of wilderness characteristics was defined as "Broader Wilderness Areas".
- For inclusion into MARXAN, the "Core Wilderness Areas" were treated as a feature, while the "Core Wilderness Areas" plus the "Broader Wilderness Areas" were grouped as a second feature. This allows us to set targets for overlapping features, and ensure that the "Core Wilderness Areas" are selected first and then the combined broader areas. This ensures that targets are first met in the areas with highest greatest wilderness characteristics and then in the adjacent landscapes with higher levels of human presence and impact.

- Targets for these features are examined in the section on Target Setting on page 10.

Data providers

This is a new analysis for the current study. The data sources for the underlying layers and the data processing are set out in the 'cost surface' section from page 75.

Ramsar Sites - Lisima Water Tower (Lisima Lya Mwono) and Okavango Delta System Ramsar Site

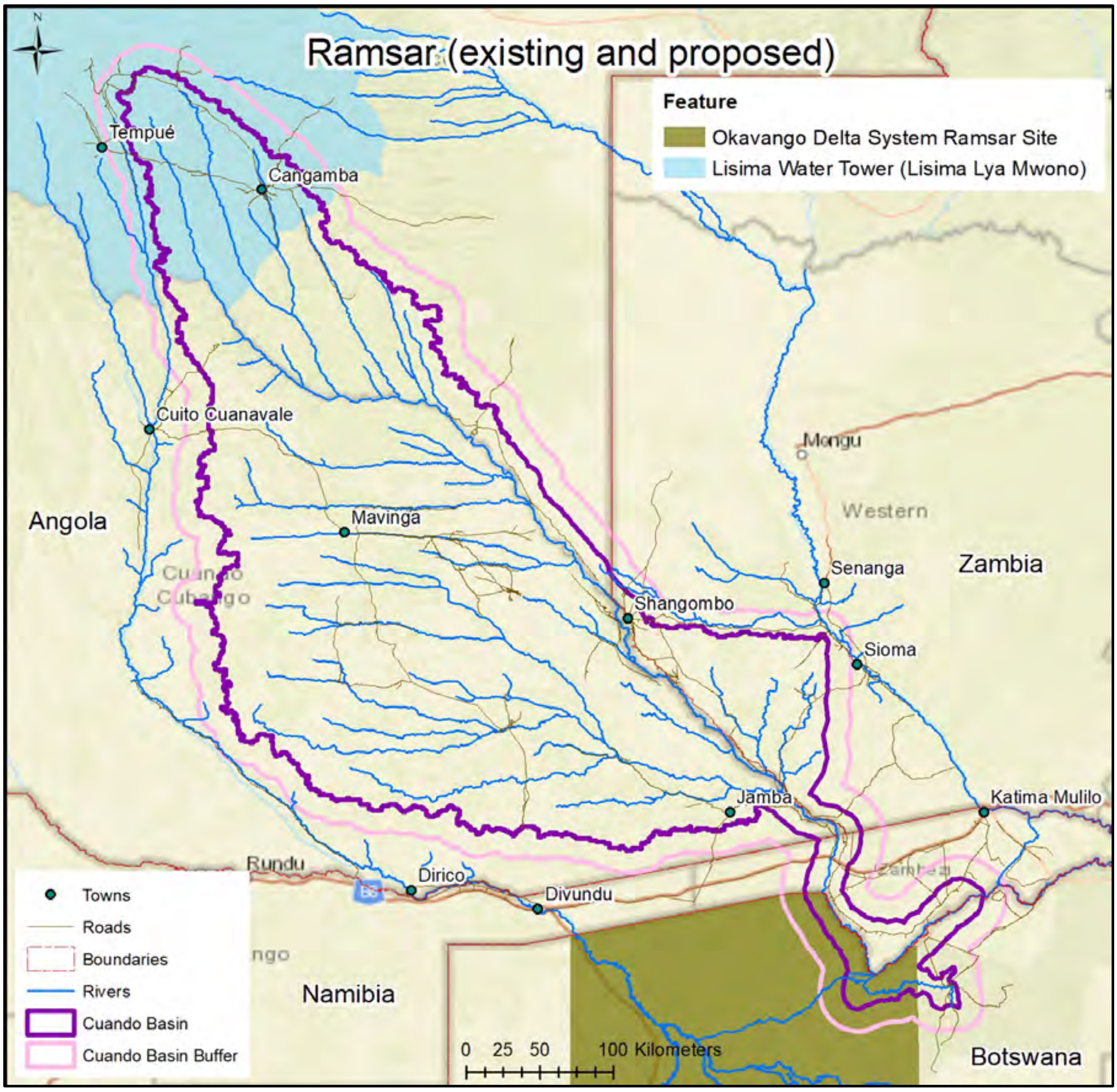


Figure 9: Map showing the existing Okavango Delta System Ramsar Site and the proposed Lisima Water Tower (Lisima Lya Mwono) Ramsar site.

Description

Ramsar Sites are priority wetlands designated as such under the Ramsar Convention, an international treaty, established in 1971 to conserve and sustainably use these areas. These sites, numbering over 2 400 globally, include marshes, swamps, and coastal areas, recognized for their ecological importance. The Ramsar Convention aims to promote international cooperation for the conservation and wise use of wetlands, emphasizing their role in biodiversity, water regulation, and as habitats for migratory birds. Member countries commit to measures ensuring the sustainable management of these crucial ecosystems.

Two current or proposed Ramsar sites extend into the planning domain (Figure 9):

- **Okavango Delta System Ramsar Site:** The Okavango Delta System Ramsar Site was designated as a Ramsar Site of International Importance in September 1996, it encompasses an expansive area exceeding 55,000 square kilometers, making it the largest Ramsar site in Southern Africa and the third largest globally. The site encompasses a diverse array of wetland habitats including the permanent swamps of the Delta itself, seasonally flooded plains surrounding the Delta, the ephemeral Lake Ngami, and the perennial Kwando-Linyanti river system. It is portions of the last section which extend into the planning domain.
- **Lisima Water Tower (Lisima Lya Mwono) Ramsar site:** The Wild Bird Trust compiled a proposal for the designation of the Lisima Water Tower (Lisima Lya Mwono) Ramsar site in November 2022 (Wild Bird Trust, 2022) (Figure 9). The proposed Ramsar site follows the gazetted administrative boundaries of Cangumbe, Lutuai, Tempué, Cassamba and Cangamba comunas, which are the most local administrative areas within the Angolan government structure. It extends over an area of 5 367 000 ha, and covers a portion of the north-west of the planning domain. Characterized by forested watersheds, the region encompasses the unique Bié Plateau, also known as the Central Plateau of Angola or the Angolan Highlands. The Bié Plateau lies south of the Great Equatorial Divide, a significant African watershed. This expansive divide separates north-flowing river catchments, such as the Cuanza and Cassai Rivers, from those flowing south into the Greater Kalahari Sand Basin, including the Cubango, Cuito, Cuando, and Zambezi Rivers (into SE Angola). Referred to as a 'Water Tower' (Lourenco and Woodborne, 2023), much of this area is underlain by deep Kalahari sand, influencing hydrological and ecological processes that shape biological and socio-economic activities. Water from the 'Water Tower' flows into both north and south-draining rivers, gradually entering tributaries after filtration through layers of sand. This process results in exceptionally clear water devoid of minerals or suspended solids. The proposed Lisima Water Tower Ramsar site harbours the unique crystal-clear, high-lying source lakes, peated wetlands and headwaters of the Cuando, as well as the Okavango and Zambezi Basins. Moreover, most of the area is in a natural and pristine condition. River water supplied by the proposed site supports perennial wetlands in the Okavango Delta, Linyanti Swamps, Barotse Floodplains and other wetlands along the Cuito, Cuando and Zambezi rivers.

Overview of mapping methods and incorporation into planning

The existing and proposed Ramsar sites were included as separate features in the Systematic Conservation Plan.

Link to Valued Ecosystem Components (VECs)

The Lisima Water Tower (Lisima Lya Mwono) Ramsar site is a core area of **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** The Okavango Delta System Ramsar Site includes the Savuti area and significant areas adjacent to the Linyati Swamps, and is hence critical to **VEC 3 – Linyanti Swamps and Savuti area.** In addition, the Okavango Delta System Ramsar Site is a key area supporting regional landscape connectivity which underpins **VEC 5 – Wildlife corridors and ecological connectivity.**

Data providers

Data from the World Database on Protected Areas (UN Environment Programme World Conservation Monitoring Centre) and Mauro Lourenco (Wild Bird Trust).

Wetlands and Peat

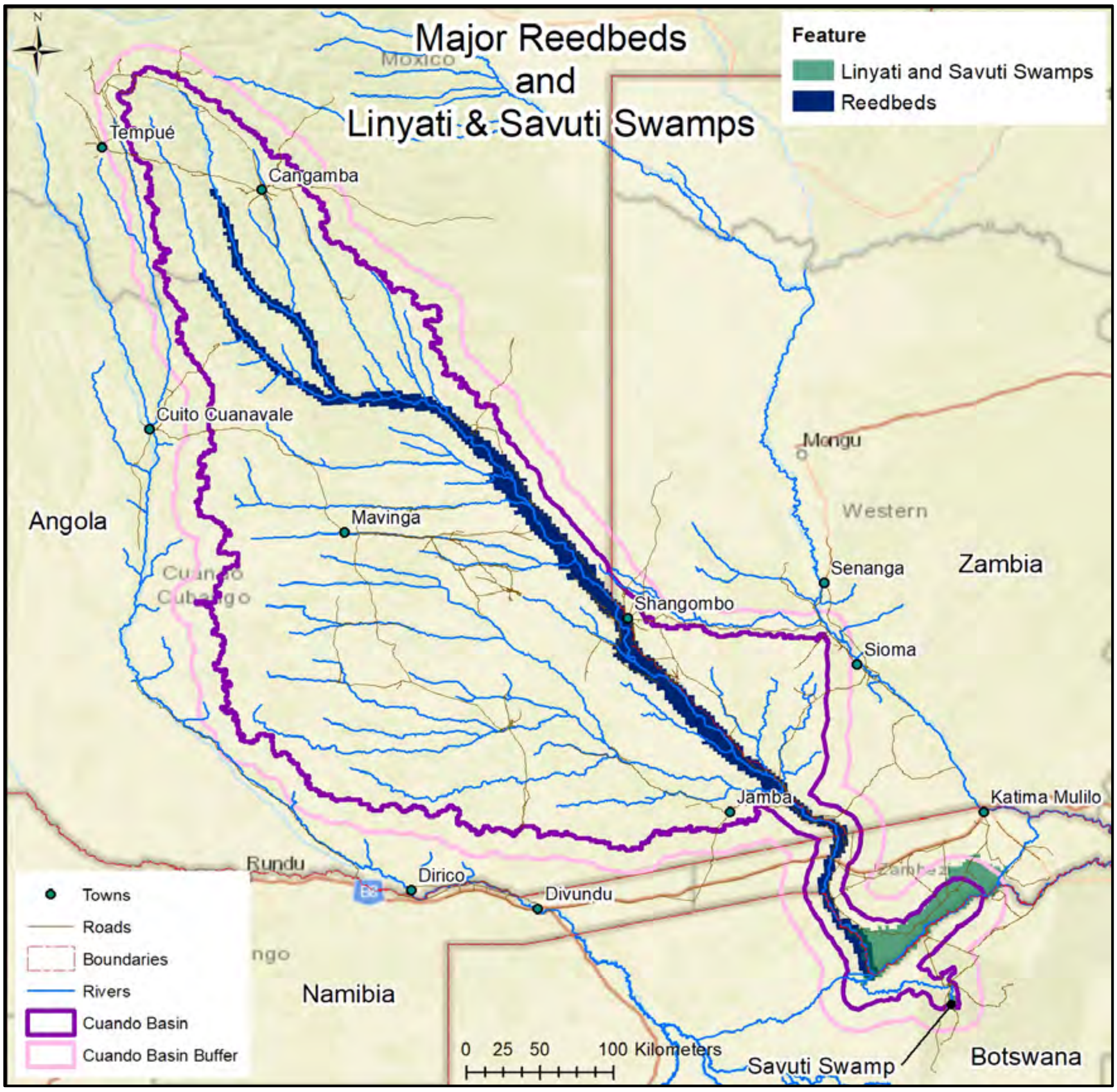


Figure 10: Map showing the major reedbeds of the Cuando River, and the Linyati Swamp and Savuti Marsh. Data from the CURB SEA (SAIEA, 2024).

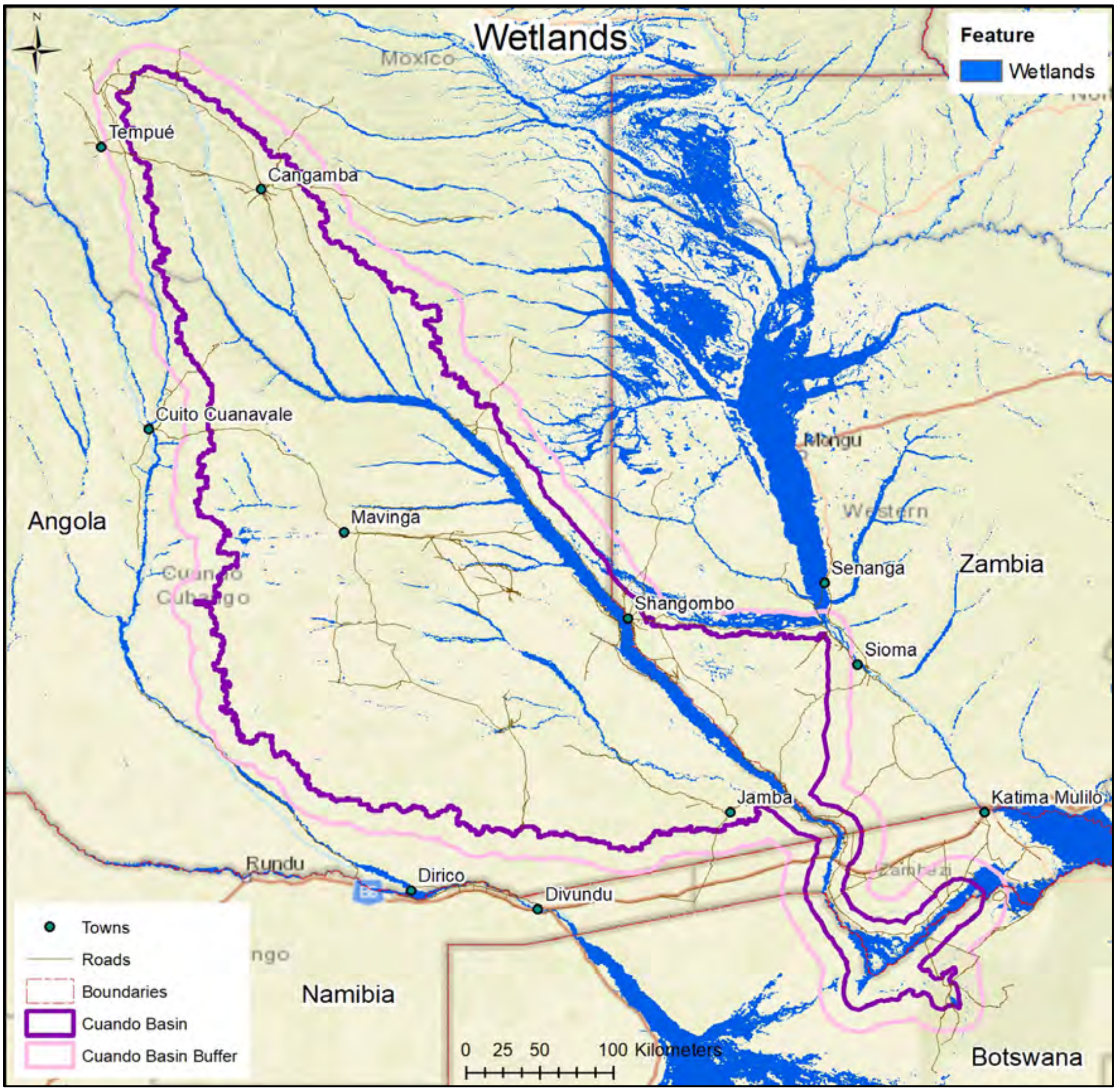


Figure 11: Wetland distribution from the global subtropical wetlands dataset (Gumbricht et al., 2017a, 2017b).

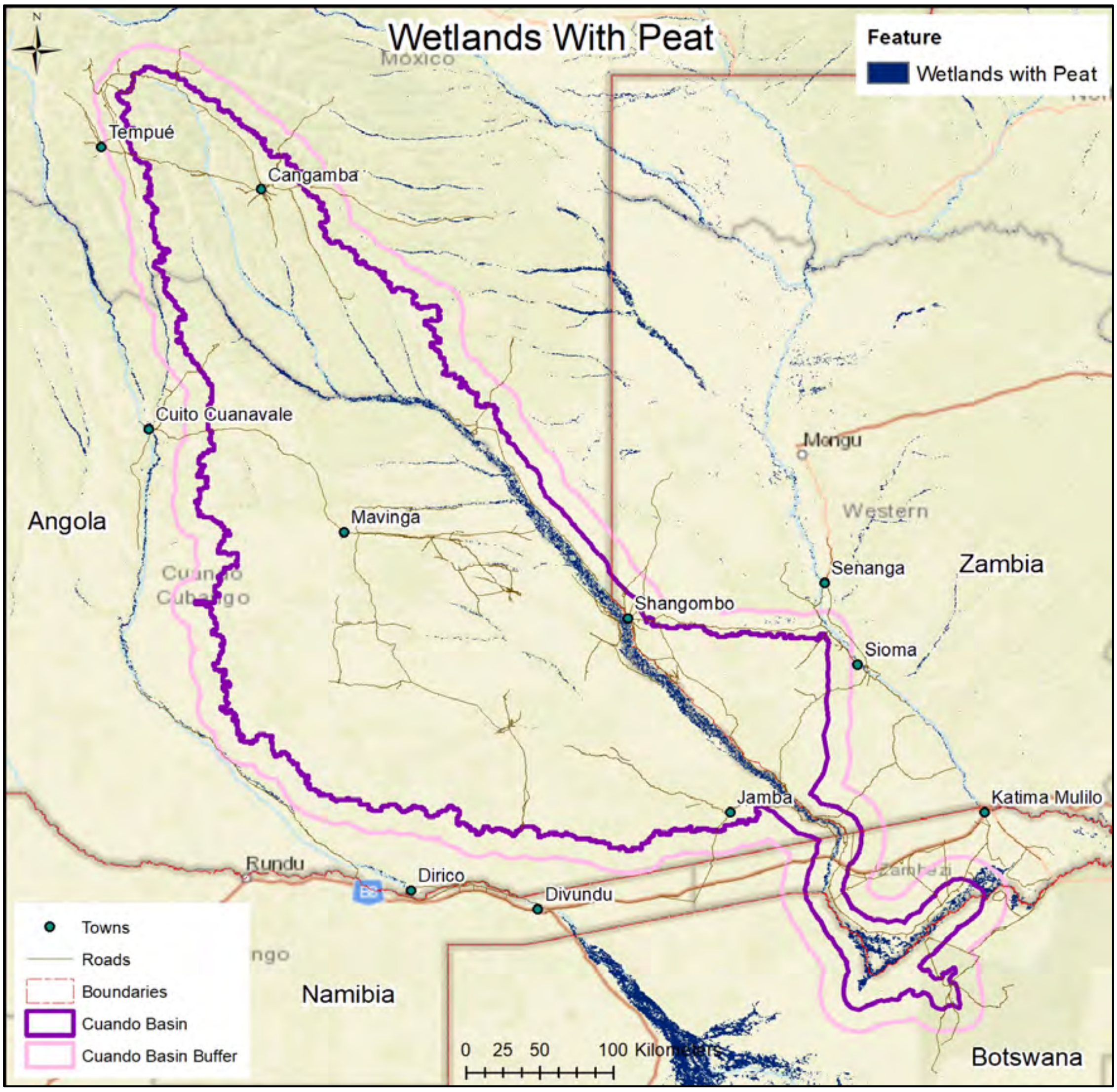


Figure 12: Peat distribution from the global subtropical wetlands dataset (Gumbricht et al., 2017a, 2017b).

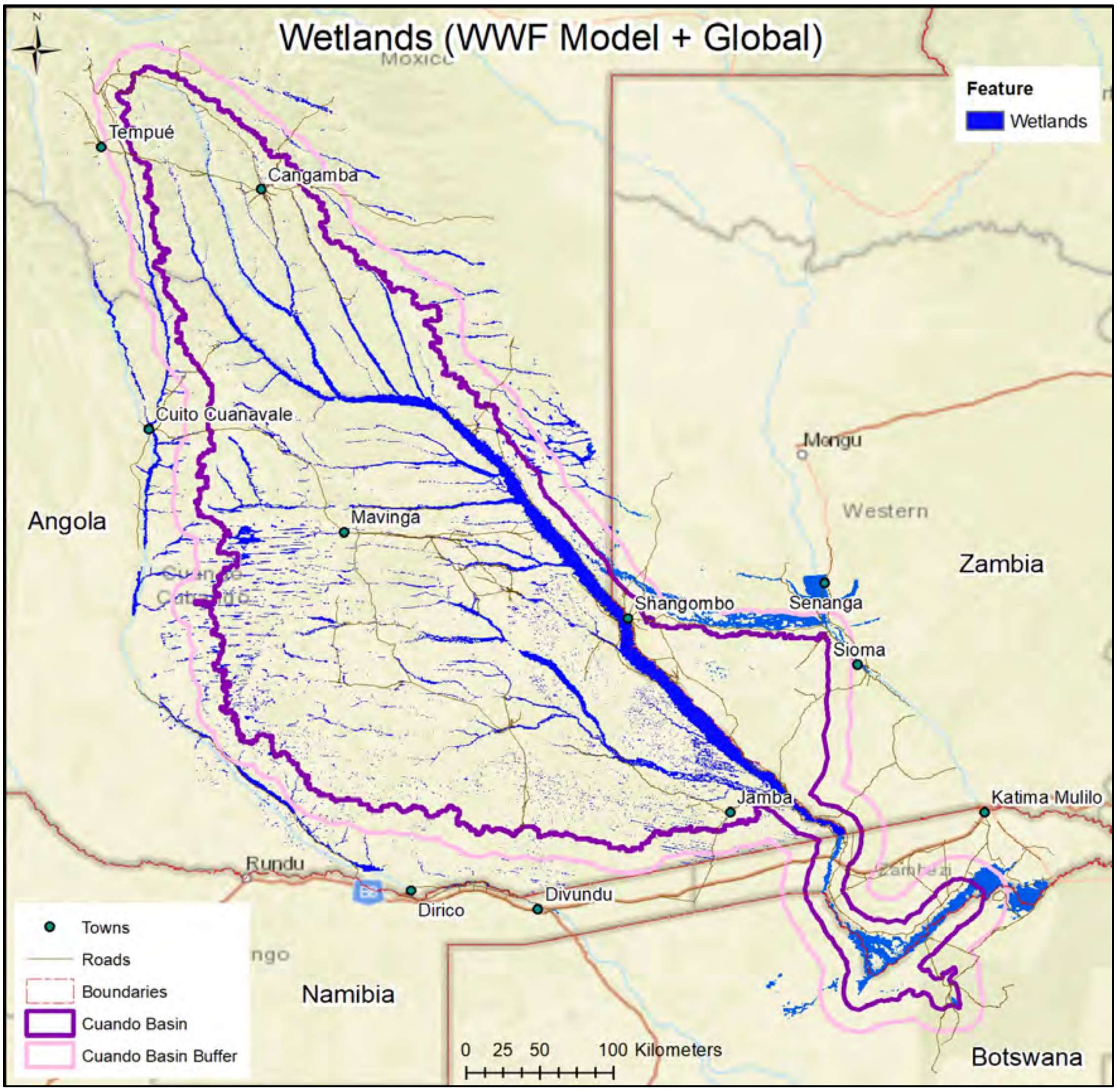


Figure 13: Wetlands from the WWF freshwater systems mapping for Angola (WWF, 2023) , supplemented by global data in the other countries (Gumbricht et al., 2017a, 2017b).

Description

The wetlands and peat lands of the Cuando River Basin play a significant role in regional hydrology and ecology (Figure 10, Figure 11, Figure 12 and Figure 13). Peat lands are crucial carbon-rich ecosystems and represent the largest terrestrial carbon store (Lourenco et al., 2022). Tropical peat lands play a crucial hydrological role by acting as significant water storage and regulation systems. These ecosystems, characterized by waterlogged conditions, absorb and store vast amounts of rainwater, contributing to flood prevention and mitigation. The peat layers act like natural sponges, releasing water during drier periods, thereby maintaining consistent water flow in rivers and sustaining downstream ecosystems. Additionally, tropical peat lands help improve water quality by filtering and purifying water as it percolates through the peat, influencing the overall hydrological balance in tropical regions. The conservation of these peat lands is essential for preserving their hydrological functions and the associated ecological and societal benefits. Further, the protection of peat lands and their associated carbon stores are likely to present a significant conservation funding priority for the region given the global climate emergency.

We used four datasets to comprehensively represent wetlands and peat lands:

- Mapping of the major reedbeds of the Cuando River, and the Linyati Swamp and Savuti Marsh form the CURB SEA (SAIEA, 2024). This dataset is extremely useful as it allows us to highlight the core reedbeds on the mainstem of the Cuando, as well as the major downstream sinks of Linyati and Savuti. Critically it allows us to separately and specifically set targets for these VECs. This is shown in Figure 10.
- Wetland distribution from the global subtropical wetlands dataset (Gumbricht et al., 2017a, 2017b). This mapping highlights a subset of the largest and most obvious (using remote sensing) wetlands. The benefit of using this data in additional to the detailed dataset is that this combination allows both for the comprehensive inclusion of wetlands. This is shown in Figure 11.
- Data on peatland occurrence from the global subtropical wetlands dataset (Gumbricht et al., 2017b, 2017a). This mapping allows us to directly the largest peat lands. This is shown in Figure 12. Note that this data is substantially corroborated by more detailed work undertaken in the Angolan Highlands that covers a portion of the planning domain (Lourenco et al., 2022; Lourenco and Woodborne, 2023).
- The most comprehensive data comes from the modelled wetlands from the WWF freshwater systems mapping for Angola (WWF, 2023). However, as this data only covers Angola, we had to supplement it with global wetland data in the other countries (Gumbricht et al., 2017a, 2017b). This mapping is shown in Figure 13.

Overview of mapping methods and incorporation into planning

The following are key points in the mapping methodology:

- The wetland and peat datasets represent a probability of peat occurrence in a pixel, or alternatively the presence of a wetland in that pixel.
- A sum of the total occurrence value for each pixel was calculated for each planning unit for each of the wetland or peat datasets. This gave better results than a mean value or a presence / absence value as it allowed both the extent and the strength of the peatland signal to be incorporated.
- Values for each wetland or peat dataset were then calculated using the following approach. Values were normalized to the range 0-100 using the formula 100*(n/n90) where n90 is the 90th percentile value. Values over 100 reclassified to 100.
- Targets for these features are examined in the section on Target Setting on page 10.

Link to Valued Ecosystem Components (VECs)

The wetland and peat features are fundamental to the functioning of the Cuando River Basin, and are perhaps the single most important set of features targeted by the SCP. Key links to the VECs are:

- **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** This supply is fundamental to the structure, functioning and value of the entire river basin. The wetlands (and especially peatlands) are at the core of this perennial water supply.
- **VEC 2 – The immense area of swamp or reedbeds**. The Cuando includes some of the largest expanses of reeds, papyrus and sedges in Africa. The reedbeds are hydrologically important, support important biodiversity, and include significant carbon storage in peat beds. These are directly included as a feature.

- **VEC 3 – Linyanti Swamps and Savuti area.** The Cuando feeds water, dissolved minerals and suspended solids into the Linyanti Swamps, the Savuti River and Savuti Marsh where the water disappears, and the minerals and sediments remain trapped to feed concentrations of plants and wildlife; which in turn support the livelihoods of local residents and a tourism industry that contributes much to the economy of northern Botswana and Namibia's Zambezi region. These areas are directly included as a feature.
- **VEC 4 – Western flanks of the Cuando.** The wetland areas are supportive (historically) of an abundance of wildlife as a result of supplies of surface water in the Cuando and its ephemeral tributaries.
- **VEC 5 – Wildlife corridors and ecological connectivity.** The wetlands are critical to the value of this landscape for wildlife.
- **VEC 6 - Cuando aquifers**. Wetlands support the recharge of groundwater.

Data providers

Data provided by the WWF, the CURB SEA or sourced from the Center for International Forestry Research (CIFOR).

Water Tower and Source Lakes

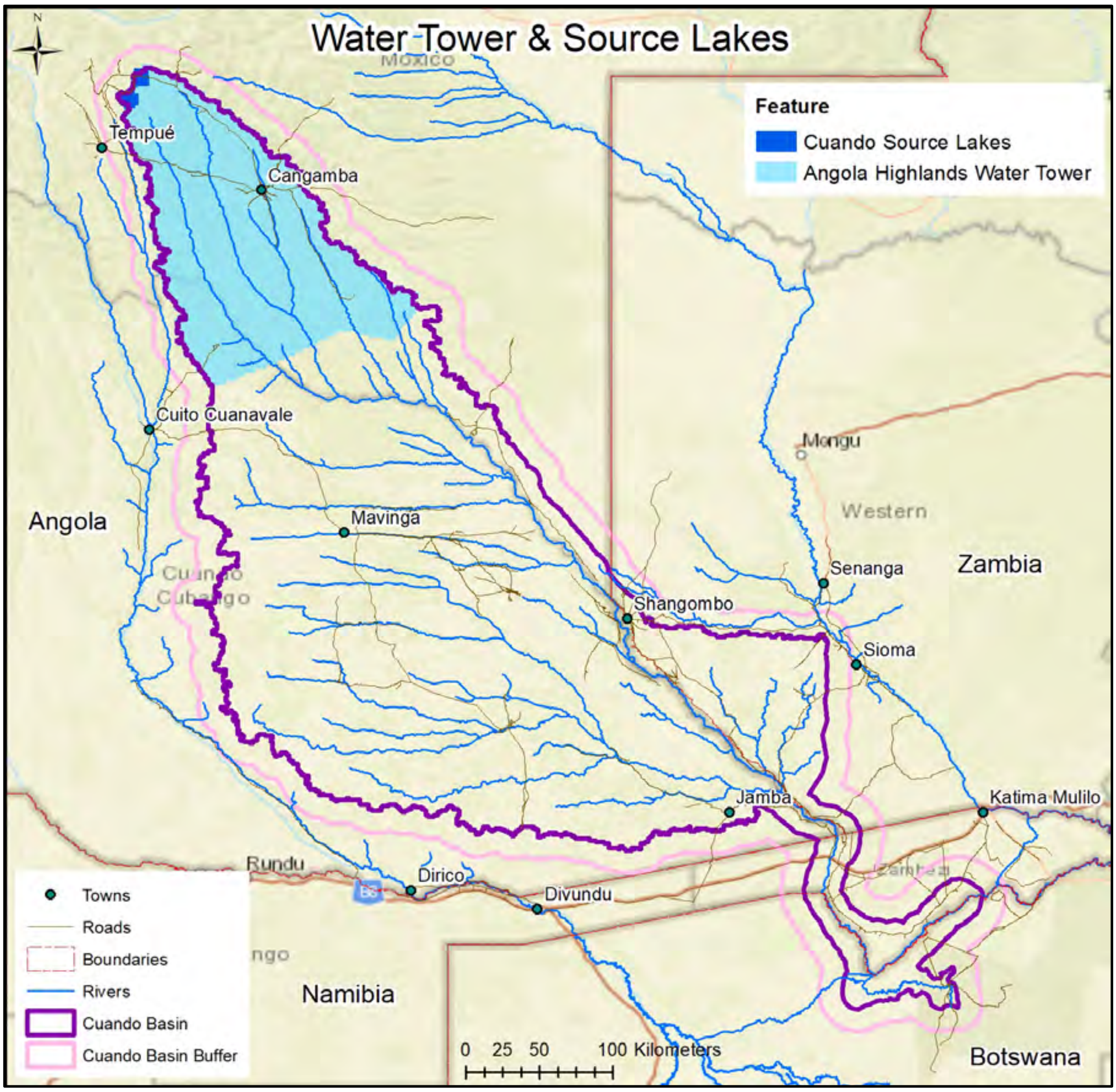


Figure 14: Map showing the portions of the Angola Highlands Water Tower (Lourenco and Woodborne, 2023) and source lakes with a 5km buffer that were included as features in the Systematic Conservation Plan.

Figure 15: The Cuando Source lake is more of a marshland, but for the purposes of the SCP is considered to be a "source lake". Imagery from Google Earth. Original location from Mauro Lourenco (Wild Bird Trust)

Figure 16: The Saliakembo Source lake is clearly defined. Imagery from Google Earth. Original location from Mauro Lourenco (Wild Bird Trust).

Description

The Angolan Highlands Water Tower (Lourenco and Woodborne, 2023) is a vital freshwater source and reservoir for the region, feeding a network of key rivers including the Zambezi, Okavango and Cuando. The area was mapped by Mauro Lourenco of the National Geographic Okavango Wilderness Project (NGOWP) run by the Wild Bird Trust. The landscape in general and the source lakes of the Angolan Water Tower are key contributors to the region's hydrological landscape (Figure 14). Situated in the elevated Angolan highlands, these lakes serve as the starting points for a number of rivers in the area (Figure 15 and Figure 16). Two source lakes or features are found in the Cuando basin: the Saliakembo Source Lake is clearly defined , while the Cuando "source lake" appears to be more of a marsh, and is not considered to be a source lake in the state of the basin report (Pallett et al., 2022). Confirmation of the value of the source lakes is required. In the current study it is assumed that they are important, but they may be over-rated as they may be relatively sparse in biodiversity value, and may not actually be sources of the rivers, but rather simple impoundments near the sources. Nevertheless, the broader areas of the Angola Highlands Water Tower, inclusive of the source lakes and the specific 5km buffer that were included as features in the Systematic Conservation Plan, are clearly of great importance to the hydrological functioning of the Cuando Basin (Lourenco and Woodborne, 2023). The areas are also identified as important in the SCP by the NatGeo / Wild Bird Trust for the Okavango Zambezi Water Tower (Wild Bird Trust, 2022; Wild Bird Trust National Geographic Okavango Wilderness Project, 2024).

Overview of mapping methods and incorporation into planning

<u>The following are key points in the mapping methodology:</u>

- Source lake point data were buffered by 5km. Any planning unit that intersected with this buffer was considered to be part of the source lakes feature. The source lake locations were confirmed by use of Google Earth Imagery.
- Data on the Angola Highlands Water Tower provide by Mauro Lourenco (Lourenco and Woodborne, 2023). The area was clipped to the Cuando Basin. Planning units that intersected with this feature were selected.
- Targets for these features are examined in the section on Target Setting on page 10.

Link to Valued Ecosystem Components (VECs)

The feature is directly linked to **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** The Water Tower is specifically included as a feature. The source lakes are critical to the perennial water supply of the basin. Water from the portions of the Water Tower in the Cuando Basin and the source lakes are directly supportive of **VEC 2 – The immense area of swamp or reedbeds** and **VEC 3 – Linyanti Swamps and Savuti area** further downstream.

Data providers

Data on the Angola Highlands Water Tower provided by Mauro Lourenco of the Wild Bird Trust (Lourenco and Woodborne, 2023). Source lakes locations from Mauro Lourenco were modified by Stephen Holness using Google Earth imagery.

Rivers and associated hydrological processes (discharge and floodplains)

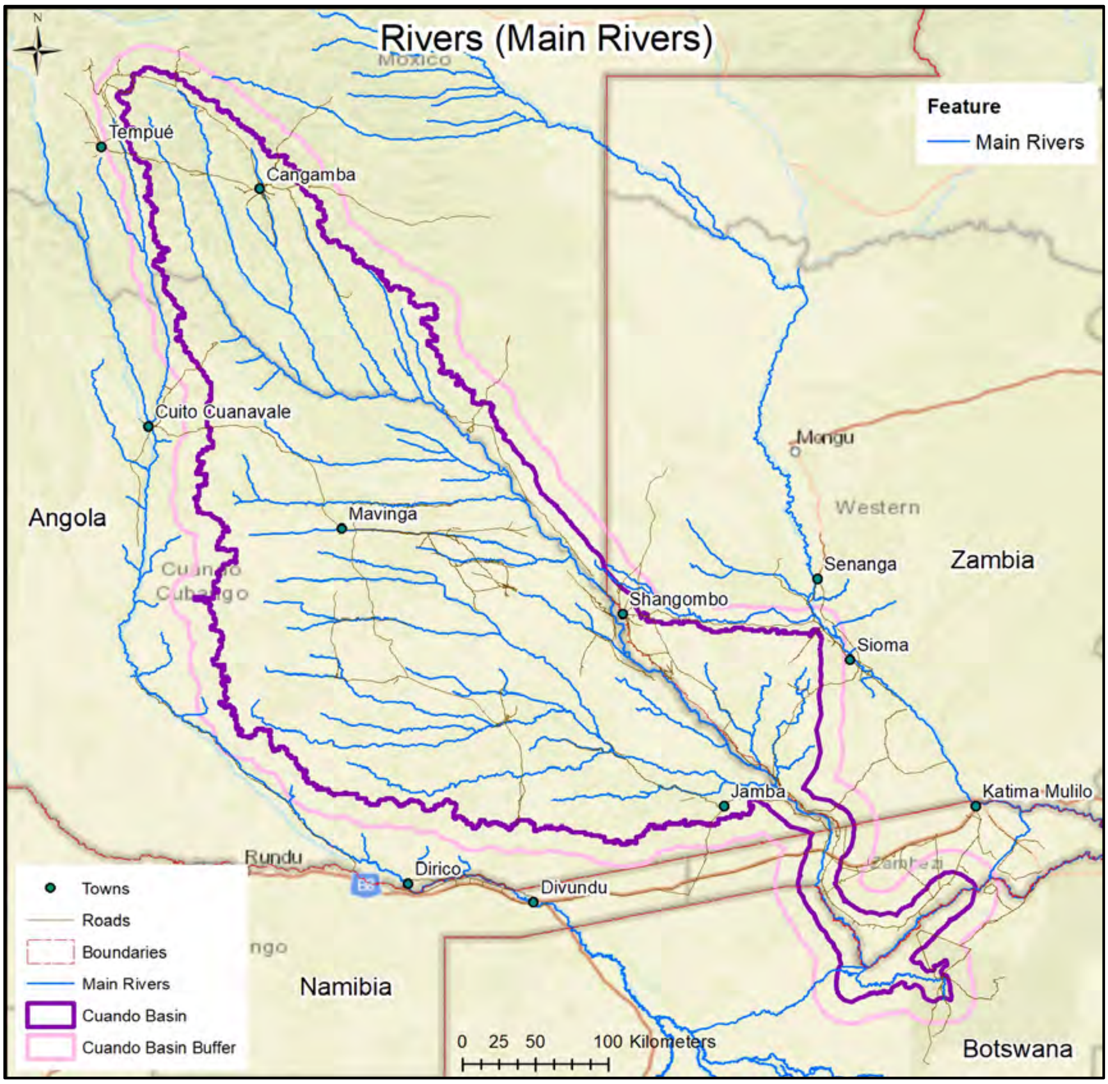


Figure 17: Map showing the main rivers feature which consists of all larger rivers in the planning domain. This river dataset is from the CURB SEA.

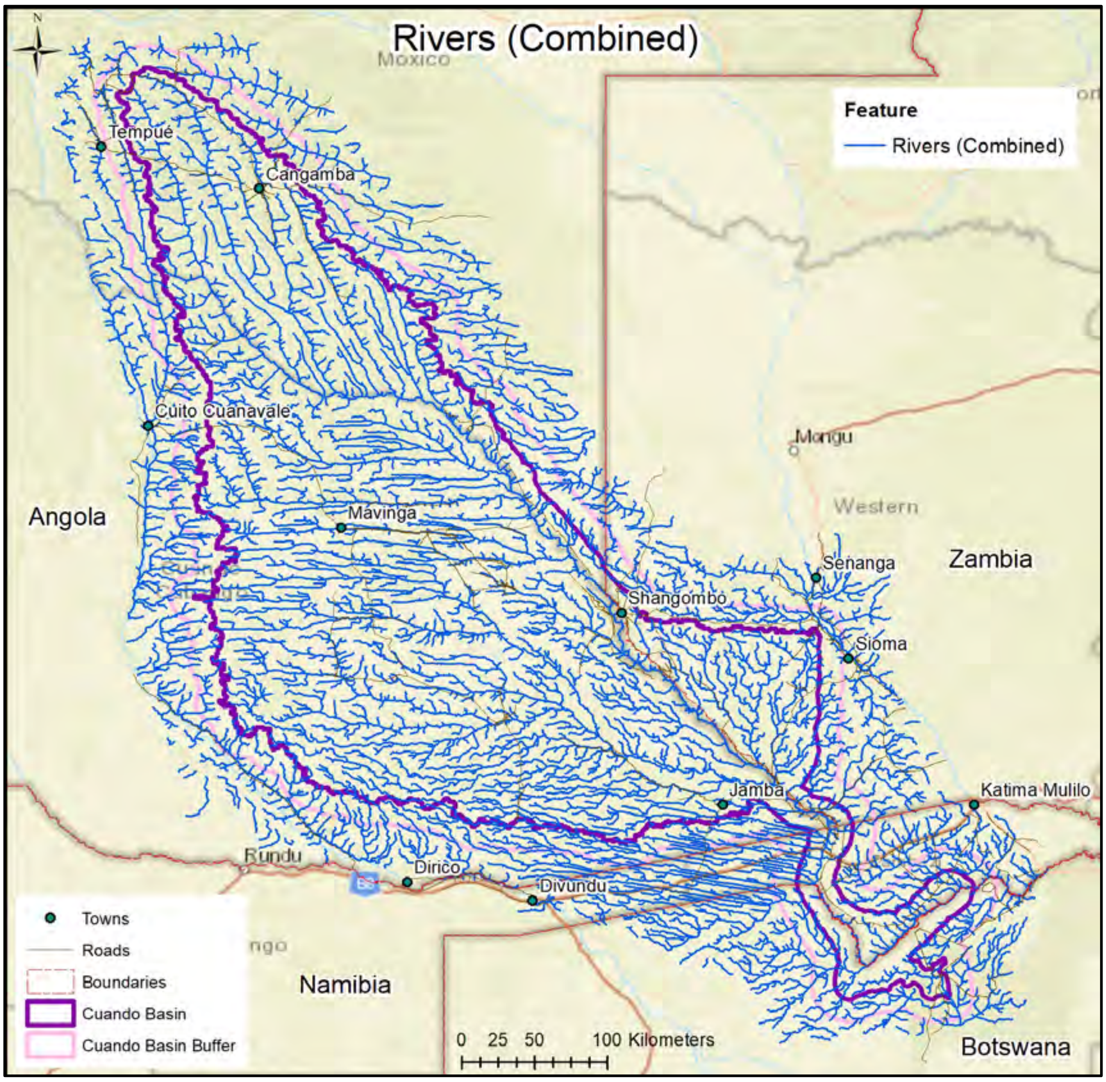


Figure 18: Map showing the rivers (combined) feature which consists of all rivers in the planning domain. This river dataset is from the World Wildlife Fund (WWF) HydroSHEDS[1] (RIV) - Africa river network (stream lines) dataset (Lehner et al., 2006). This includes small rivers and tributaries.

[1] Requested citation: HydroSHEDS: Lehner, B., Verdin, K., Jarvis, A. (2006): HydroSHEDS Technical Documentation. World Wildlife Fund US, Washington, DC. Available at http://hydrosheds.cr.usgs.gov.

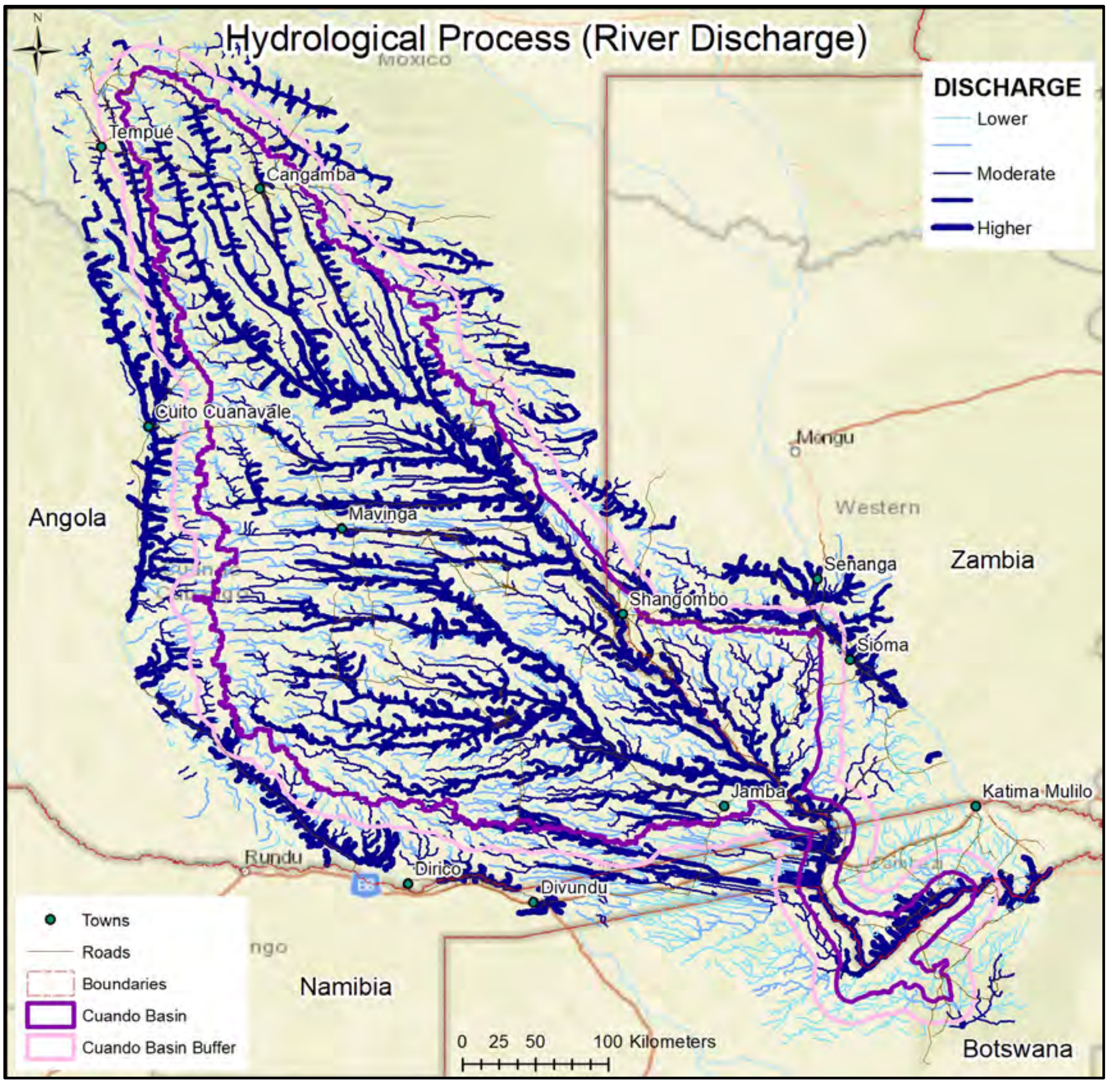


Figure 19: Map showing modelled river discharge categories. Data from World Wildlife Fund (WWF) HydroSHEDS (RIV) - Africa river network (stream lines) dataset (Lehner et al., 2006). Discharge categories calculated by Stephen Holness (see methods). Note that this assessment clearly over-emphasizes river discharge in the flat southern sandy flat catchment area where there is very little runoff and almost all the rivers and tributaries are strictly ephemeral (Mendelsohn, 2022; Mendelsohn and Martins, 2019).

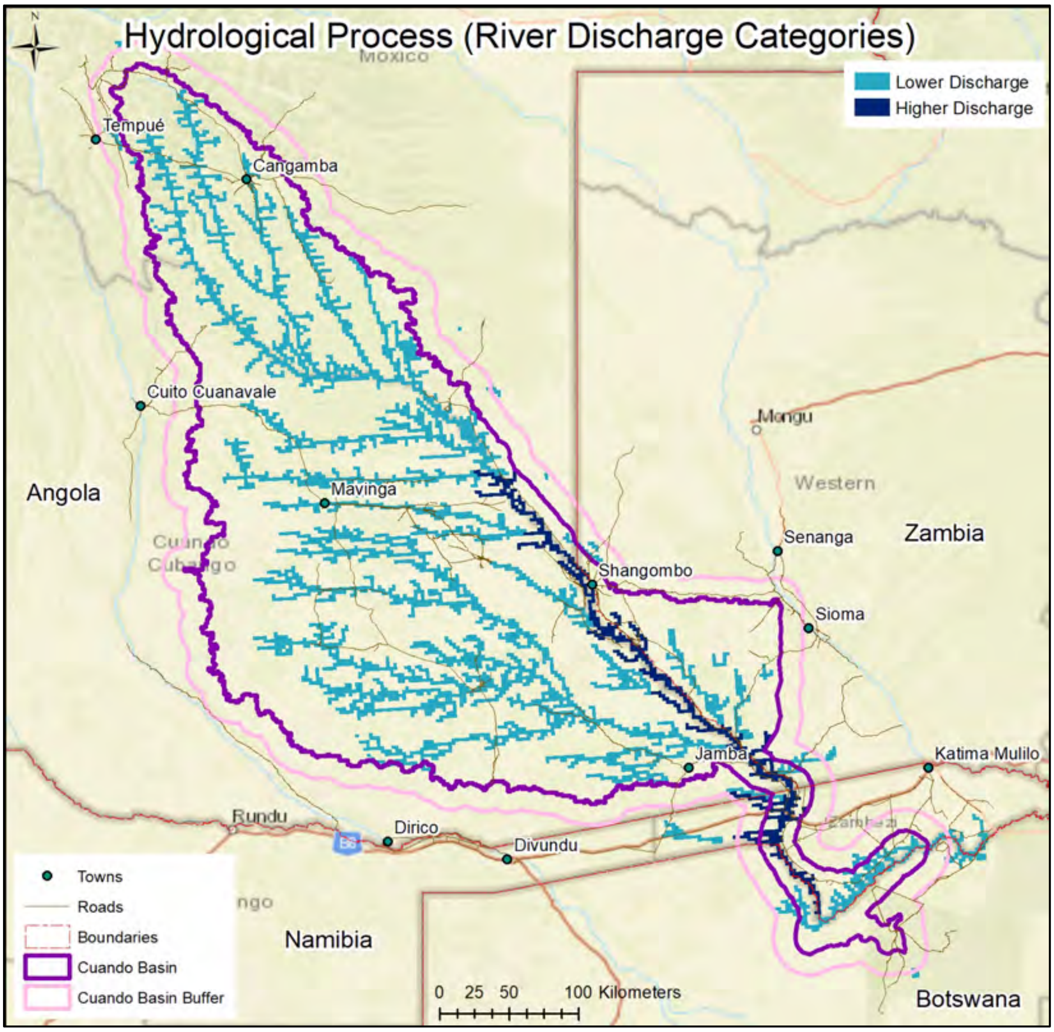


Figure 20: Map showing discharge of larger rivers. Data from World Wildlife Fund (WWF) HydroSHEDS (RIV) - Africa river network (stream lines) dataset (Lehner et al., 2006). Discharge categories calculated by Stephen Holness (see methods). Note that this assessment clearly over-emphasizes river discharge in the flat southern sandy flat catchment area where there is very little runoff and almost all the rivers and tributaries are strictly ephemeral (Mendelsohn, 2022; Mendelsohn and Martins, 2019).

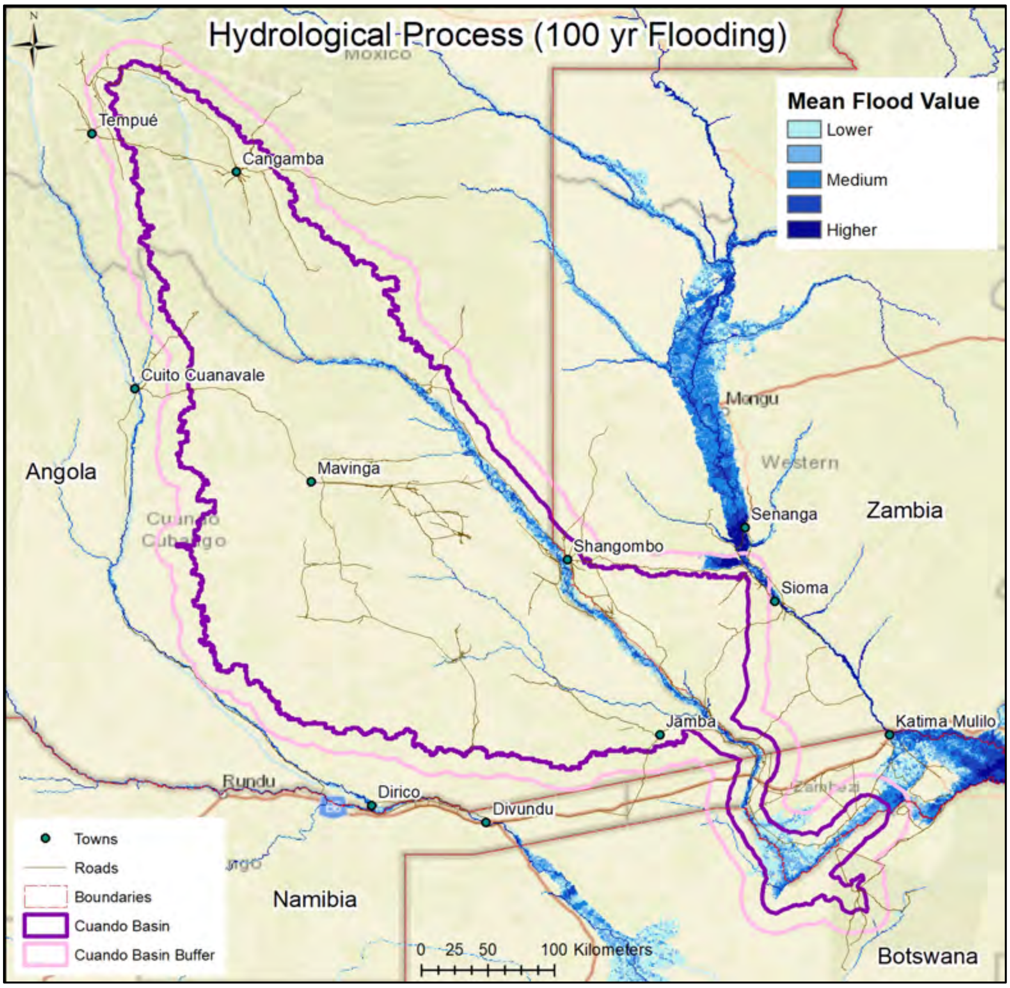


Figure 21: Map showing flood areas of 100 year flood events. Data from the European Commission Flood hazard map of the World - 100-year return period (F. Dottori et al., 2016; F Dottori et al., 2016; Trigg et al., 2016).

Description

The rivers (major and minor), river discharge and floodplains of the Cuando River Basin are pivotal components of regional hydrology and ecology (Figure 17 to Figure 21). Flowing from the Angolan Highlands Water Tower, the Cuando River and its tributaries serve as a vital hydrological lifeline for the basin, sustaining diverse landscapes and fostering rich biodiversity downstream. They are crucial for supporting areas in Zambia, Namibia, and Botswana. Beyond Angola, their impact shapes water resources crucial for downstream nations, functioning as natural regulators ensuring consistent water supply for agriculture, wildlife habitats, and local communities. The significance of the Angolan Water Tower extends to regional water security, with these rivers contributing to the vitality of wetlands, floodplains, and delta ecosystems downstream, directly impacting the livelihoods of many. Readers are referred to the detailed work available on the catchments of South East Angola for more depth of analysis which is beyond the scope of the current report (Mendelsohn, 2022; Mendelsohn and Martins, 2019). Some key issues are highlighted, for example that the datasets used by the current assessment clearly over-estimate river discharge in the flat southern sandy flat catchment area where there is very little runoff and almost all the rivers and tributaries are strictly ephemeral.

Based on the importance of this river system we have attempted to include these features comprehensively by adopting the following approach:

- **A feature for major rivers**. The main rivers feature consists of all larger rivers in the planning domain (Figure 17). This river dataset is from the CURB SEA.
- **A feature for all river systems.** This feature includes the larger as well as many smaller rivers in the planning domain. This river dataset is from the World Wildlife Fund (WWF) HydroSHEDS2 (RIV) - Africa river network (stream lines) dataset (Lehner et al., 2006). This dataset includes some improved mapping of smaller systems and tributaries, and hence we have used it to ensure comprehensiveness of river and riparian habitat inclusion. For this feature, a single target is used for all river features (Figure 18). This feature includes both the larger perennial rivers and the rivers in the flat southern sandy flat catchment area where there is very little runoff and almost all the rivers and tributaries are strictly ephemeral.
- **River discharge:** This dataset shown in Figure 19, maps modelled river discharge categories. The Data is from the World Wildlife Fund (WWF) HydroSHEDS (RIV) - Africa river network (stream lines) dataset (Lehner et al., 2006). We used this layer to ensure that the prioritised areas included the river reaches containing the bulk of river flow in the Cuando Basin. This feature includes all rivers to ensure that even minor contributions are reflected in the prioritisation. Note that the datasets used by the current assessment clearly over-estimate river discharge in the flat southern sandy flat catchment area where there is very little runoff and almost all the rivers and tributaries are strictly ephemeral.
- **River discharge (high discharge categories):** This dataset shown in Figure 20, maps the higher modelled river discharge categories. The Data is from the World Wildlife Fund (WWF) HydroSHEDS (RIV) - Africa river network (stream lines) dataset (Lehner et al., 2006). We used this layer to ensure that the prioritised areas included the largest and most important reaches containing the bulk of river flow in the Cuando Basin. Note that the datasets used by the current assessment clearly over-estimate river discharge in the flat southern sandy flat catchment area where there is very little runoff and almost all the rivers and tributaries are strictly ephemeral.
- **Flood Areas (hydrological processes):** Floodplains are a key component of the hydrological functioning of the river system (Figure 21). We used the modelled flood areas for 100 year flood events as a proxy for floodplains (F. Dottori et al., 2016; F Dottori et al., 2016; Trigg et al., 2016). We aimed to focus the SCP selection on major floodplains, which are most likely to be critical for ecological processes in the planning domain. They also provide a key landscape planning backbone to help MARXAN focus selection on key features linking the landscape.

Overview of mapping methods and incorporation into planning

<u>The following are key points in the mapping methodology:</u>

- Planning units which overlapped the various categories of river lines were coded with river codes for the major rivers, the combined rivers, river discharge (raw values and categories) and the overlap with areas within 100-year modelled floodplains.
    - Planning units with major rivers were coded with 1 if they overlapped the major river dataset.
    - Planning units with all rivers were coded with 1 if they overlapped the combined river dataset.
    - The maximum discharge value of all rivers in a planning unit was coded to the planning unit. Targets were set against the total aggregated discharge for all planning units.

[2] Requested citation: HydroSHEDS: Lehner, B., Verdin, K., Jarvis, A. (2006): HydroSHEDS Technical Documentation. World Wildlife Fund US, Washington, DC. Available at http://hydrosheds.cr.usgs.gov.

   - Discharge categories for rivers were split into 5 quantiles, and scored with values of 1, 2, 5, 8 and 10 with increasing discharge. The two highest categories were included in the SCP, with the highest value coded into the planning unit. Targets were set against the total aggregated discharge score for all planning units.
- Targets for these features are examined in the section on Target Setting on page 10.

Link to Valued Ecosystem Components (VECs)

These features are directly linked to **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** The rivers are also directly supportive of **VEC 2 – The immense area of swamp or reedbeds** and **VEC 3 – Linyanti Swamps and Savuti area**. **VEC 2** and **VEC 3** are also tightly linked to the mapped floodplain areas.

Data providers

Data provided by the World Wildlife Fund (WWF) and the European Commission.

Groundwater

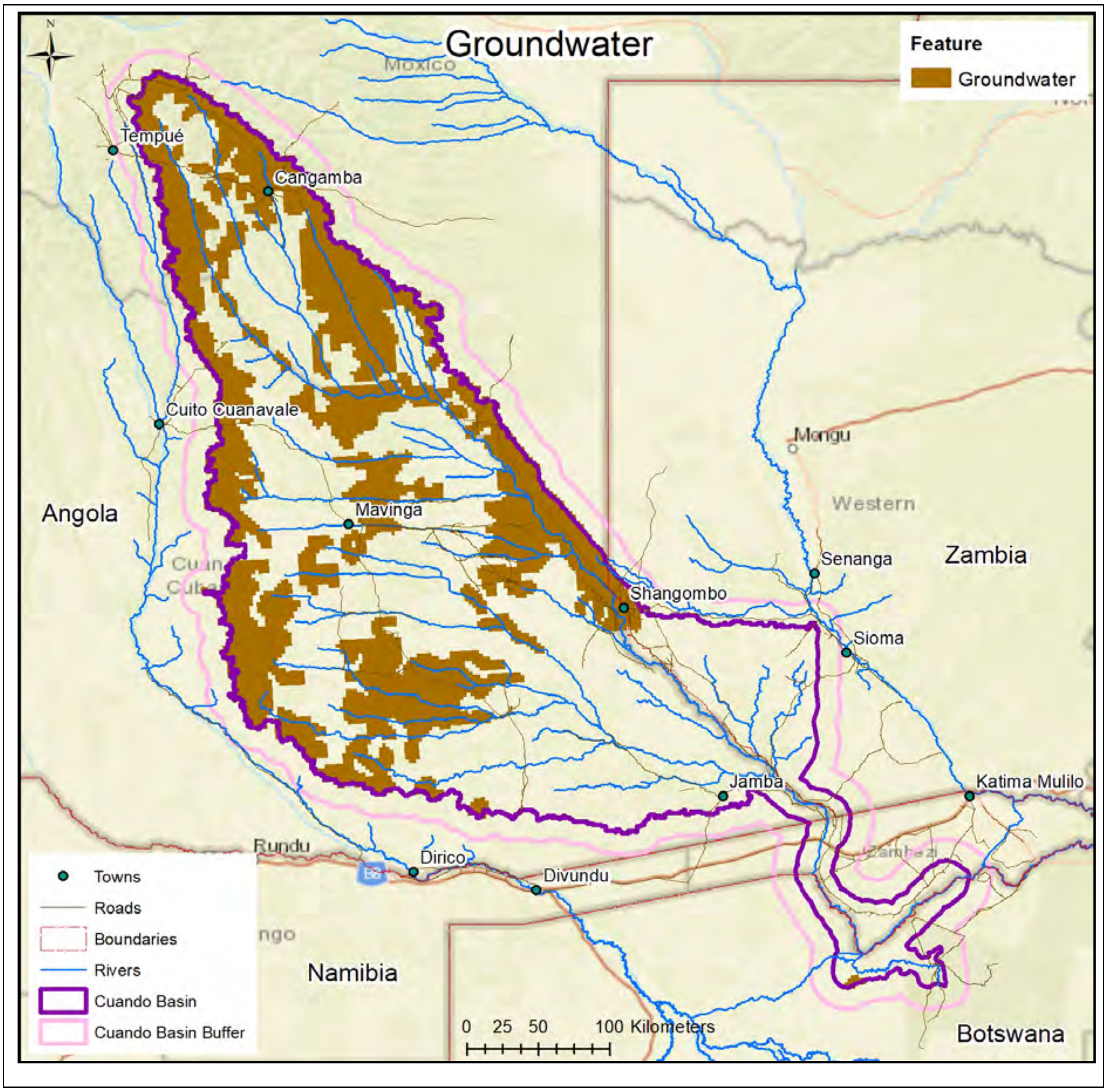


Figure 22: High value groundwater areas mapped by the CURB SEA (SAIEA, 2024) from map in "Hotspots for Groundwater Development in Kwando River Basin and Wildlife Dispersal Area" (Ebrahim and Magombeyi, 2022).

Description

Known groundwater resources in the Cuando Basin are generally rather poor, but are still an important resource for rural people who live some distance from available surface water (SAIEA, 2024). Groundwater is therefore a valued resource, especially the shallow waters. High value areas identified by the project "Hotspots for Groundwater Development in Kwando River Basin and Wildlife Dispersal Area (Final Report). Sustainable Groundwater Development and Management for Humans, Wildlife, and Economic Growth in the Kavango Zambezi Transfrontier Conservation Area" (Ebrahim and Magombeyi, 2022) were included.

Overview of mapping methods and layer incorporation

Planning units overlapping the "good" category in the high value groundwater areas mapped by the CURB SEA (SAIEA, 2024) from the map in "Hotspots for Groundwater Development in Kwando River Basin and Wildlife Dispersal Area" (Ebrahim and Magombeyi, 2022) were flagged as the "groundwater" feature.

Link to Valued Ecosystem Components (VECs)

This feature is directly linked to **VEC 6 - Cuando aquifers**.

Data providers

Data provided by the CURB SEA (SAIEA, 2024) based on a map in Hotspots for Groundwater Development in Kwando River Basin and Wildlife Dispersal Area (Final Report). Sustainable Groundwater Development and Management for Humans, Wildlife, and Economic Growth in the Kavango Zambezi Transfrontier Conservation Area" (Ebrahim and Magombeyi, 2022).

Wildlife Concentrations and Dispersal Areas

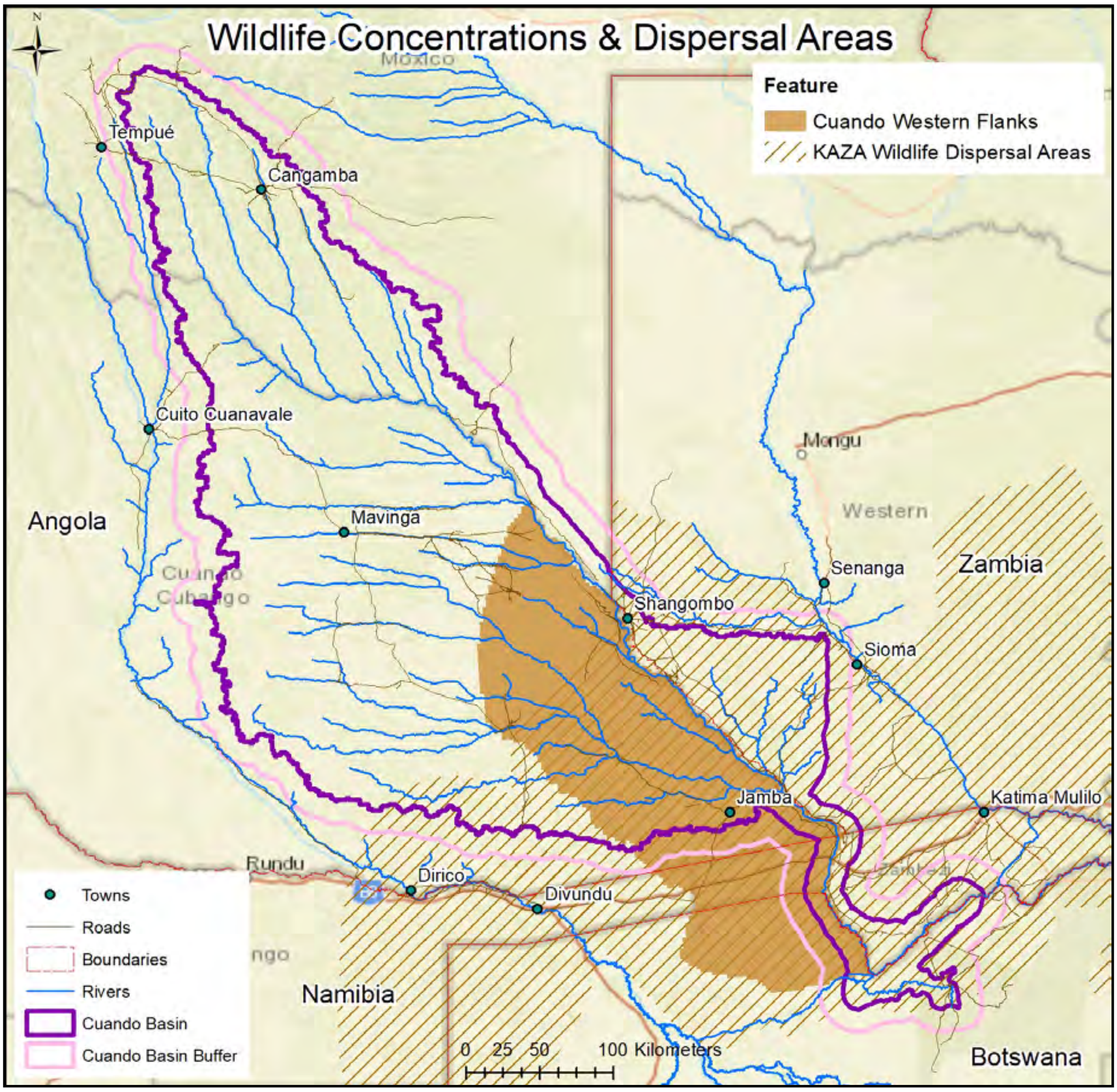


Figure 23: The Cuando Basin SEA highlighted the Cuando Western Flanks as a current and especially future key area for wildlife populations (SAIEA, 2024). Previously, fairly extensive wildlife dispersal areas have been identified in the KAZA TFCA. Both of these features have been included in the SCP.

Description

The Cuando Basin SEA highlighted the Cuando Western Flanks as a current and especially future key area for wildlife populations, and designated then as Valued Ecosystem Component (VEC) 4. Areas immediately west of the Cuando River and its swamps once supported an abundance of wildlife as a result of supplies of surface water in the Cuando and its ephemeral tributaries and the area's diverse habitats and relatively fertile soils. Wildlife numbers are likely to recover if the area is managed for conservation. The density and diversity of life is highest close to the main Cuando and its ephemeral tributaries (SAIEA, 2024).

Extensive wildlife dispersal areas have been identified in the KAZA TFCA ("Kavango Zambezi - Peace Parks Foundation," 2018). These areas offer critical ecological and, in particular, wildlife movement linkages between protected areas across the landscape. They include the Khaudum-Ngamiland and especially Kwando. The former WDA extends a limited distance from Namibia into the south western portion of the Cuando Basin in Angola. More importantly, the Kwando WDA extends over extensive portions of the south and east of the Cuando River basin. Unlike other WDAs within KAZA, the Kwando lacks fencing along its borders, encompassing Angola's Luengue-Luiana National Park, Zambia's Sioma-Ngwezi National Park, and Namibia's Mudumu and Bwabwata National Parks alongside their associated conservancies and game management areas. This absence of fencing facilitates unrestricted wildlife movement, particularly for large mammals like elephants. Notably, elephant populations from Chobe National Park in Botswana can traverse freely through the network of Namibian conservancies and national parks, following the Kwando River into both Luengue-Luiana National Park in Angola and Sioma-Ngwezi National Park in Zambia.

Overview of mapping methods and layer incorporation

- The Cuando Western Flanks was designated and mapped as Valued Ecosystem Component (VEC) 4 in the current Cuando Basin SEA (SAIEA, 2024). We have used the mapping from the project. Boundaries of the KAZA WDAs provided by WWF-Namibia.
- Targets for these features are examined in the section on Target Setting on page 10.

Link to Valued Ecosystem Components (VECs)

These features are directly linked two VECs:

- **VEC 4 – Western flanks of the Cuando**. The Cuando Western Flanks feature directly maps this VEC. In addition, the broader Kwando WDA is directly linked to and supportive of wildlife presence and movement in the VEC.
- **VEC 5 – Wildlife corridors and ecological connectivity.** Both features directly support wildlife corridors and connectively across the southern and central portions of the Cuando River basin.

Data providers

Data provided by SAIEA and WWF-Namibia.

Priority Areas from Other Analyses

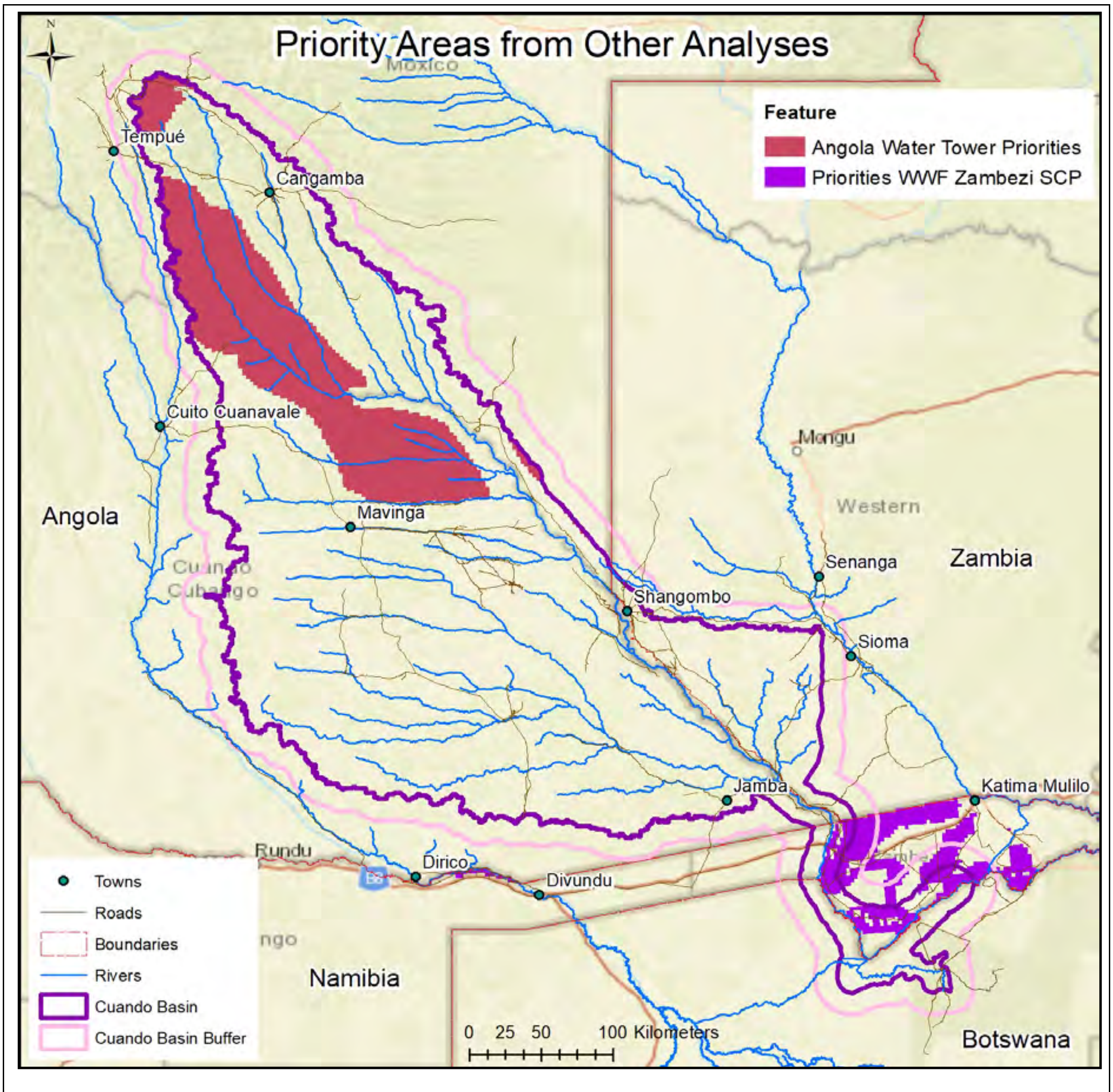


Figure 24: A key issue within any new Systemic Conservation Plan is ensuring that the outputs are aligned (as far as is appropriate) with existing priorities identified by earlier planning processes. Two recently completed projects exist for the area: a prioritisation for the Zambezi and Kavango East areas of Namibia undertaken by WWF (WWF Namibia, 2022) and a prioritisation for the Okavango Zambezi Water Tower undertaken by the Wild Bird Trust (Wild Bird Trust National Geographic Okavango Wilderness Project, 2024). In addition, significant work has been undertaken for the region by TNC on terrestrial animal populations and WWF on aquatic species (WWF, 2023). Although spatial priorities for the last two projects have not been integrated / finalised yet, underlying data from these projects has been included to ensure alignment.

Description

Systemic Conservation Plan needs to align as far as possible with existing conservation initiatives in any planning domain. This ensures that implementation efforts are aligned, supports consistent conservation and use decision making, and avoids confusing stakeholders. Two recently completed projects have identified priorities in the Cuando River Basin. First, a prioritisation for the Zambezi and Kavango East areas of Namibia was undertaken by WWF (WWF Namibia, 2022). This analysis focussed on critical wildlife corridors linking Namibia to its neighbouring TFCA countries, Angola, Botswana, Zambia and Zimbabwe; and key areas for integrated conservation actions to promote a more sustainable, inclusive and coordinated development vision. The analysis incorporated existing analyses and identification of wildlife corridors (Ministry of Environment, Forestry and Tourism, 2021; WWF, 2020), as well a land use planning for the area (Ministry of Lands and Resettlement, 2015a, 2015b). The second project was recently undertaken for the Okavango Zambezi Water Tower (which extends beyond the Cuando River Basin) by the Wild Bird Trust (Wild Bird Trust National Geographic Okavango Wilderness Project, 2024). This project focussed on areas of high biodiversity and landscape function value which could guide conservation actions (both for wilderness areas and for more community managed landscapes). The project identified focus areas for potential conservation actions. Note that the identified areas are still subject to consultation processes, but nevertheless these do represent overall high value spatial priorities in the Water Tower. Further, this analysis used additional high-quality datasets (e.g. newly gathered species occurrence records), which are not available for the entire basin. Hence, specific areas that came out of this analysis are based on a rich set of spatial data.

In addition, significant work has been undertaken for the region by TNC on terrestrial animal populations and WWF on aquatic species (Verissimo, 2023). Although spatial priorities for the last two projects have not been integrated / finalised yet, underlying data from these projects has been included to ensure alignment. For this, see the Species Occurrence Data (from page 45) for details.

Overview of mapping methods and layer incorporation

Priority focus areas from the Zambezi and Kavango East areas of Namibia undertaken by WWF (WWF Namibia, 2022) and the Okavango Zambezi Water Tower (Wild Bird Trust National Geographic Okavango Wilderness Project, 2024) were included as features.

- Targets for these features are examined in the Target Setting section on page 10.

Link to Valued Ecosystem Components (VECs)

These features are strongly linked to three VECs:

- **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** The priorities from the Okavango Zambezi Water Tower reflect detailed planning for the Angolan Highlands Water Tower, and incorporate a range of key hydrological features such as wetlands, detailed mapping of peatlands and sacred/source lakes.
- **VEC 3 – Linyanti Swamps and Savuti area.** The priorities from the Zambezi and Kavango East areas of Namibia undertaken by WWF reflect detailed land use and conservation focussed planning undertaken around the Linyati Swamps.
- **VEC 5 – Wildlife corridors and ecological connectivity.** Both features directly support wildlife corridors and connectively across the northern Angolan and southern (Namibia / Botswana /Angola) portions of the planning domain.

Data providers

Data provided by WWF Namibia and Wild Bird Trust.

Species Distribution Data

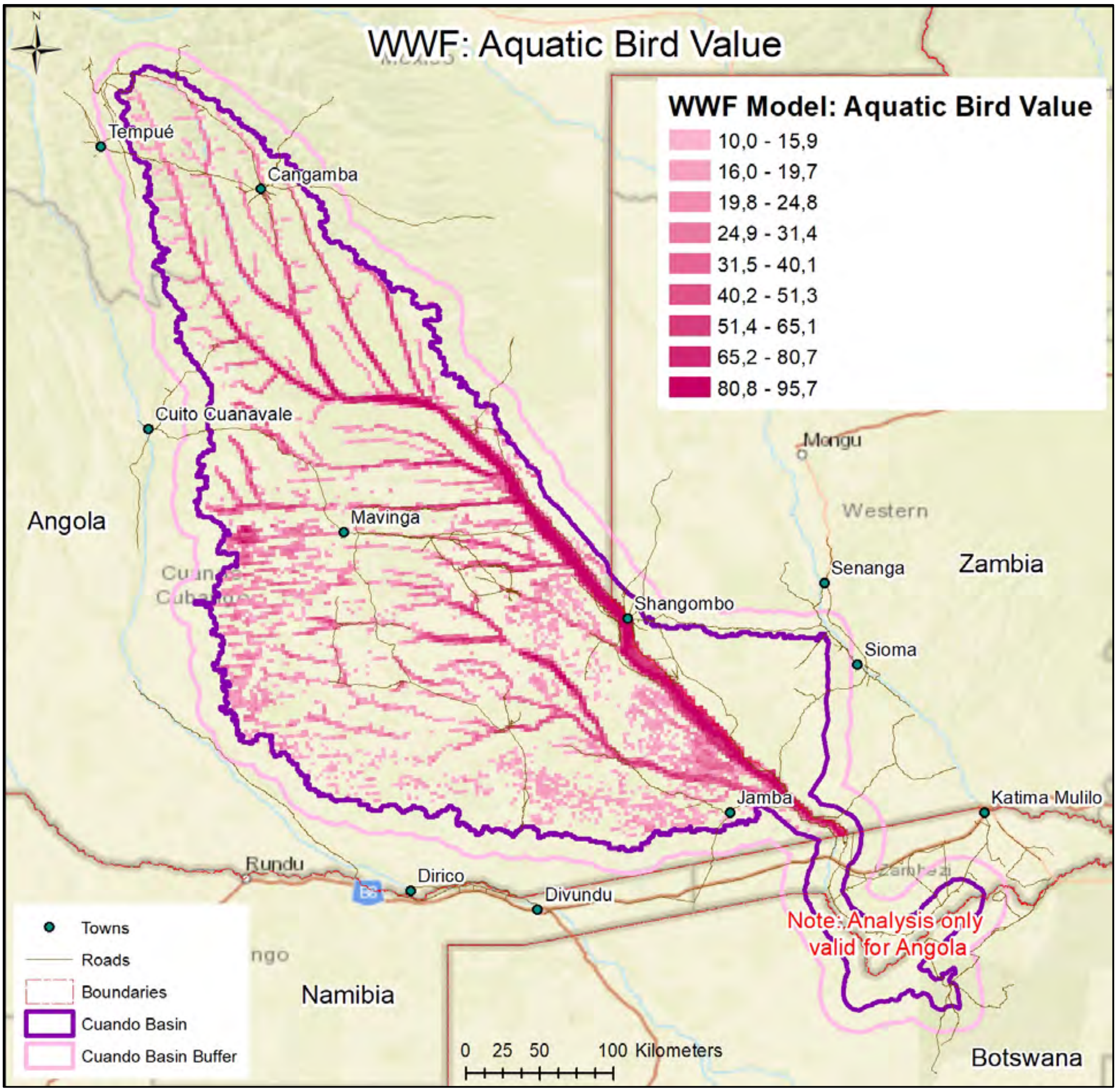


Figure 25: An analysis of combined landscape value for selected aquatic (or water associated) bird species was undertaken for WWF's SE Angola Freshwater Ecosystems Mapping Initiative (WWF, 2023). Values were included into the Cuando Basin SCP. Note that the lowest values were not included in the analysis.

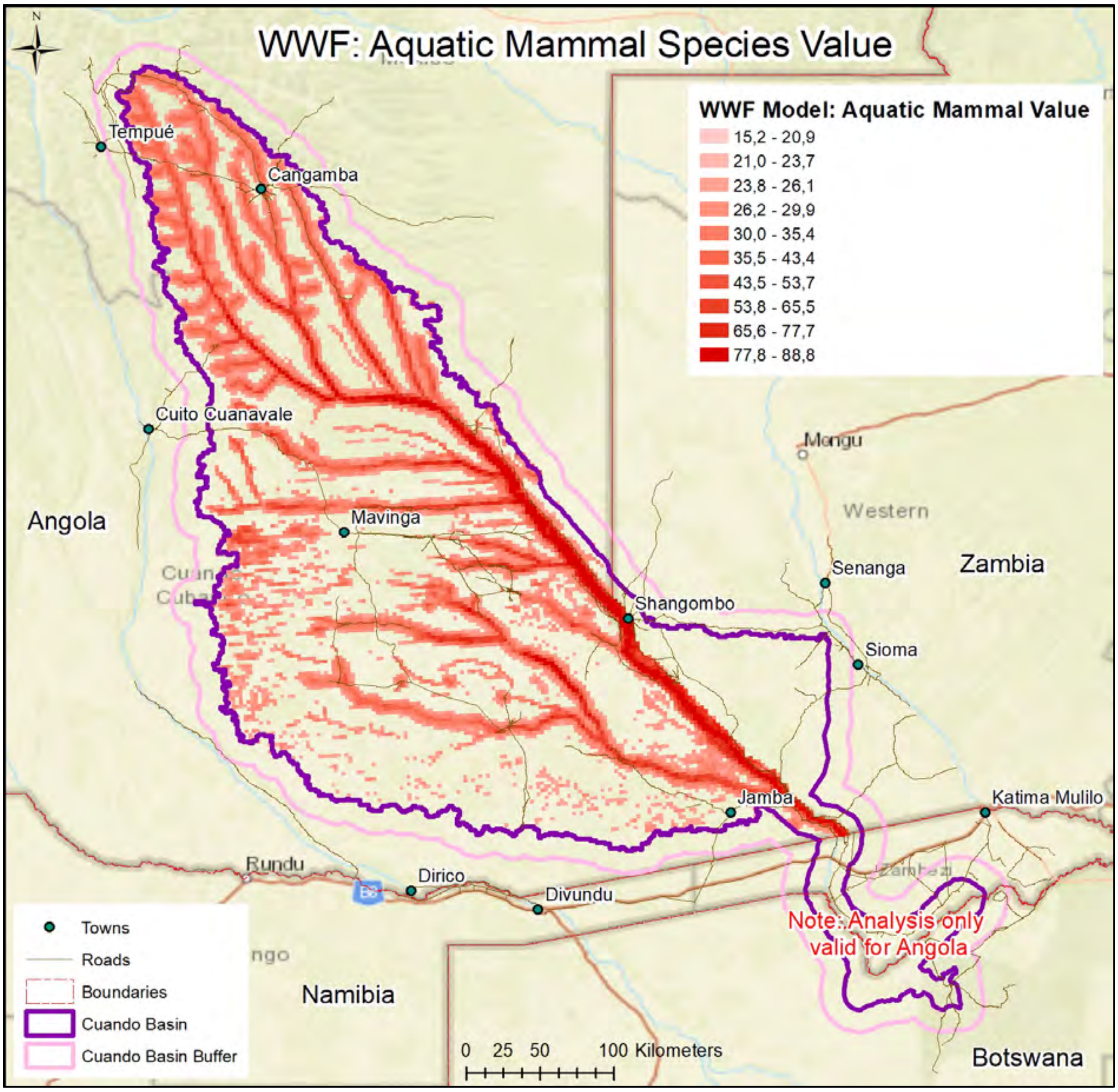


Figure 26: An analysis of combined landscape value for selected water associated mammal species was undertaken for WWF's SE Angola Freshwater Ecosystems Mapping Initiative (WWF, 2023). Values were included into the Cuando Basin SCP. Note that the lowest values were not included in the analysis.

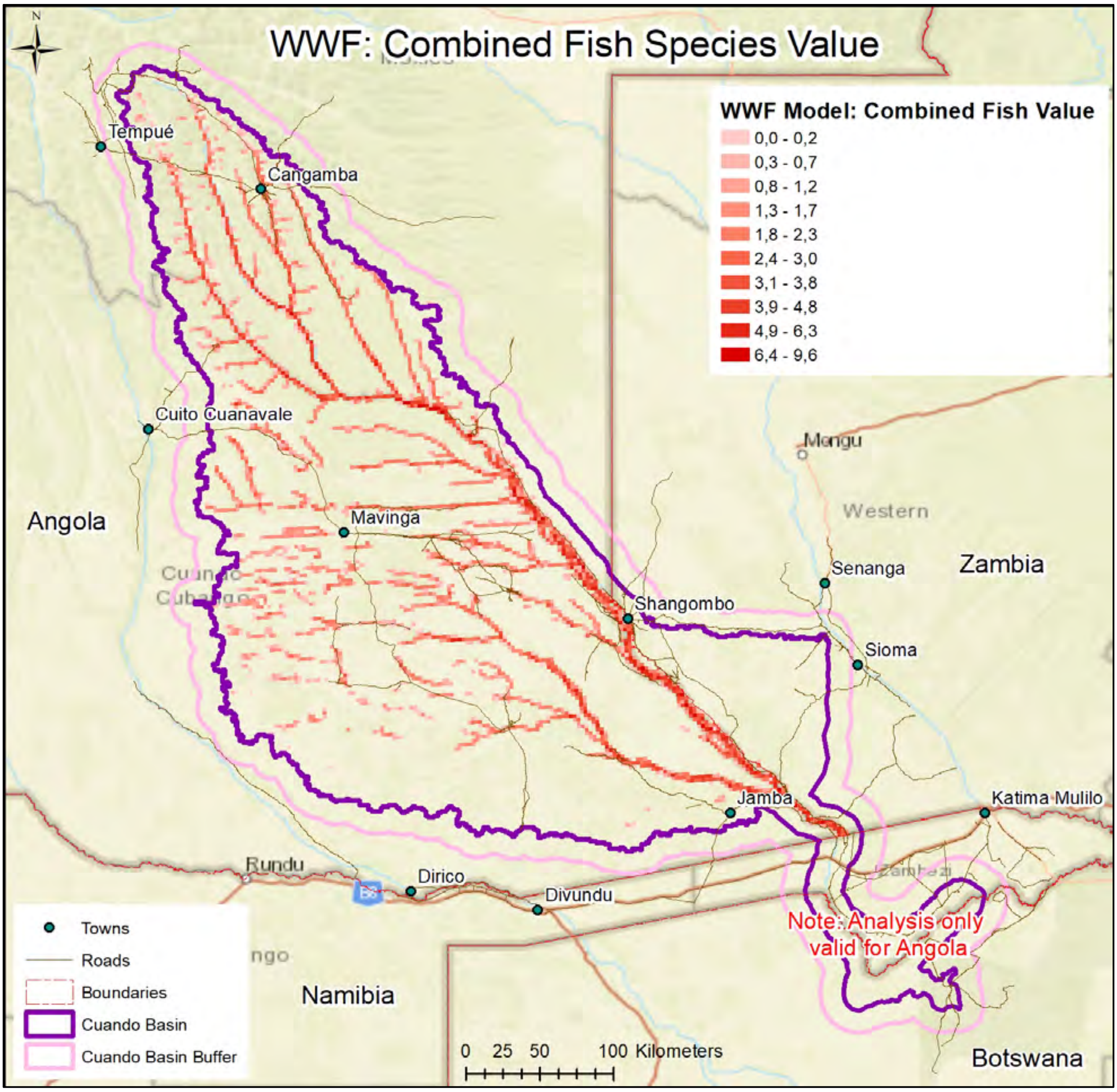


Figure 27: An analysis of combined landscape value for selected fish species was undertaken for WWFs SE Angola Freshwater Ecosystems Mapping Initiative (WWF, 2023). Values were included into the Cuando Basin SCP.

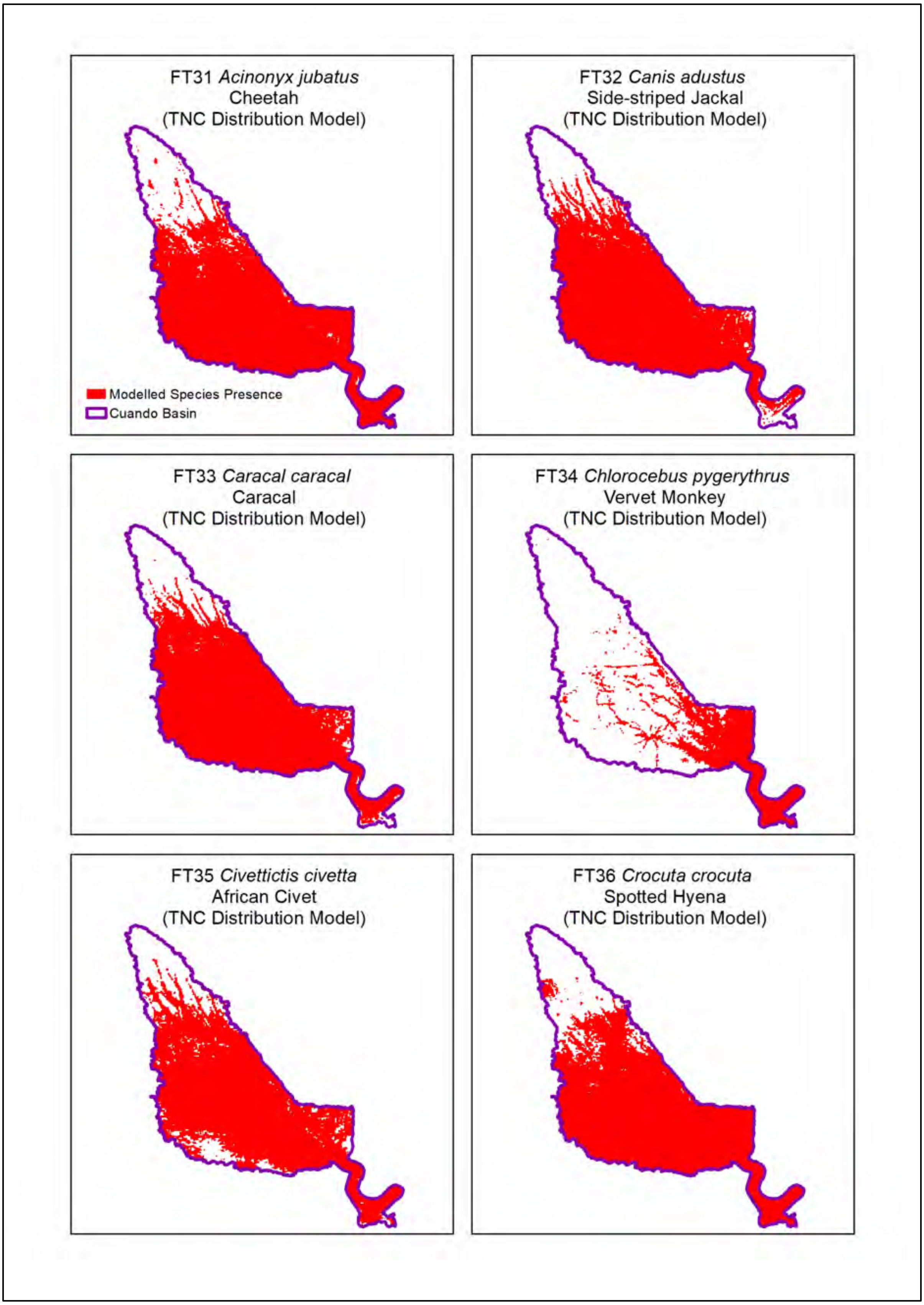


Figure 28: Maxent models for a range of terrestrial mammal and bird species were developed by The Nature Conservancy (TNC). Results were include in the SCP. Maps show the results for FT31 Acinonyx jubatus – Cheetah, FT32 Canis adustus - Side-striped Jackal, FT33 Caracal caracal – Caracal, FT34 Chlorocebus pygerythrus - Vervet Monkey, FT35 Civettictis civetta - African Civet and FT36 Crocuta crocuta - Spotted Hyena.

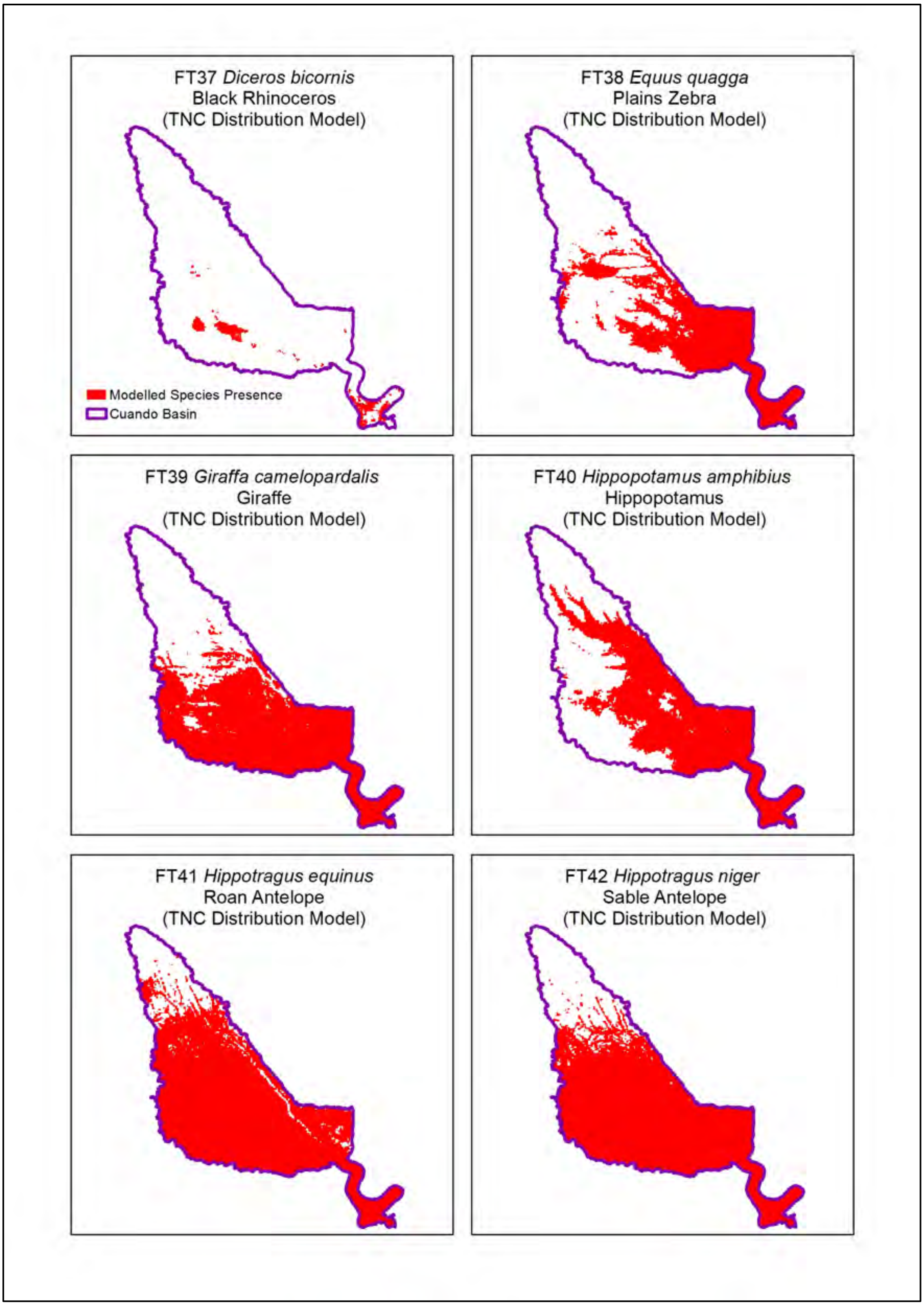


Figure 29: Maxent models for a range of terrestrial mammal and bird species were developed by The Nature Conservancy (TNC). Results were include in the SCP. Maps show the results for FT37 Diceros bicornis - Black Rhinoceros, FT38 Equus quagga - Plains Zebra, FT39 Giraffa camelopardalis – Giraffe, FT40 Hippopotamus amphibius Hippopotamus, FT41 Hippotragus equinus Roan Antelope and FT42 Hippotragus niger Sable Antelope. Note that for some wetland associated species the modelling reflects broader landscape presence rather than specific use of a site.

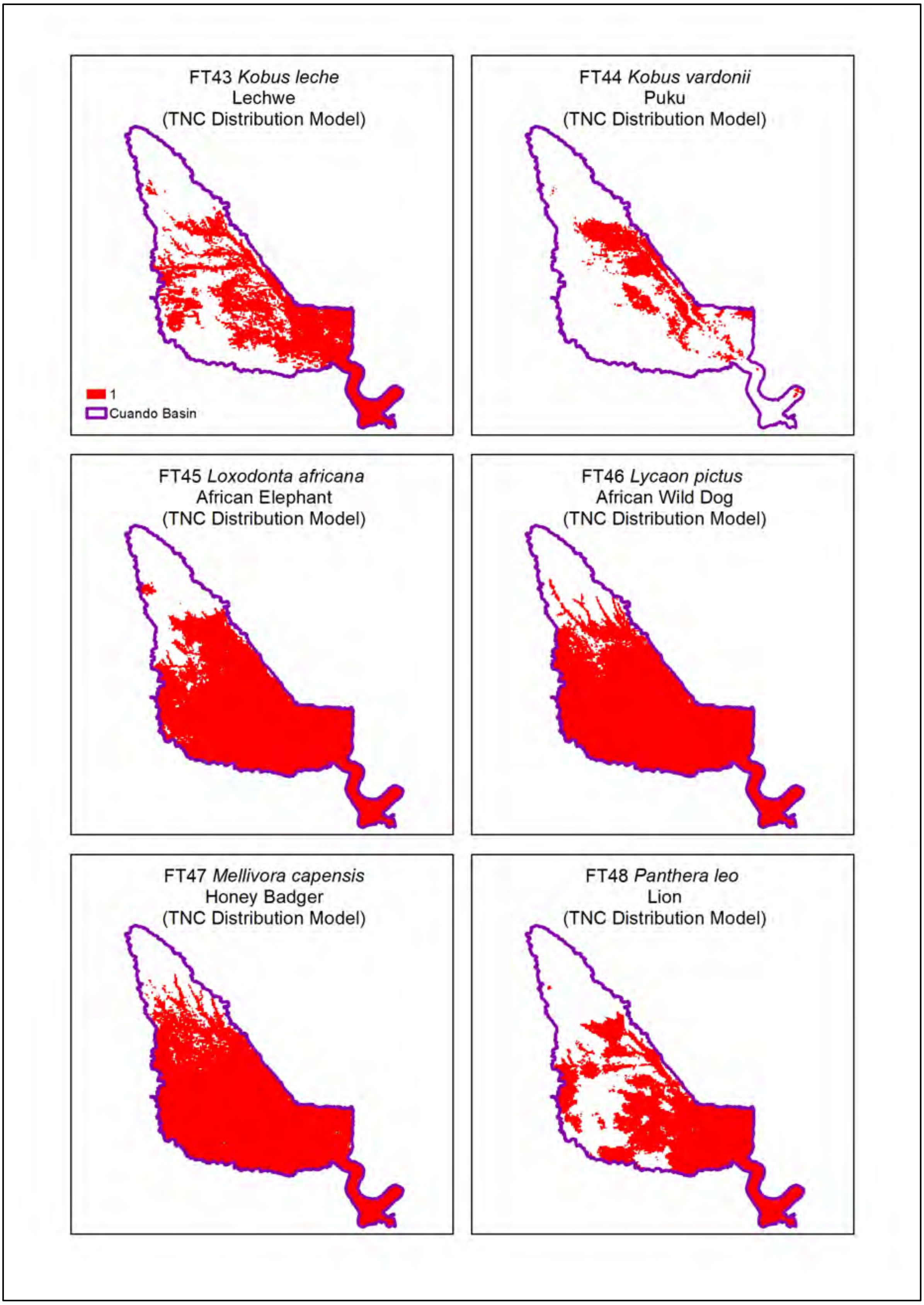


Figure 30: Maxent models for a range of terrestrial mammal and bird species were developed by The Nature Conservancy (TNC). Results were include in the SCP. Maps show the results for FT43 Kobus leche Lechwe, FT44 Kobus vardonii Puku, FT45 Loxodonta africana African Elephant, FT46 Lycaon pictus African Wild Dog, FT47 Mellivora capensis Honey Badger and FT48 Panthera leo Lion.

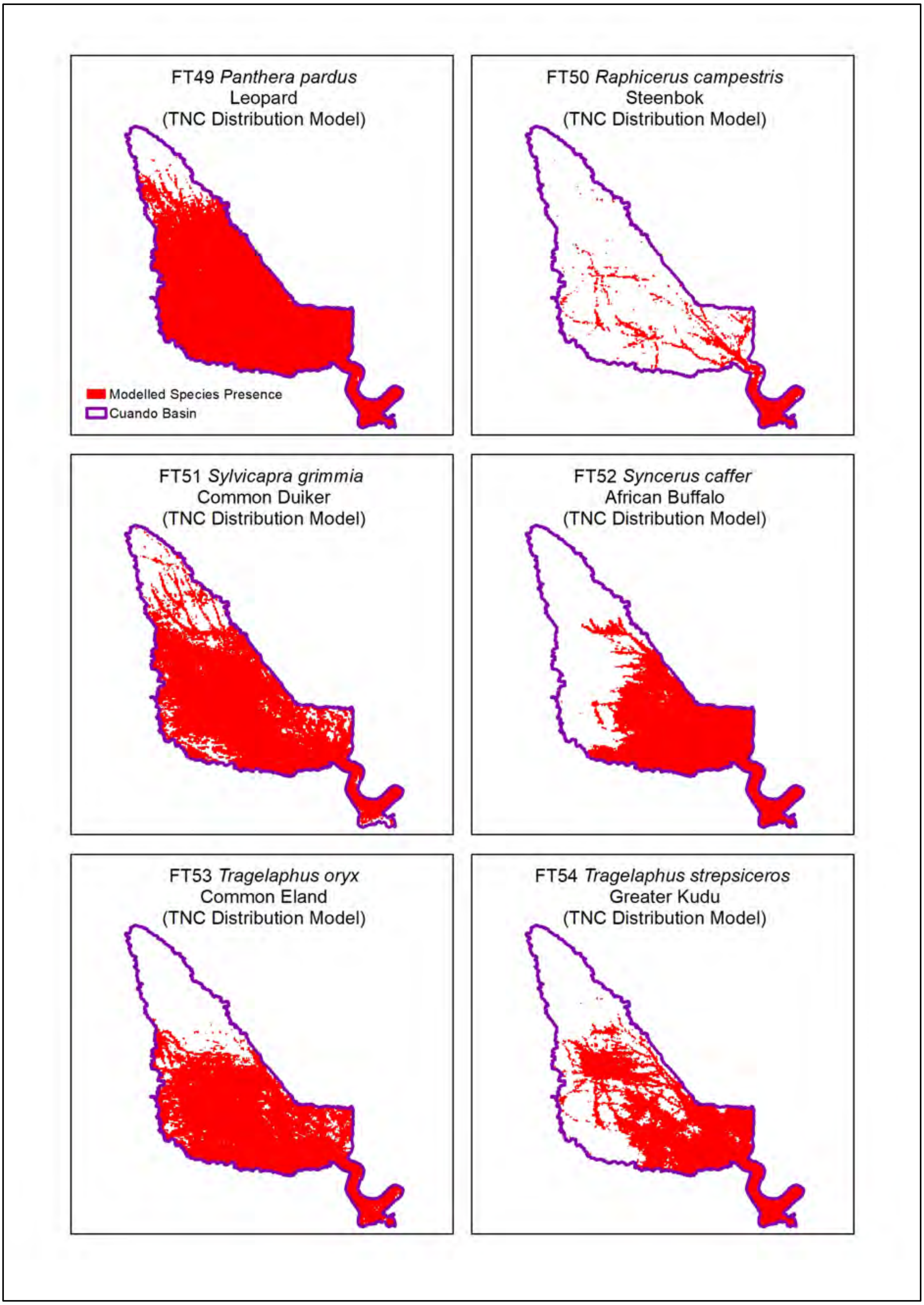


Figure 31: Maxent models for a range of terrestrial mammal and bird species were developed by The Nature Conservancy (TNC). Results were include in the SCP. Maps show the results for FT49 Panthera pardus Leopard, FT50 Raphicerus campestris Steenbok, FT51 Sylvicapra grimmia Common Duiker, FT52 Syncerus caffer African Buffalo, FT53 Tragelaphus oryx Common Eland and FT54 Tragelaphus strepsiceros Greater Kudu.

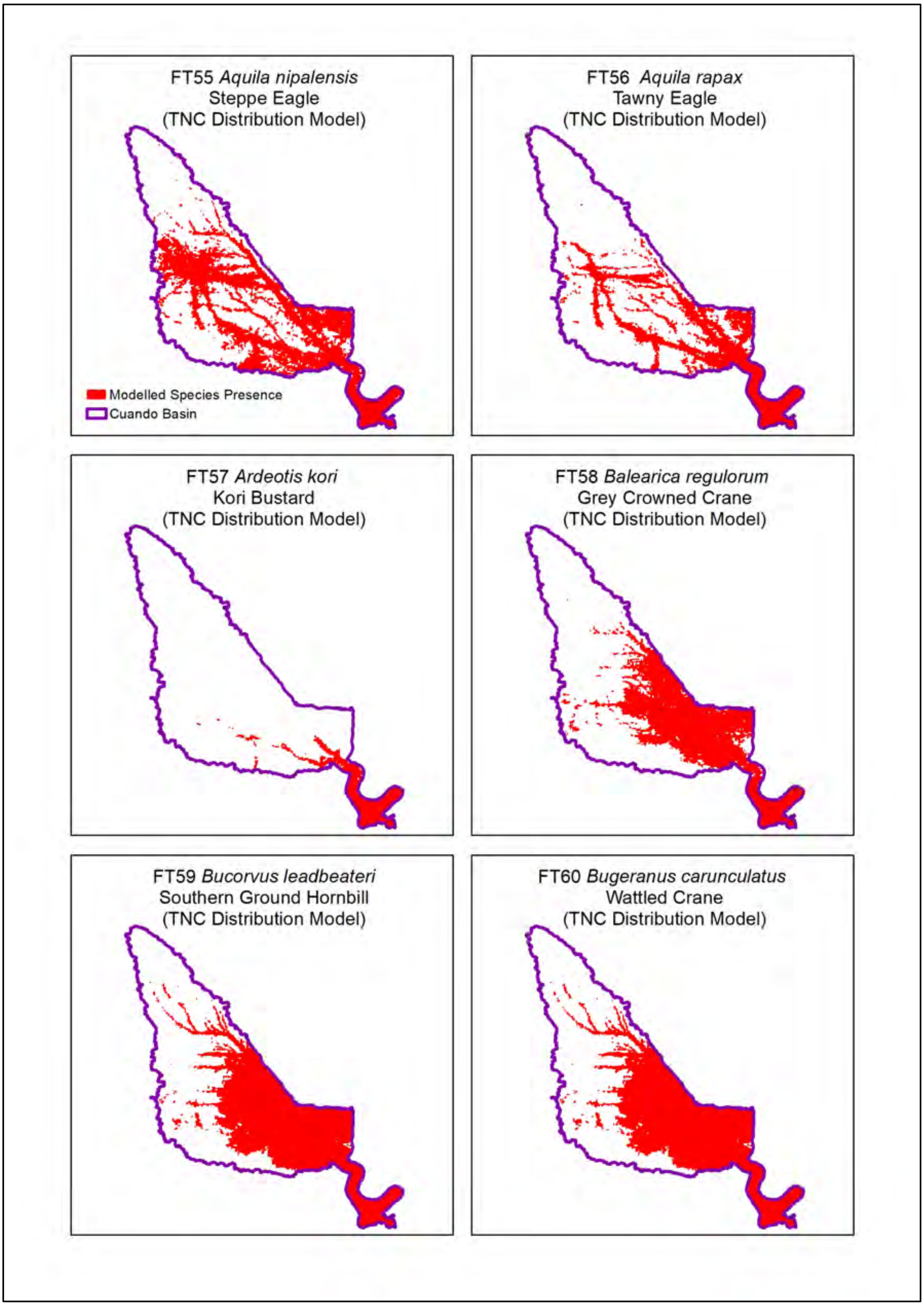


Figure 32: Maxent models for a range of terrestrial mammal and bird species were developed by The Nature Conservancy (TNC). Results were include in the SCP. Maps show the results for FT55 Aquila nipalensis Steppe Eagle, FT56 Aquila rapax Tawny Eagle, FT57 Ardeotis kori Kori Bustard, FT58 Balearica regulorum Grey Crowned Crane, FT59 Bucorvus leadbeateri Southern Ground Hornbill and FT60 Bugeranus carunculatus Wattled Crane. Note that for some wetland associated species the modelling reflects broader landscape presence rather than specific use of a site.

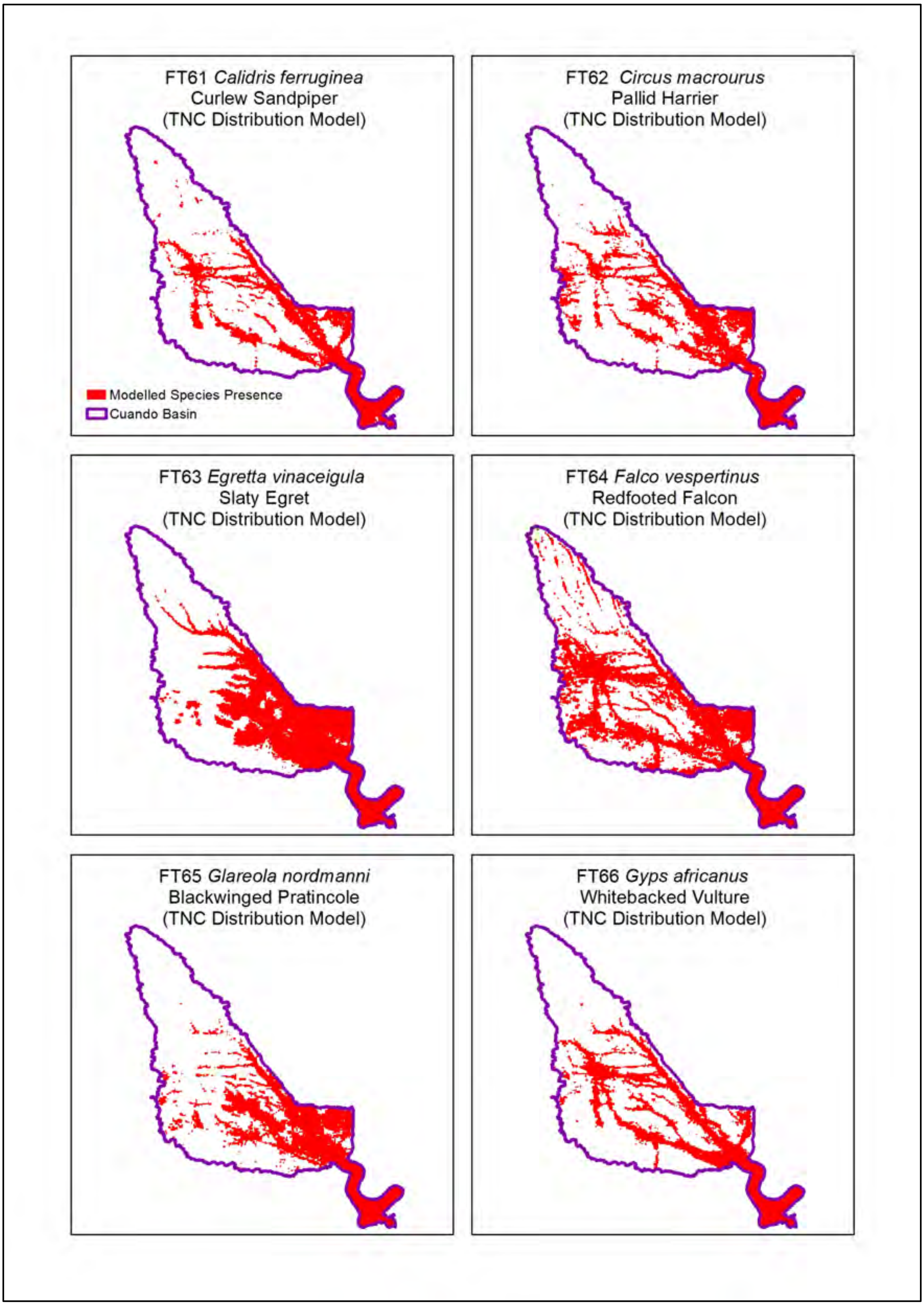


Figure 33: Maxent models for a range of terrestrial mammal and bird species were developed by The Nature Conservancy (TNC). Results were include in the SCP. Maps show the results for FT61 Calidris ferruginea Curlew Sandpiper, FT62 Circus macrourus Pallid Harrier, FT63 Egretta vinaceigula Slaty Egret, FT64 Falco vespertinus Redfooted Falcon, FT65 Glareola nordmanni Blackwinged Pratincole, and FT66 Gyps africanus Whitebacked Vulture. Note that for some wetland associated species the modelling reflects broader landscape presence rather than specific use of a site.

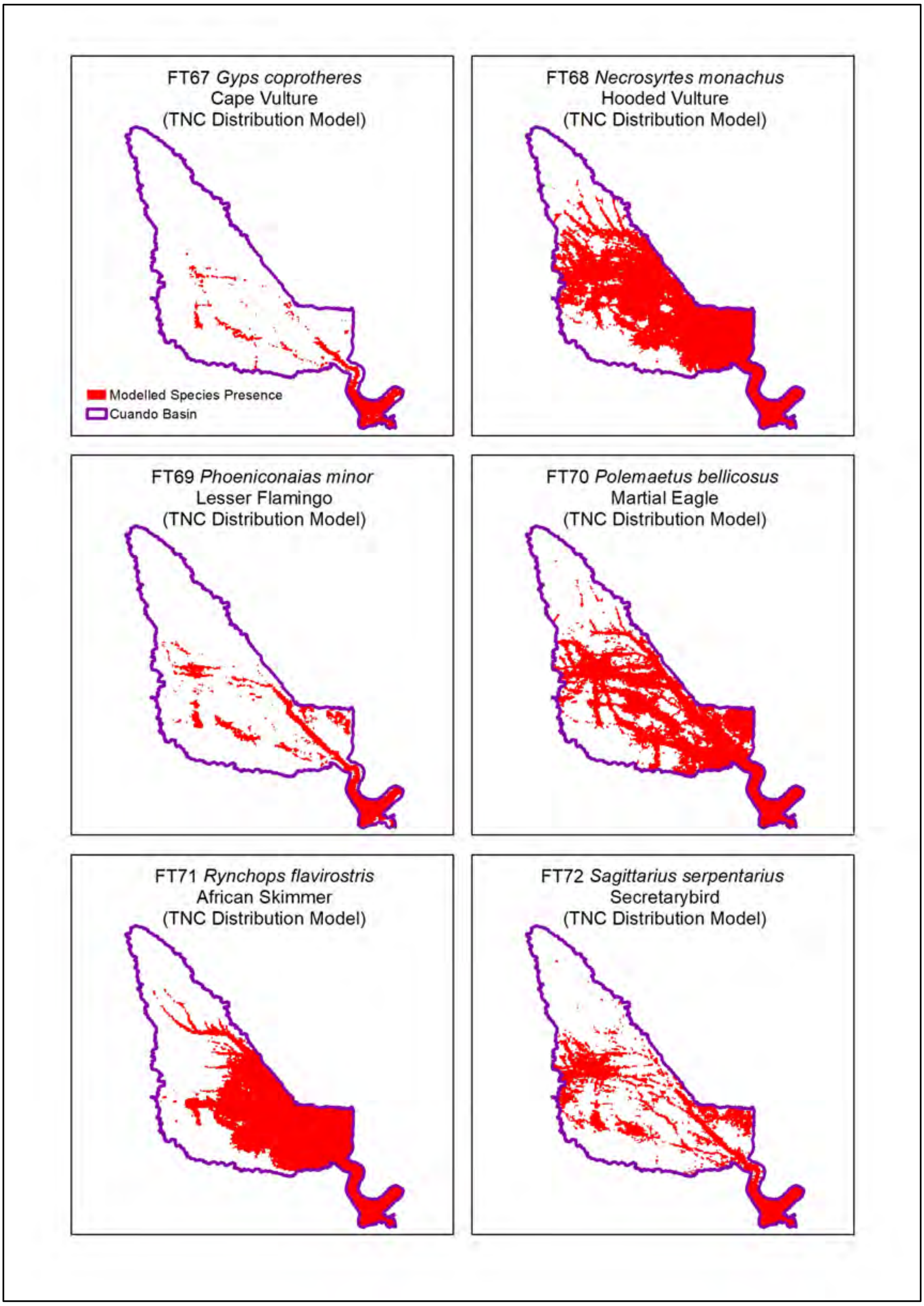


Figure 34: Maxent models for a range of terrestrial mammal and bird species were developed by The Nature Conservancy (TNC). Results were include in the SCP. Maps show the results for FT67 Gyps coprotheres Cape Vulture, FT68 Necrosyrtes monachus Hooded Vulture, FT69 Phoeniconaias minor Lesser Flamingo, FT70 Polemaetus bellicosus Martial Eagle, FT71 Rynchops flavirostris African Skimmer and FT72 Sagittarius serpentarius Secretarybird. Note that for some wetland associated species the modelling reflects broader landscape presence rather than specific use of a site.

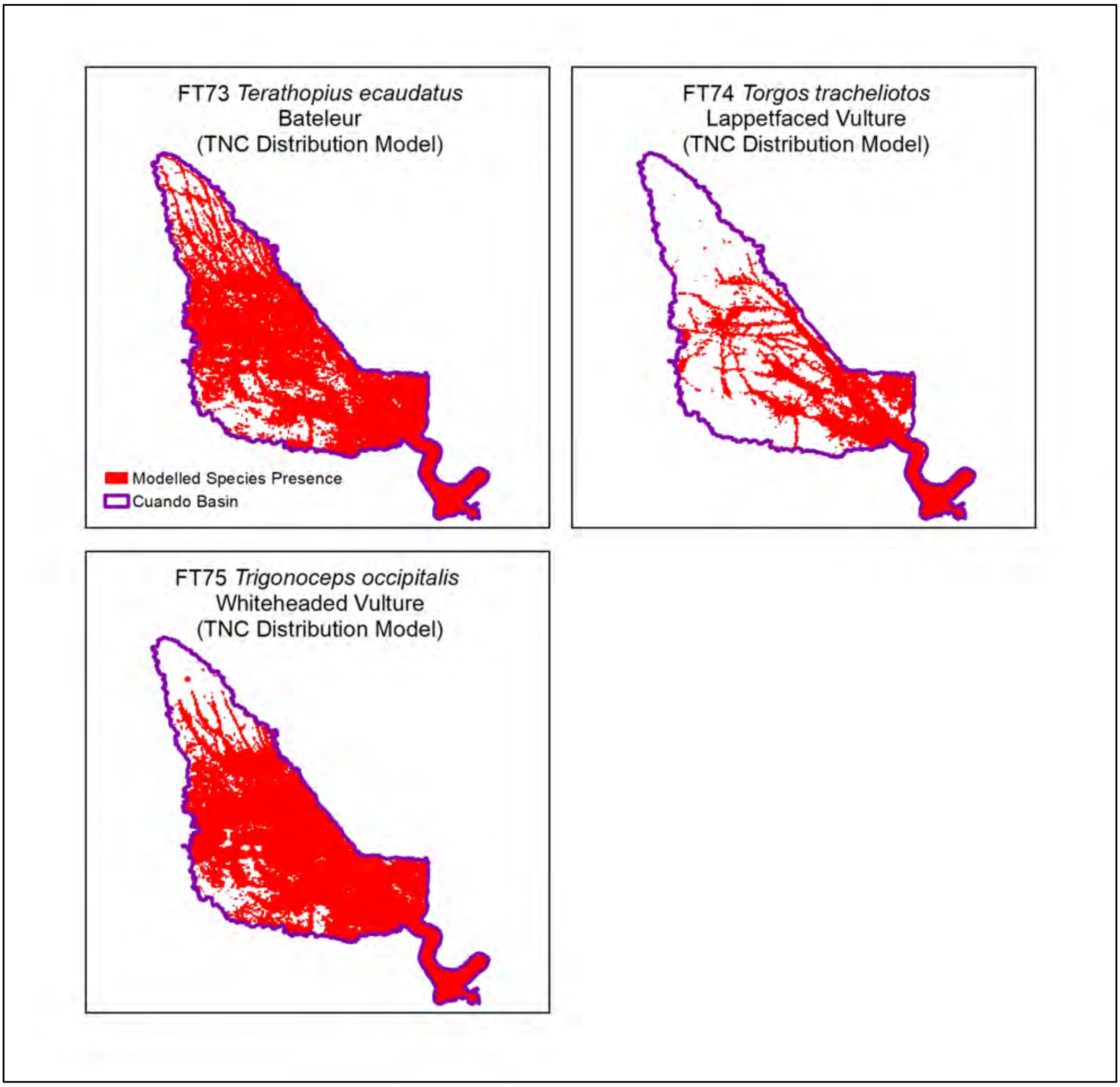


Figure 35: Maxent models for a range of terrestrial mammal and bird species were developed by The Nature Conservancy (TNC). Results were include in the SCP. Maps show the results for FT73 Terathopius ecaudatus Bateleur, FT74 Torgos tracheliotos Lappetfaced Vulture and T75 Trigonoceps occipitalis Whiteheaded Vulture.

Description

Consistent and systematically sampled species data for the planning domain remain sparse for the planning domain. However, recently there has been a concerted effort to improve our knowledge of the distribution of key species. Significant work has been undertaken for the region by TNC on terrestrial animal populations (TNC, 2024) and WWF on aquatic species (WWF, 2023). We have included these in the Systematic Conservation Plan for the Cuando Basin.

Although they both reflect best estimated potential distributions for key species there are a number of key differences in approach by the two projects:

- The WWF aquatic species analysis was undertaken for SE Angola (WWF, 2023). The approach used a multi-variate analysis of most suitable landscape classes / elements to build a model of potential habitat value for each species. These were then combined into uniform layers which aggregated values across a group of species (e.g. fish or aquatic mammals). Unfortunately, the analysis only covered Angola. However, given that most of the Cuando River Basin is in Angola, we used the data despite the incomplete coverage.

- The Nature Conservancy (TNC) used a Maxent modelling approach to identify potential range for species terrestrial mammals and birds across a broader region under current climate conditions (TNC, 2024). The approach uses species occurrence records to build a model of likely range rather than specific use of a particular site. We used a presence / absence layer for each individual species as an input into the SCP. Note that the results are still subject to verification and may be updated in the future. Note that the modelling reflects broader landscape presence/ potential / range rather than specific use of a site, particularly for the wetland associated species. Further, some species such as Steppe Eagle may not actually be present in the area currently.

Species selection and incorporation was done by the original WWF and TNC projects. We have used the full set of available data and did not further select species for inclusion. Although there is some overlap of species between the two datasets, given the different approaches used and different geographic coverage, we have not exclude duplicated species. A key aspect of the decision on the approach, was the clear usefulness of the WWF integrated continuous variable habitat value layers for the groups of species.

<u>The data included are:</u>

- WWF Integrated ecosystem value data for grouped taxa of aquatic birds, aquatic mammals and fish within the planning domain.
- The WWF modelled 11 aquatic bird species were:
    - Anastomus amelligerus: African Openbill
    - Balearica regulorum: Grey Crowned-crane
    - Botaurus stellaris: Eurasian Bittern
    - Bugeranus carunculatus: Wattled Crane
    - Circus ranivorus: African Marsh Harrier
    - Egretta vinaceigula: Black-banded Heron
    - Ephippiorhynchus senegalensis: Saddle-billed Stork
    - Microparra capensis: Lesser Jacana
    - Nettapus auritus: African Pygmy-goose
    - Porphyrio alleni: Allen's Gallinule
    - Scotopelia peli: Fishing Owl
- The WWF modelled 8 aquatic mammals were:
    - Hippopotamus amphibius: Common Hippopotamus
    - Tragelaphus spekei: Speke's Greater Kudu
    - Kobus ellipsiprymnus: Waterbuck
    - Kobus leche: Lechwe
    - Redunca arundinum: Southern Reedbuck
    - Aonyx capensis: Cape Clawless Otter
    - Hydrictis maculicolis: Spotted-necked Otter
    - Atilax paludinosus: Water Mongoose
- The WWF modelled 14 fish species were:
    - Chiloglanis fasciatus: Banded upside-down catfish
    - Clariallabes platyprosopos

  - Mastacembelus vanderwaali
  - Nannocharax dageti
  - Parakneria fortuita
  - Hepsetus cuvieri: African Pike Characin
  - Hydrocynus vittatus: Tigerfish
  - Labeo cylindricus: Roundbelly Labeo
  - Labeo lunatus: Highfin Labeo
  - Labeobarbus codringtonii
  - Petrocephalus okavangensis: Okavango Electric Fish
  - Synodontis macrostoma: Largemouth Squeaker
  - Zaireichthys conspicuous
  - Zaireichthys kavangoensis
- The TNC models for mammals covered 24 individual species. Each of these was include as a separate feature:
  - FT31 Acinonyx jubatus - Cheetah
  - FT32 Canis adustus - Side-striped Jackal
  - FT33 Caracal caracal - Caracal
  - FT34 Chlorocebus pygerythrus - Vervet Monkey
  - FT35 Civettictis civetta - African Civet
  - FT36 Crocuta crocuta - Spotted Hyena
  - FT37 Diceros bicornis - Black Rhinoceros
  - FT38 Equus quagga - Plains Zebra
  - FT39 Giraffa camelopardalis - Giraffe
  - FT40 Hippopotamus amphibius - Hippopotamus
  - FT41 Hippotragus equinus - Roan Antelope
  - FT42 Hippotragus niger - Sable Antelope
  - FT43 Kobus leche - Lechwe
  - FT44 Kobus vardonii - Puku
  - FT45 Loxodonta africana - African Elephant
  - FT46 Lycaon pictus - African Wild Dog
  - FT47 Mellivora capensis - Honey Badger
  - FT48 Panthera leo - Lion
  - FT49 Panthera pardus - Leopard
  - FT50 Raphicerus campestris - Steenbok
  - FT51 Sylvicapra grimmia - Common Duiker
  - FT52 Syncerus caffer - African Buffalo
  - FT53 Tragelaphus oryx - Common Eland
  - FT54 Tragelaphus strepsiceros - Greater Kudu
- The TNC models for birds covered 21 individual species. Each of these was include as a separate feature:
  - FT55 Aquila nipalensis - Steppe Eagle
  - FT56 Aquila rapax - Tawny Eagle
  - FT57 Ardeotis kori - Kori Bustard
  - FT58 Balearica regulorum - Grey Crowned Crane
  - FT59 Bucorvus leadbeateri - Southern Ground Hornbill
  - FT60 Bugeranus carunculatus - Wattled Crane
  - FT61 Calidris ferruginea - Curlew Sandpiper
  - FT62 Circus macrourus - Pallid Harrier

- FT63 Egretta vinaceigula - Slaty Egret
- FT64 Falco vespertinus - Redfooted Falcon
- FT65 Glareola nordmanni - Blackwinged Pratincole
- FT66 Gyps africanus - Whitebacked Vulture
- FT67 Gyps coprotheres - Cape Vulture
- FT68 Necrosyrtes monachus - Hooded Vulture
- FT69 Phoeniconaias minor - Lesser Flamingo
- FT70 Polemaetus bellicosus - Martial Eagle
- FT71 Rynchops flavirostris - African Skimmer
- FT72 Sagittarius serpentarius - Secretarybird
- FT73 Terathopius ecaudatus - Bateleur
- FT74 Torgos tracheliotos - Lappetfaced Vulture
- FT75 Trigonoceps occipitalis - Whiteheaded Vulture

Overview of mapping methods and incorporation into planning

The species data were included as follows:

- The combined WWF analyses on landscape value for the groups of species (aquatic birds, aquatic mammals and fish) were each included as a continuous variable. Average values (0-100) for each group were calculated for each planning unit. Targets were set against the total aggregated value across the domain with a target as described in the Target Setting section on page 10. Note that these values are only for Angola, and hence do not influence selection outside of this country. We undertook a sensitivity analysis to determine whether the inclusion of this partial dataset (Angola only) was detrimental to the overall outcome. Inclusion of the data helped to refine selection in Angola, but did not bias the selection across countries. Bias was avoided by the use of the ecosystem data as a coarse filter to ensure avoidance of regional bias. Bias was further reduced by the use of species data (i.e. the TNC data) which covered the entire domain, other data (e.g. for wetlands and rivers) which covered the whole domain, and the fact that species priorities from Namibia had already been included via the Zambezi Plan (WWF Namibia, 2022)
- Presence / absence values of 1 and 0 for specific species data from TNC were coded into each planning unit for the domain. A planning unit was coded as present (1) if there was any overlap with species presence. Targets were set against the total number of occupied planning units for the Cuando River Basin, with a target as described in the Target Setting section on page 10.

Link to Valued Ecosystem Components (VECs)

The species features are linked to the overall sustainability and ecological value of the Cuando River Basin, rather than being directly linked to specific VECs. Nevertheless, there are some specific stronger linkages:

- **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** The freshwater species are strongly linked to the water courses, especially the larger perennial aquatic features.
- **VEC 3 – Linyanti Swamps and Savuti area.** The freshwater species, and broadly water associated species such as Lechwe, are strongly linked to these swamp / wetland features.

- **VEC 4 – Western flanks of the Cuando.** The species (especially the terrestrial mammals) are closely associated with this feature.
- **VEC 5 – Wildlife corridors and ecological connectivity.** The species, and their movement, are directly linked to wildlife corridors and ecological connectivity.

Data providers

Data provided by WWF US and The Nature Conservancy.

Protected Areas

Figure 36: Map showing the Protected Areas of the Cuando River Basin and adjacent areas. Codes for the smaller unlabelled forest reserves in Zambia: 1. Lilengo West, 2. Shelangu East, 3. Sikabenga and 4. Shelungu West Forest Reserve.

Description

There are a number of existing Protected Areas (PAs) in and around the planning domain (Figure 36). Reflecting existing Protected Areas, and their contribution to achieving targets, is a key component of any Systematic Conservation Planning process.

Large portions of the central and south of the Cuando River basin are within existing formal Protected Areas. The larger PAs include Mavinga and Luengue-Luiana National Parks in Angola; portions of Sioma

Ngwezi National Park in Zambia; the whole of Nkasa Rupara and portions of Bwabwata and Mudumu National Parks and Zambezi Sate Forest in Namibia; and portions of Chobe National Park in Botswana. In addition, a number of smaller forest reserves are located in Zambia (Lilengo West, Shelangu East, Sikabenga and Shelungu West).

Overview of mapping methods and incorporation into planning

The following are key points in the mapping methodology:

- A review of the best a UNEP World Database on Protected Areas (UNEP-WCMC, 2020), identified some errors in the Protected Area network in Angola.
- We updated the PA layer in Angola based on substantial inputs from Mike Knight, John Mendelsohn (who had worked on the delineation of Mavinga NP) and data from Luis Verissimo. This resulted insubstantial changes to the delineation of the northern and eastern boundaries of Mavinga NP. In addition, some naming and declaration issues were updated for Zambezi State Forest.
- Planning units that overlapped with any Protected Area were flagged as "Conserved". This is a planning category within MARXAN which guarantees that the PAs are consistently part of the identified conservation network. Effectively this sets a 100% target for all PAs adjacent to the planning domain. This target enables strong edge matching and spatial alignment or joining. In addition, to allow the partial inclusion of PAs in some MARXAN runs, we also created features where planning units which had the majority of their area in a PA were identified, as well as ones where planning units with their centroids were in PAs were identified.

Link to Valued Ecosystem Components (VECs)

The Protected Area data are linked to the overall management, sustainability and ecological value of the Cuando River Basin, rather than being directly linked to specific VECs. Nevertheless, there are some specific stronger linkages:

- **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** Portions of the perennial mainstem of the Cuando River and its major tributaries are within Protected Areas.
- **VEC 3 – Linyanti Swamps and Savuti area.** Portions of the Linyati Swamps and all of the Savuti Marsh are in Protected Areas.
- **VEC 4 – Western flanks of the Cuando.** Almost the entire VEC is within one of the Protected Areas, with Mavinga, Luengue-Luiana and, to a lesser extent, Bwabwata National Parks all being critically important to the VEC.
- **VEC 5 – Wildlife corridors and ecological connectivity.** The extensive Protected Areas in the central and southern portions of the Cuando River basin are critical core areas supporting this VEC.

Data providers

The data is from the UNEP World Database on Protected Areas (UNEP-WCMC, 2020), Luis Verissimo Mike Knight and John Mendelsohn.

Other Conservation Areas: Community Forests, Communal Conservancies and Game Management Areas

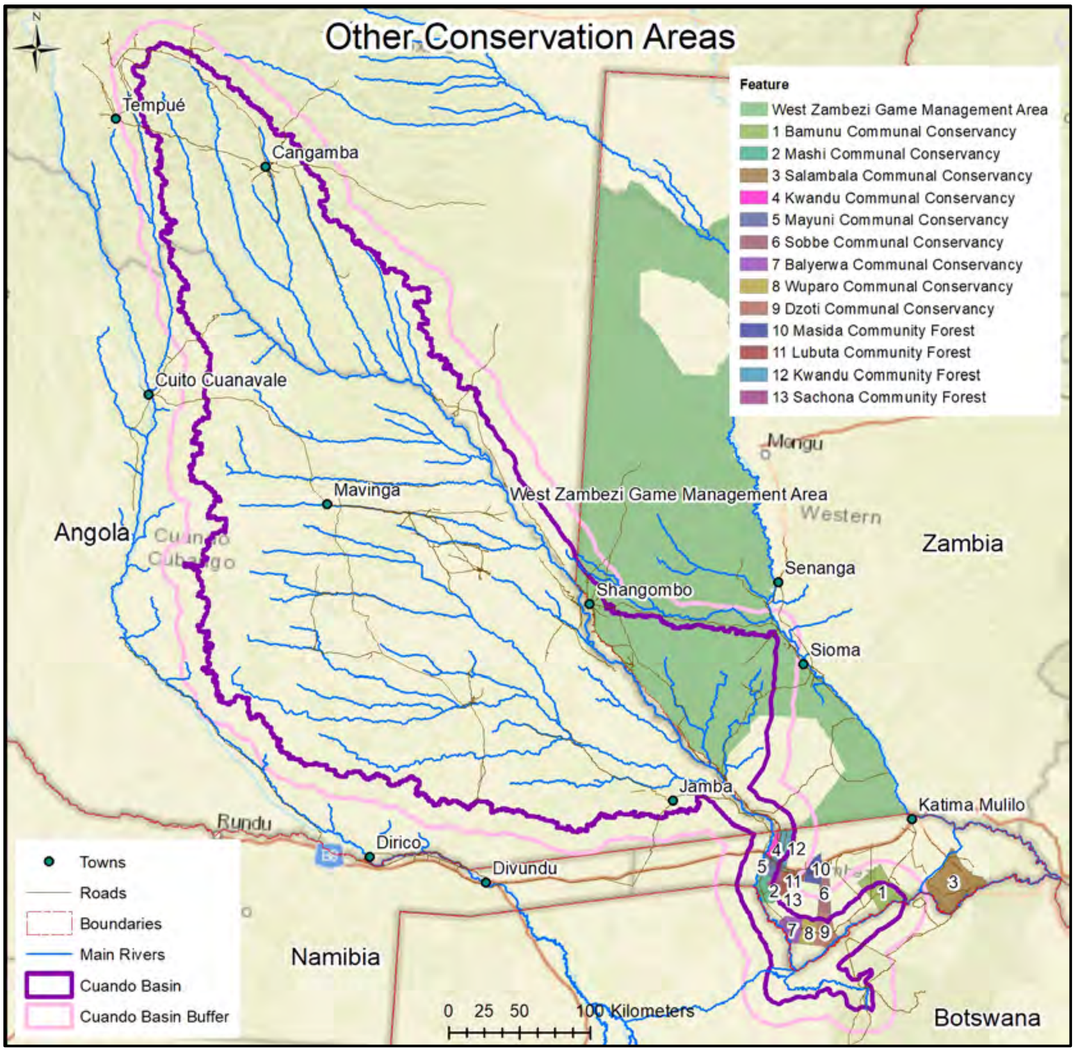


Figure 37: Map showing areas under other forms of conservation or sustainable management (i.e. not formal Protected Areas) such as Community Forests, Communal Conservancies and Game Management Areas. Codes for the smaller unlabelled areas are given in the legend.

Description

A number of areas under other (i.e. they are not formal Protected Areas) forms of conservation or sustainable management such as Community Forests, Communal Conservancies and Game Management Areas are found in the Cuando River Basin (Figure 37). The areas are mostly in Namibia and Zambia; with no known existing sites in the Angolan portion of the Cuando River Basin. The West Zambezi Game Management Area (WZMGA) is by far the largest and effectively includes the remainder of the Cuando Basin in Zambia which is not within Sioma Ngwezi National Park. The WZMGA constitutes a significant component of Zambia's wildlife conservation landscape, and includes a large area of approximately 38,070 square kilometers, linking the Liuwa Plain National Park and Sioma Ngwezi National Park. The WZMGA functions as a critical wildlife corridor, both between the National parks in Zambia and the expansive wilderness regions of neighboring Angola. This connectivity is essential for maintaining healthy wildlife populations and facilitating their natural migration patterns. Similarly, a number of smaller Communal Conservancies in Namibia largely connect the National Parks (WWF Namibia, 2022). It is important to note that both the WZGMA in Zambia and the Communal Conservancies in Namibia, include settlement and cropping areas, and multiple use areas with livestock priority areas. Nevertheless, these areas represent important landscape where there is an emphasis on sustainable wildlife focussed land management.

Overview of mapping methods and incorporation into planning

- Areas under other forms of conservation or sustainable management were identified from the UNEP World Database on Protected Areas (UNEP-WCMC, 2020).
- The features were split into two categories, namely the very large West Zambezi Game Management Area (WZMGA) in Zambia, and then the group of smaller Namibian Communal Conservancies. These two categories were assigned to unique features within MARXAN. The categories were split to ensure that these other conservation areas were targeted in all the countries where they are present, as we did not want to have all the selected areas focussed on one country.
- Any planning unit that overlaps one of these conservation areas was flagged as such.
- Targets were set against the total number of occupied planning units for the Cuando River Basin, with a target as described in the Target Setting section on page 10.

Link to Valued Ecosystem Components (VECs)

The other conservation areas are linked to the overall management, sustainability and ecological value of the Cuando River Basin, rather than being directly linked to specific VECs. Nevertheless, there are some specific stronger linkages:

- **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.** Portions of the perennial mainstem of the Cuando River are in or adjacent to either the West Zambezi Game Management Area of the Namibian Communal Conservancies.
- **VEC 3 – Linyanti Swamps and Savuti area.** Portions of the Linyati Swamps are in Namibian Communal Conservancies.
- **VEC 5 – Wildlife corridors and ecological connectivity.** The extensive other conservation areas provide key linkages for wildlife and ecological connectivity between the formal National Parks and other Protected Areas. They are critical core areas supporting this VEC.

Data providers

The data is from the UNEP World Database on Protected Areas (UNEP-WCMC, 2020).

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.

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.

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 usable 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 cost surface map developed by the current project was used (See Cost surface section from page 75). This map was converted into a linkage suitability map by reclassifying (and inverting) the cost surface into the range 0-1, where 0 represents a highly unsuitable area (e.g. high densities of settlements, fields and roads) and 1 represents a highly suitable area (no linear impacts such as roads, cultivate fields etc). The layer preferentially values fully intact ecosystems, and strongly avoids intensively used ones (e.g. cropland, roads and settlements). This linkage suitability or landscape permeability map is shown in Figure 38.

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 Cuando River Basin study, four linkages were evaluated. Firstly, an overall linkage between the Source lakes area and

Chobe NP ("Source to Sink"). Then broader linkages from the entire western to eastern boundaries of the basin were explored. Then to improve overall understanding of the landscape, potential landscape linkages were evaluated from the central west to central east (specifically to examine the Mavinga to Zambia connectivity); and from the north-west to north-east to focuss on linkages in the Water Tower area.

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 Cuando River Basin 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 secondary result** (Figure 39) of the Condatis analysis; and provides a clear indication of places in the landscape where any increased habitat suitability such as restoration of natural forest or increase in the permeability / suitability of farmland would support overall landscape connectivity. A summary of the key Condatis variables used are outlined in Table 7.

Table 7: Summary of key Condatis variables used.

What kind of species are you interested in?	• Movement of terrestrial species – such as larger mammals and birds. These are seen as proxies for the remaining non-aquatic biota. • A 2.5km dispersal distance was assumed per generation after testing, and cross checking against literature.
What is your source and target?	• Source lakes area to Chobe NP • Western Edge of Cuando Basin to Eastern Edge • Central west to central east (specifically to examine the Mavinga to Zambia connectivity) • North-west to north-east to focus on linkages in the Water Tower area.
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?	$4km^2$ planning unit blocks with high levels of landscape permeability.

What kind of prioritisation are you performing?	Testing and comparing scenarios for retaining landscape connectivity.

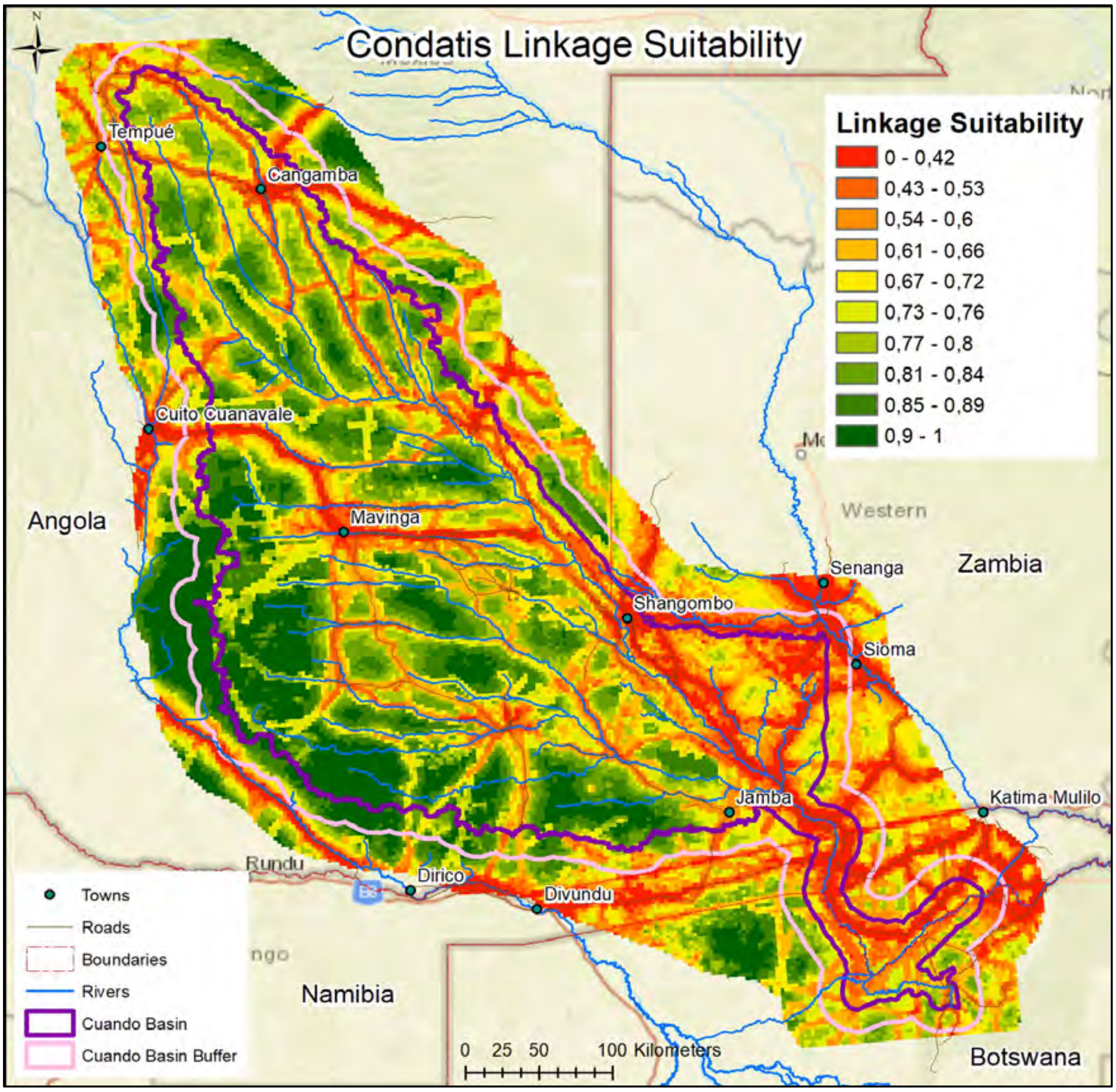


Figure 38: The combined cost surface map developed by the current project were used as the basis for the linkage suitability map (See Cost surface section from page 86). This map was converted into a linkage suitability map by reclassifying (and inverting) the cost surface into the range 0-1, where 0 represents a highly unsuitable area (e.g. high densities of settlements, fields and roads) and 1 represents a highly suitable area (no linear impacts such as roads, cultivate fields etc).

Condatis Key Landscape Bottlenecks

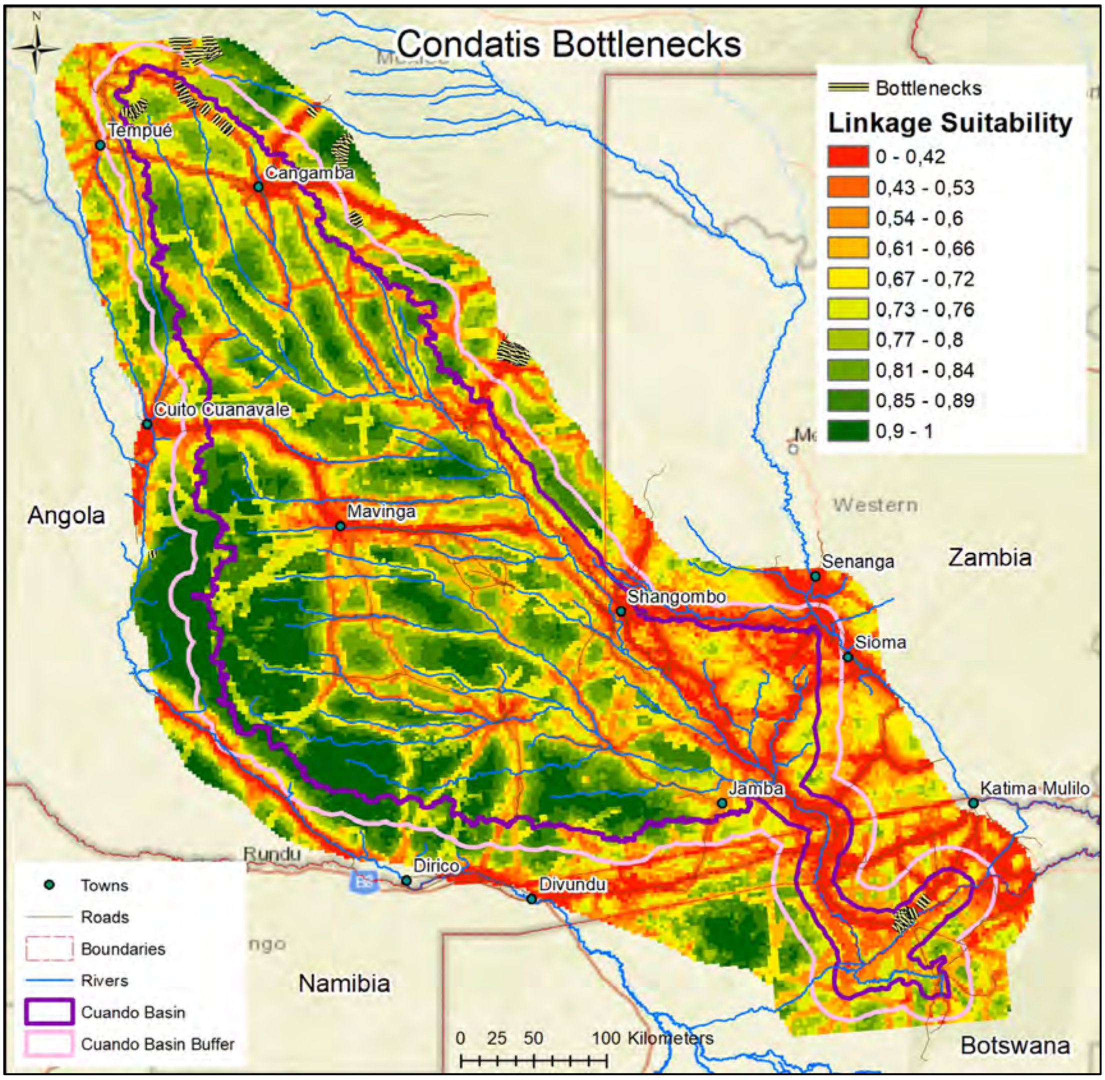


Figure 39: Key landscape connectivity bottlenecks in the planning domain.

The Condatis Landscape Connectivity software aids in delineating key bottlenecks which effectively represent areas where limited wilderness habitat exists and, consequently, where natural pathways for migration are lost or limited (Figure 39).

Condatis Landscape Connectivity Analysis

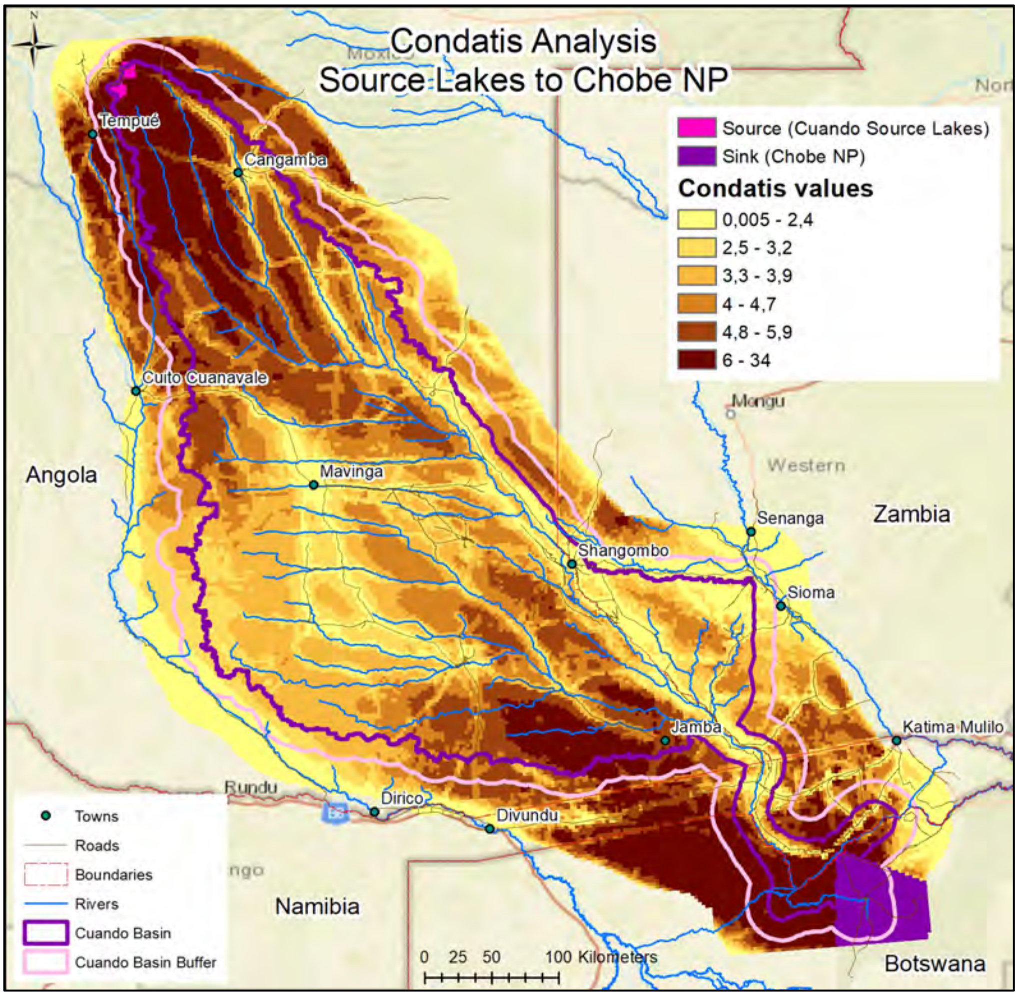


Figure 40: Condatis analysis results of most important areas for landscape connectivity between the Source Lakes and Chobe NP. Note that the Source Lakes feature is used as a geographical anchor in the upper catchment for the linkage analysis. This does not imply that specific terrestrial animals would ever move from the Source Lakes to Chobe NP.

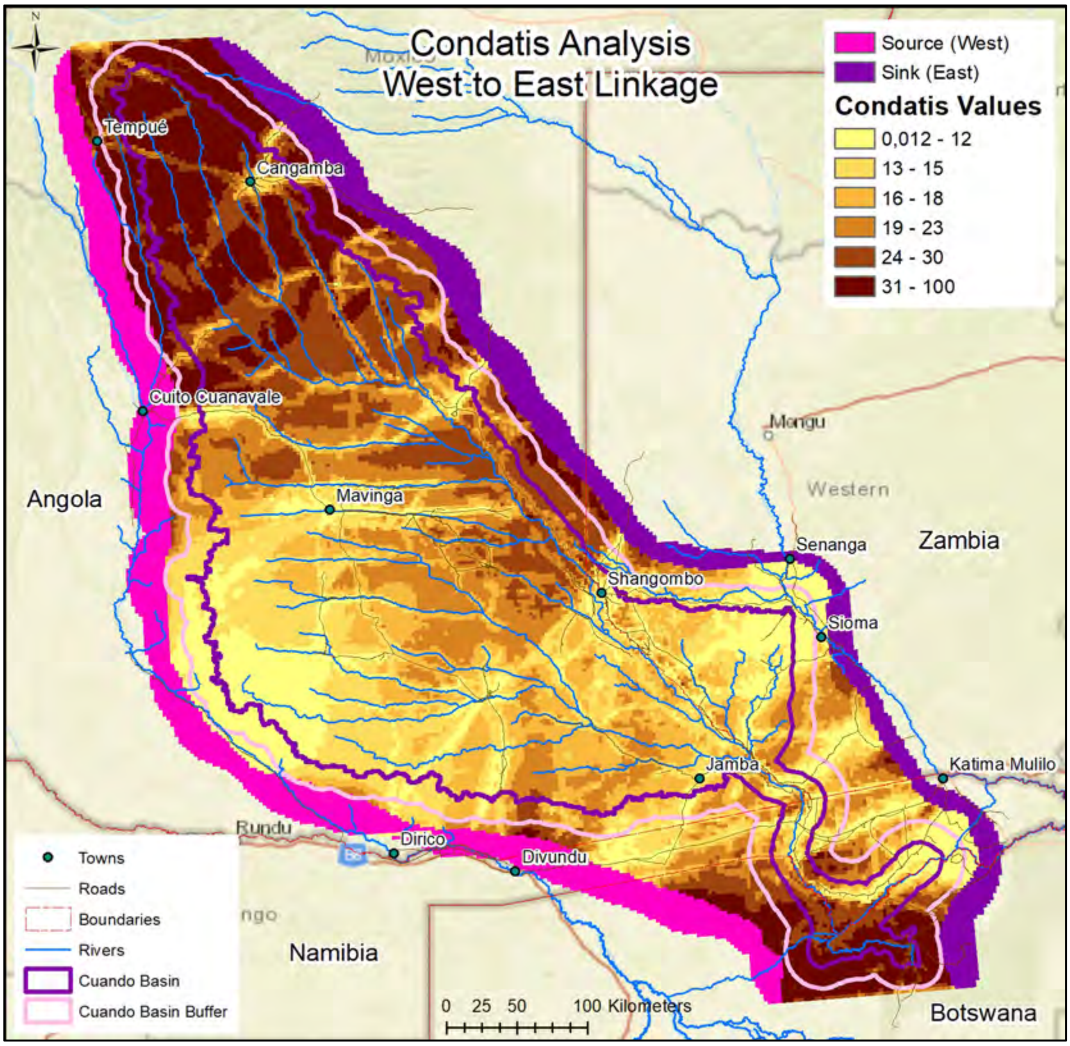


Figure 41: Condatis analysis results of most important areas for landscape connectivity between the Western Edge to the Eastern Edge of the Cuando Basin.

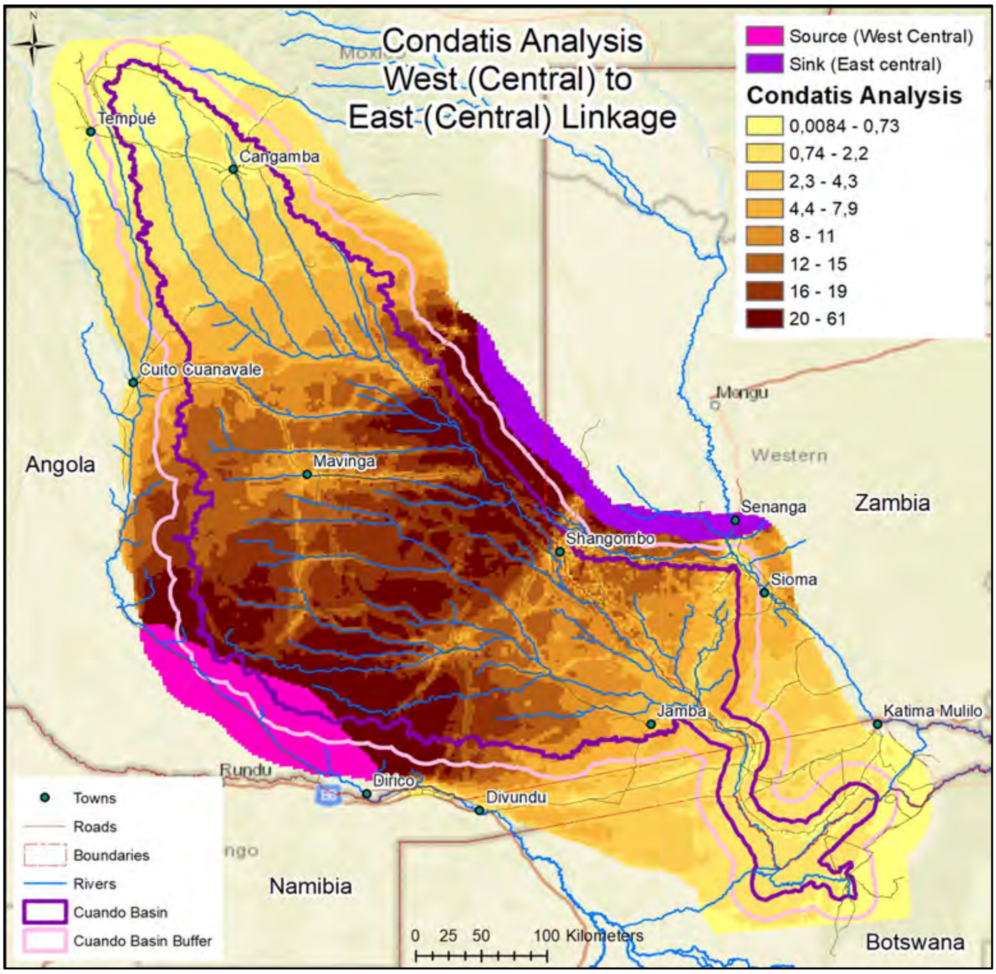


Figure 42: Condatis analysis results of most important areas for landscape connectivity between Central west to Central east (specifically to examine the Mavinga to Zambia connectivity).

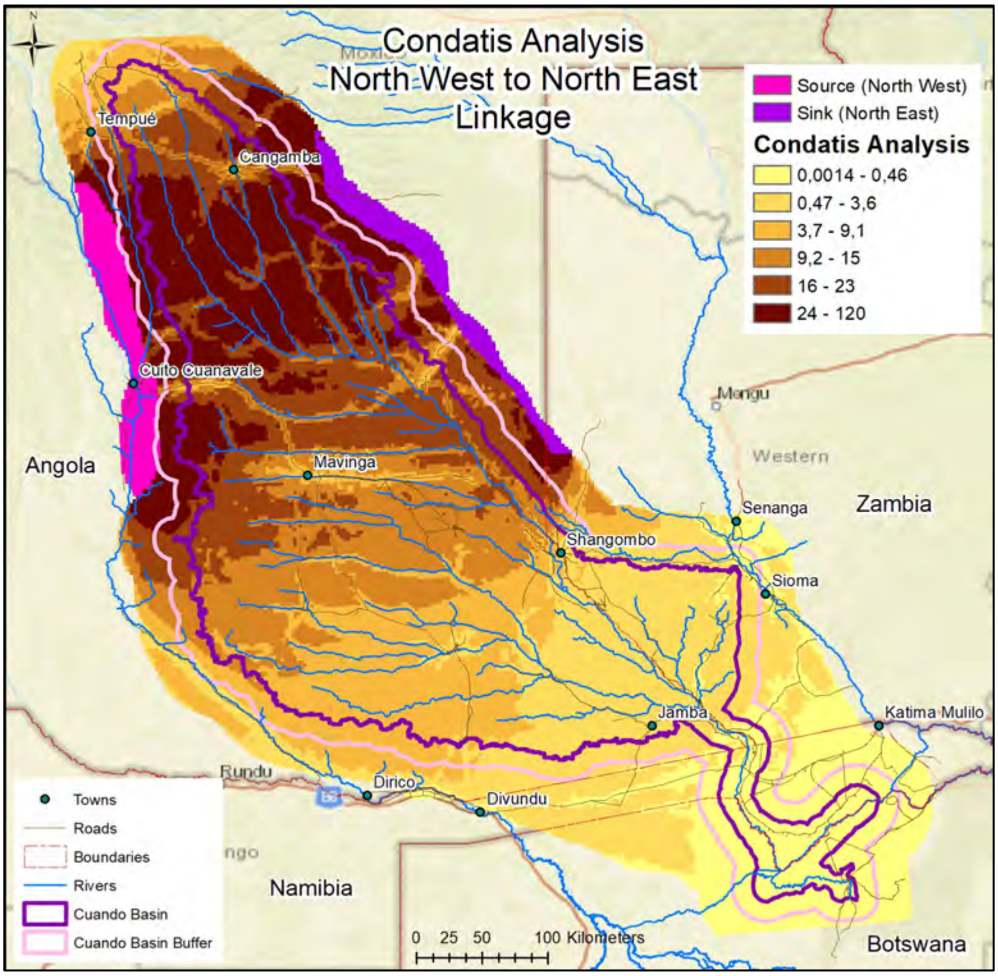


Figure 43: Condatis analysis results of most important areas for landscape connectivity between the North-west to North-east to focus on linkages in the Water Tower area.

Based on the Condatis analysis, the highest value areas for landscape connectivity from each of the analyses were mapped (Figure 40 to Figure 43). These effectively delineate the higher value landscape connectivity pathways so that they can be included as features in the MARXAN analysis, as shown in the maps below (Figure 44 to Figure 47).

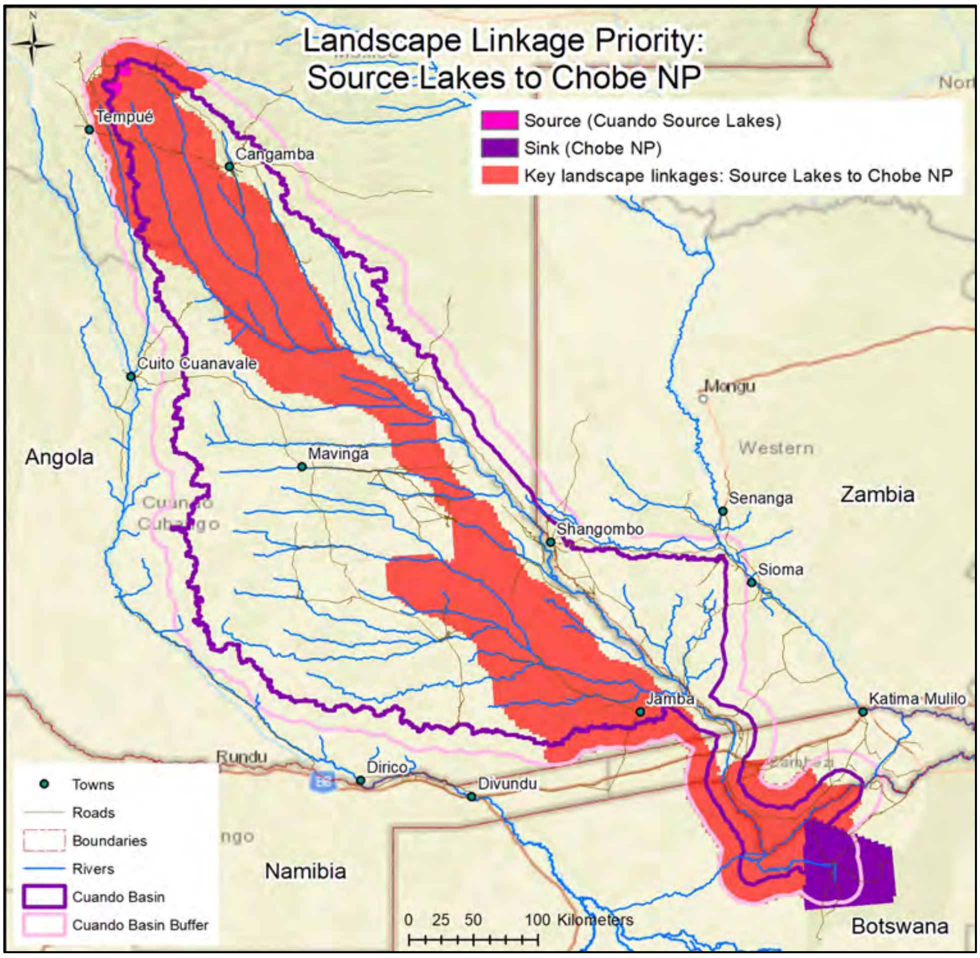


Figure 44: Key areas for landscape connectivity between the between the Source Lakes and Chobe NP. Note that the Source Lakes feature is used as a geographical anchor in the upper catchment for the linkage analysis. This does not imply that specific terrestrial animals would ever move from the Source Lakes to Chobe NP.

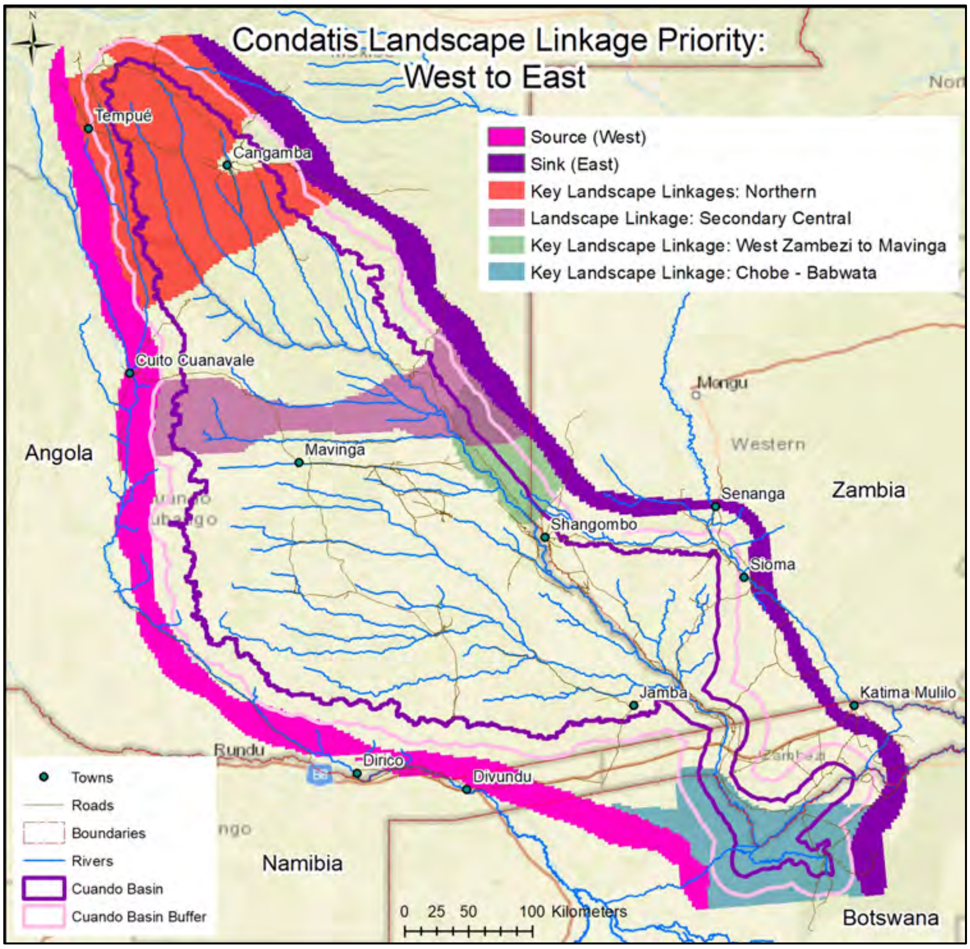


Figure 45: Key areas for landscape connectivity between the Western Edge to the Eastern Edge of the Cuando Basin.

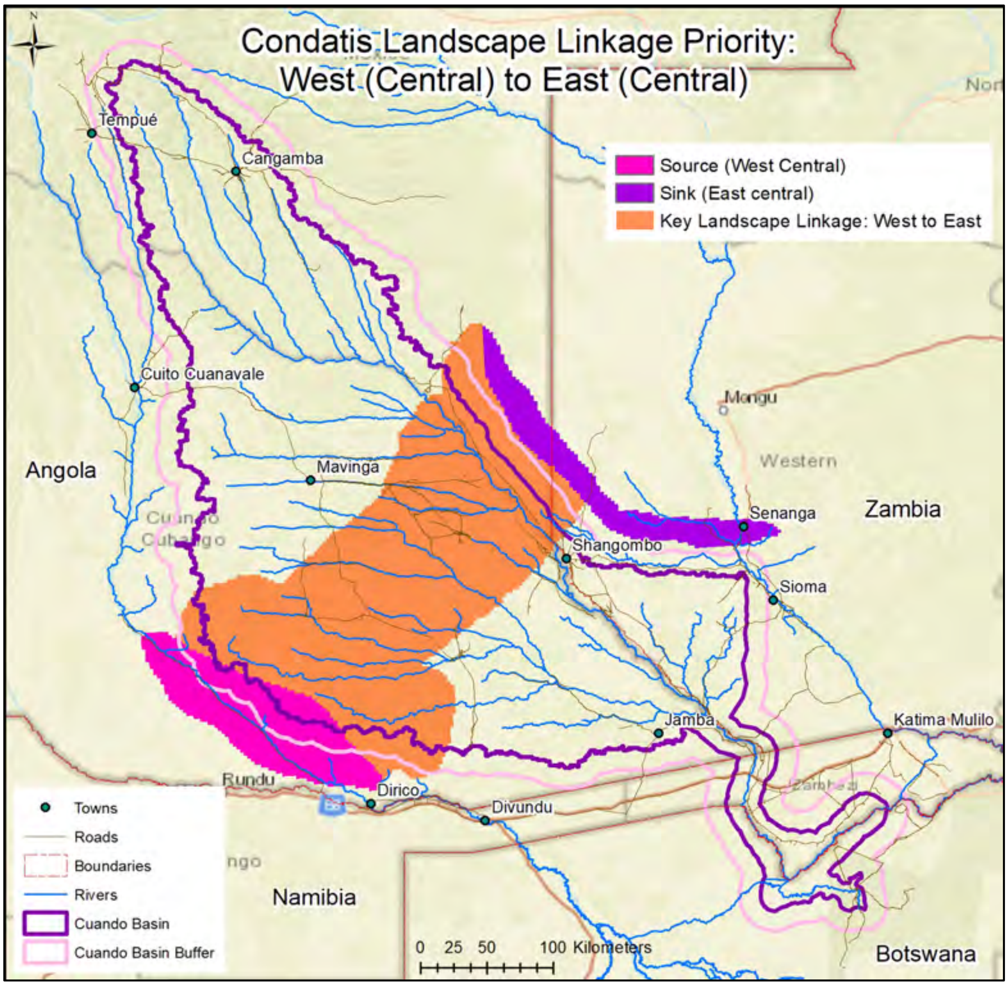


Figure 46: Key areas for landscape connectivity between the between Central west to Central east (specifically to examine the Mavinga to Zambia connectivity).

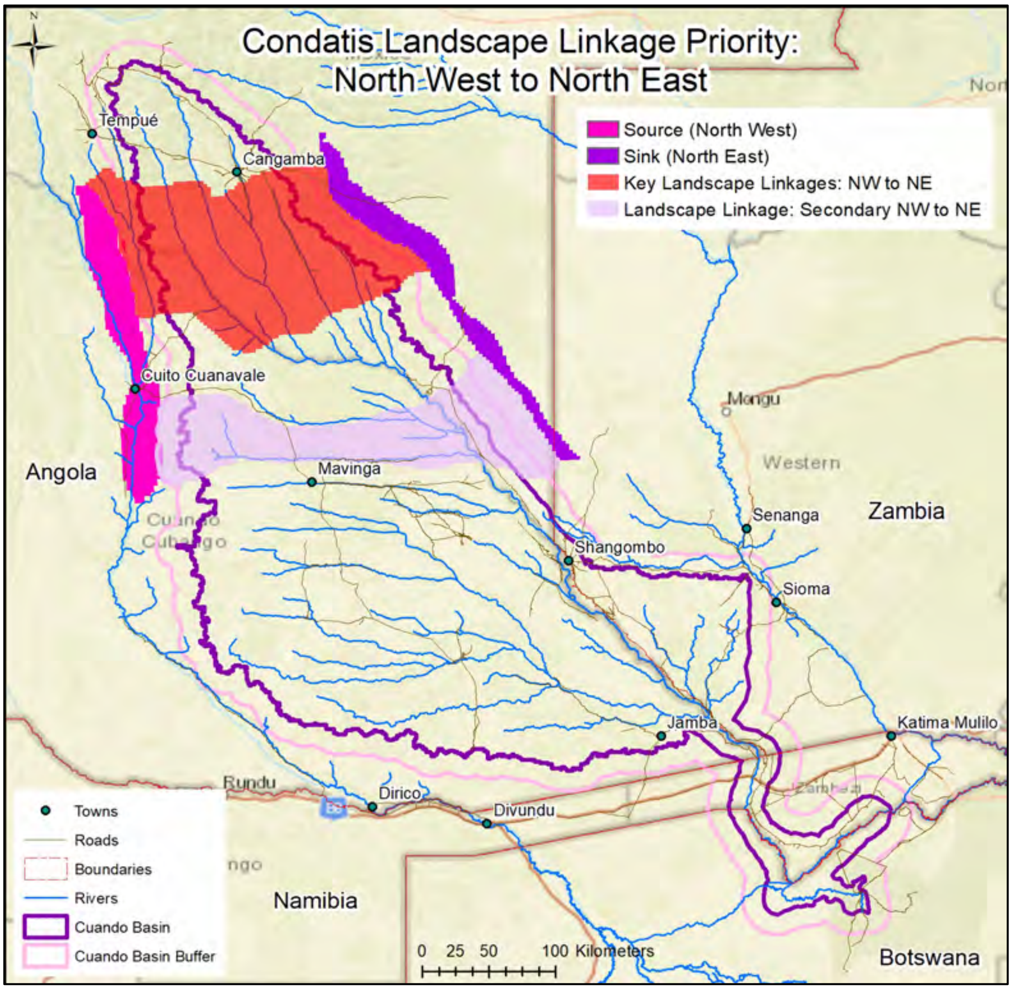


Figure 47: Key areas for landscape connectivity between the North-west to North-east (focus on linkages in the northern Water Tower area).

Link to Valued Ecosystem Components (VECs)

These connectivity features are directly linked two VECs:

- **VEC 4 – Western flanks of the Cuando**. The connectivity analysis is directly supportive of wildlife presence and movement in the VEC.
- **VEC 5 – Wildlife corridors and ecological connectivity.** All features directly reflect importance for wildlife corridors and connectively across the Cuando River Basin.

Data providers

New analysis by the current project. See cost surface section (from page 75) for source of linkage suitability input layers.

Cost Surface: Socio-economic, landcover and land use cost features

Cost surface approach and components

An overall cost surface layer (Figure 58 on Page 86) was used in the MARXAN analysis in order to ensure an efficient solution and to avoid areas that are in **poor ecological condition** (e.g. transformed landcover classes such as urban or arable fields, or with recent forest cover loss), are **highly accessible** (e.g. near roads or settlements), or have **high socio-economic cost** (e.g. are cultivated or have high building densities).

The overall cost surface is derived from the socio-economic cost layers depicted in the maps below (Figure 48 to Figure 57) and summarized in Table 8.

The integration of these components in the MARXAN Cost Layer are examined in the section starting on Page 86.

Description

Socio-economic and land use components were incorporated into the conservation planning process via a cost surface approach. The socio-economic cost layers for the Cuando Basin planning domain (as shown in Figure 48 to Figure 57) consisted of available relevant socio-economic, landcover and land use data. We used the available data on proximity to larger roads, access by any road or track, average distance to roads, proportions of transformed landcover types (i.e. cropland and settlements), areas with the lowest wilderness characteristics, accessibility to urban centres, and building density which is a proxy for human population (as listed in Table 8).

Overview of data sources and incorporation into planning

Table 8 outlines the data sources and how the individual costs surface elements were processed.

Table 8: Elements incorporated into the cost surface for use in MARXAN.

Data	Data Source	Processing Summary
Proximity to larger roads	Open Street map data from http://download.geofabrik.de/africa.html Roads data collated for the four countries.	Major, tertiary, secondary and secondary access roads buffered by 2,5 km with a score of 100, 5 km with a score of 50, and 10 km with a score of 25.
Any access by any road or track	Open Street map data from http://download.geofabrik.de/africa.html Road and track data collated for the four countries.	Any planning unit within 1km of an access road (all categories including tracks) was allocated a score of 100.

Data	Data Source	Processing Summary
Average distance to roads	Open Street map data from http://download.geofabrik.de/africa.html Roads data collated for the four countries.	Average distance in kilometres calculated for each 100m pixel. Values split into 10 quantiles and scored from 0-100. Then the average score for each planning unit was calculated. Highest cost areas are those with the lowest average distance to roads.
Transformed landcover classes: Cropland and Settlements	Transformed landcover classes derived from the 2016 European Space Agency CCI 20m Africa static Landcover data. Note that although this is not the newest landcover, it was the best for the Cuando region. Based on the landcover urban/settlement areas cover well under 1% of the planning domain and croplands cover approximately 1.5% of the domain.	These data classes were used in the calculations set out in the following transformed landcover classes assessment. There is potential to improve the landcover used in the costs surface. The transformed landcover classes were derived from the 2016 European Space Agency CCI 20m Africa static Landcover data. There are known accuracy issues, especially in terms of agricultural fields data north and south-east of Licua. These areas are likely to be natural woodlands of high conservation value. We did not alter the analysis as these areas were already included as priorities, and alterations would have required a complete re-analysis which was beyond the scope of the project.
Cultivated areas and settlements	Landcover data from the 2016 European Space Agency CCI 20m Africa static Landcover data. Urban/settlement and cropland landcover classes extracted.	Area of planning unit that is urban/settlement or cultivated, reclassified to a proportion using formula 100*n/n95 where n95 is 95 percentile for cultivation values. See note above on the accuracy of the landcover.
Areas with the lowest wilderness characteristics	Last of the Wild data from Last of the Wild Project, Version 3 (LWP-3): 2009 Human Footprint, 2018 Release (Venter et al., 2018). The data is from the Wildlife Conservation Society (WCS) and the Center for International Earth Science Information Network (CIESIN) at Columbia University to identify the last remaining 'wild' areas on the Earth's land surface, measured by mapping and measuring the extent of human ecological footprints.	Mean values from the underlying dataset were calculated for each planning unit. The values were inverted so that the least wild areas have the highest cost. These were then reclassified to a proportion using formula 100*n/n95 where n95 is 95 percentile. Values over 100 were reclassified as 100 to deal with the skewed distribution.
Access to urban centres	Data from "A global map of travel time to cities to assess inequalities in accessibility in 2015" (Weiss et al., 2018).	Data on accessibility (time/distance) from major urban centres reclassified into 10 quantiles for the study area. Mean value per planning unit calculated. Reclassified to range 0-100 using

Data	Data Source	Processing Summary
		using formula n/nmax where nmax is highest mean accessibility for a planning unit.
Density of buildings	Global Google-Microsoft Open Buildings Dataset. This dataset consolidates Google's V3 Open Buildings and Microsoft's most recent Building Footprints, comprising a staggering 2,534,595,270 footprints. As of September 2023, it stands out as the most comprehensive openly accessible dataset.	The number of buildings (building centroids) for each planning unit were counted. There were 181 109 buildings within the Cuando Basin and its buffer. Total values per planning unit were reclassified to range 0-100 using using formula 100*n/n90 where n90 is the 90^{th} percentile of number of buildings per planning unit within the planning domain. Values over 100 were reclassified as 100 to deal with the skewed distribution.

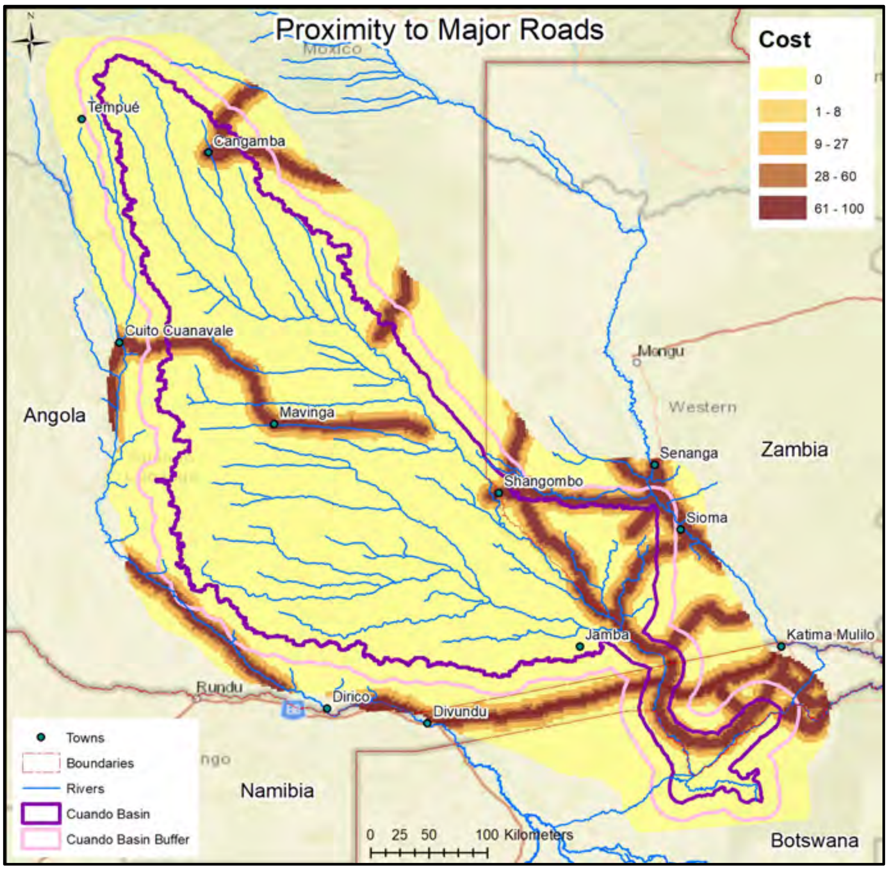


Figure 48: The socio-economic cost layer - proximity to larger roads - for the planning domain.

Figure 49: The socio-economic cost layer - access by any road or track - for the planning domain.

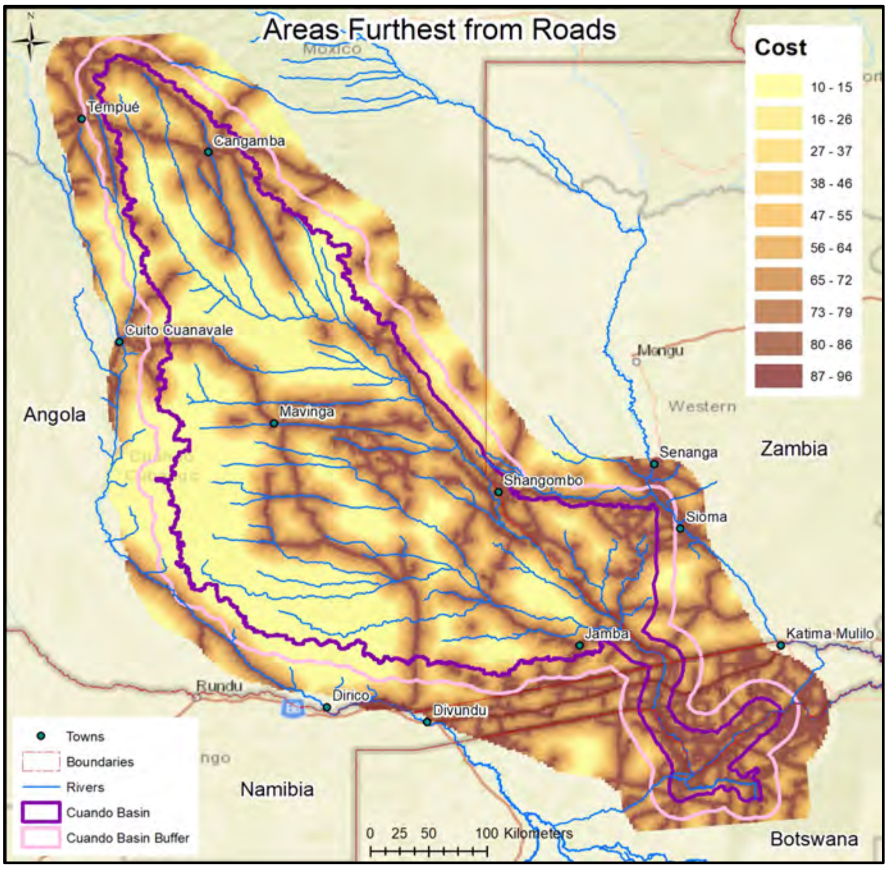


Figure 50: The socio-economic cost layer – areas furthest from roads - for the planning domain.

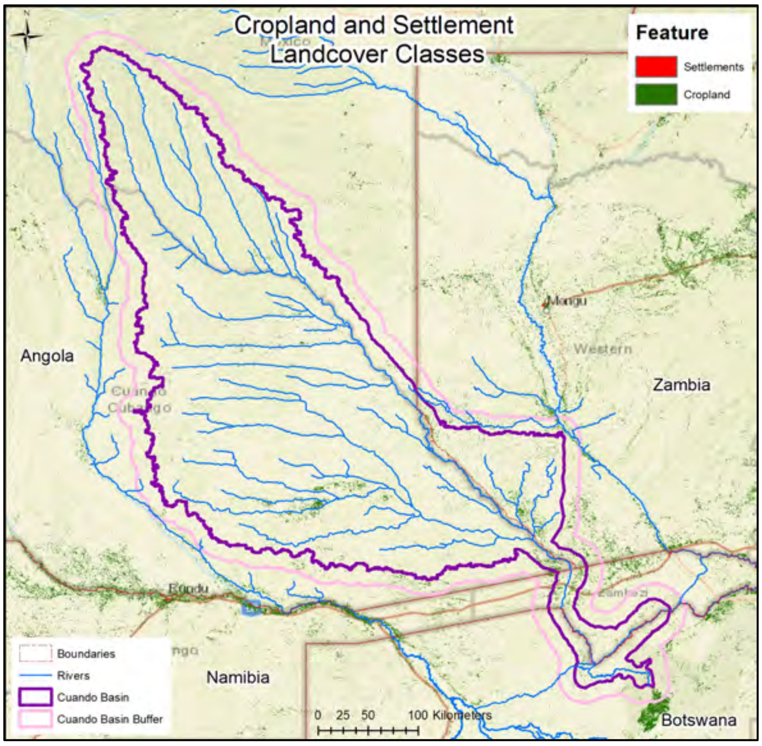


Figure 51: The socio-economic cost layer - croplands and settlements - for the planning domain. Transformed landcover classes derived from the 2016 European Space Agency CCI 20m Africa static Landcover data. Note that the landcover data has falsely identified some woodlands (e.g around Licua) as croplands. See note in Table 8.

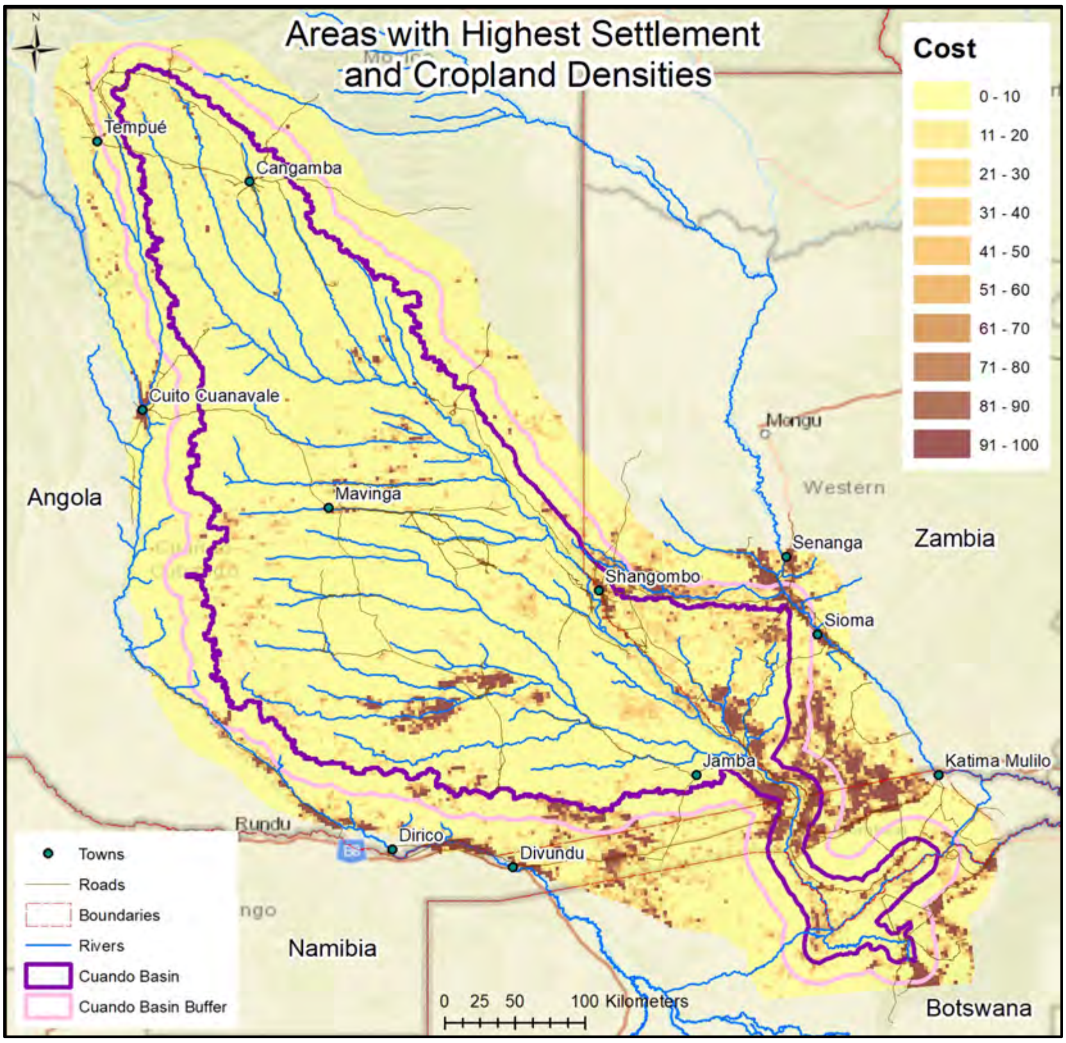


Figure 52: The socio-economic cost layer – areas with the highest settlement and cropland densities - for the planning domain. Note that the landcover data has falsely identified some woodlands (e.g around Licua) as croplands. See note in Table 8.

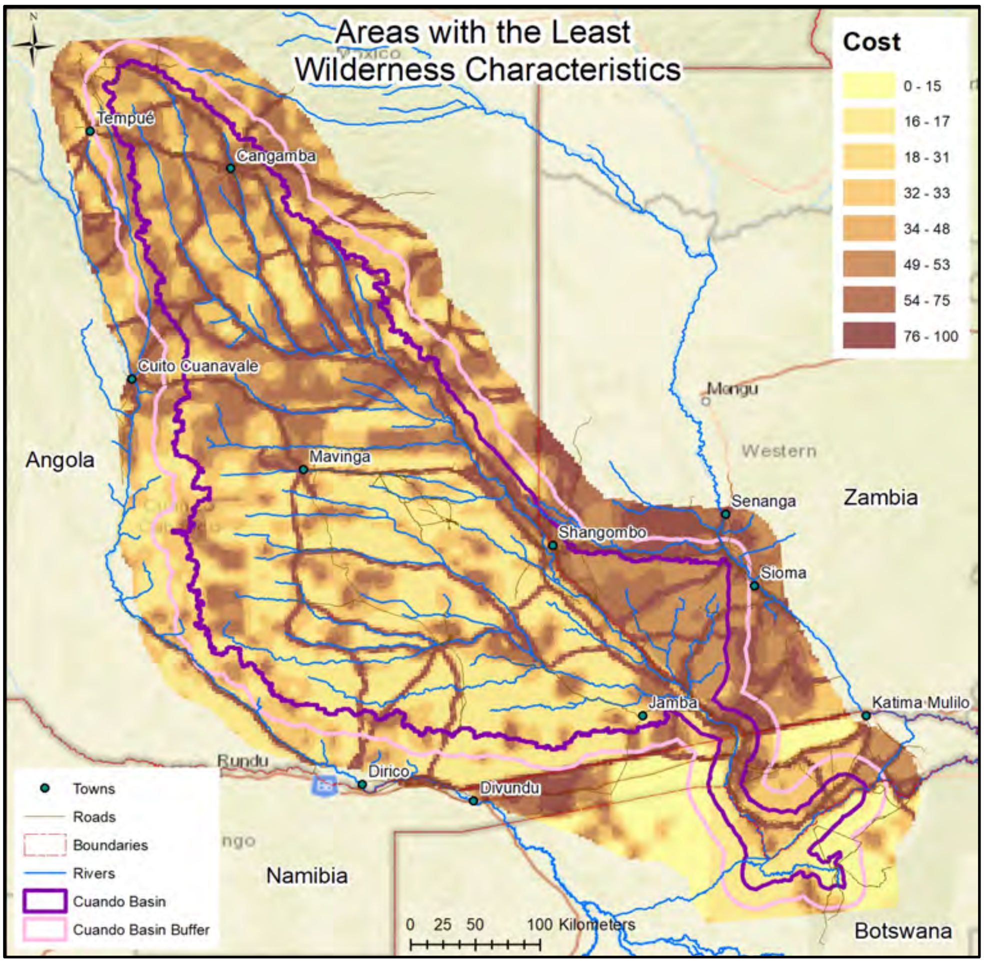


Figure 53: The socio-economic cost layer- areas with the least wilderness characteristics - for the planning domain. Data from the Last of the Wild Project, Version 3 (LWP-3): 2009 Human Footprint, 2018 Release (Venter et al., 2018).

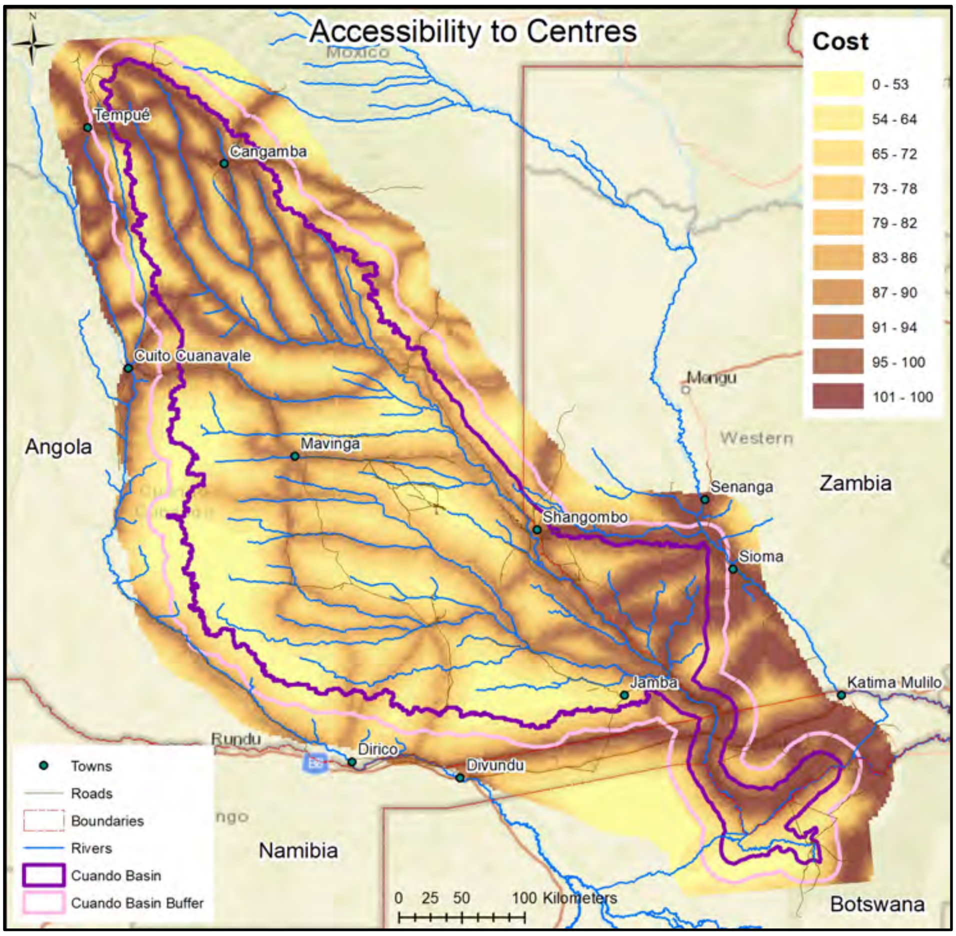


Figure 54: The socio-economic cost layer - accessibility to main centres - for the planning domain. Data from “A global map of travel time to cities to assess inequalities in accessibility in 2015” (Weiss et al., 2018).

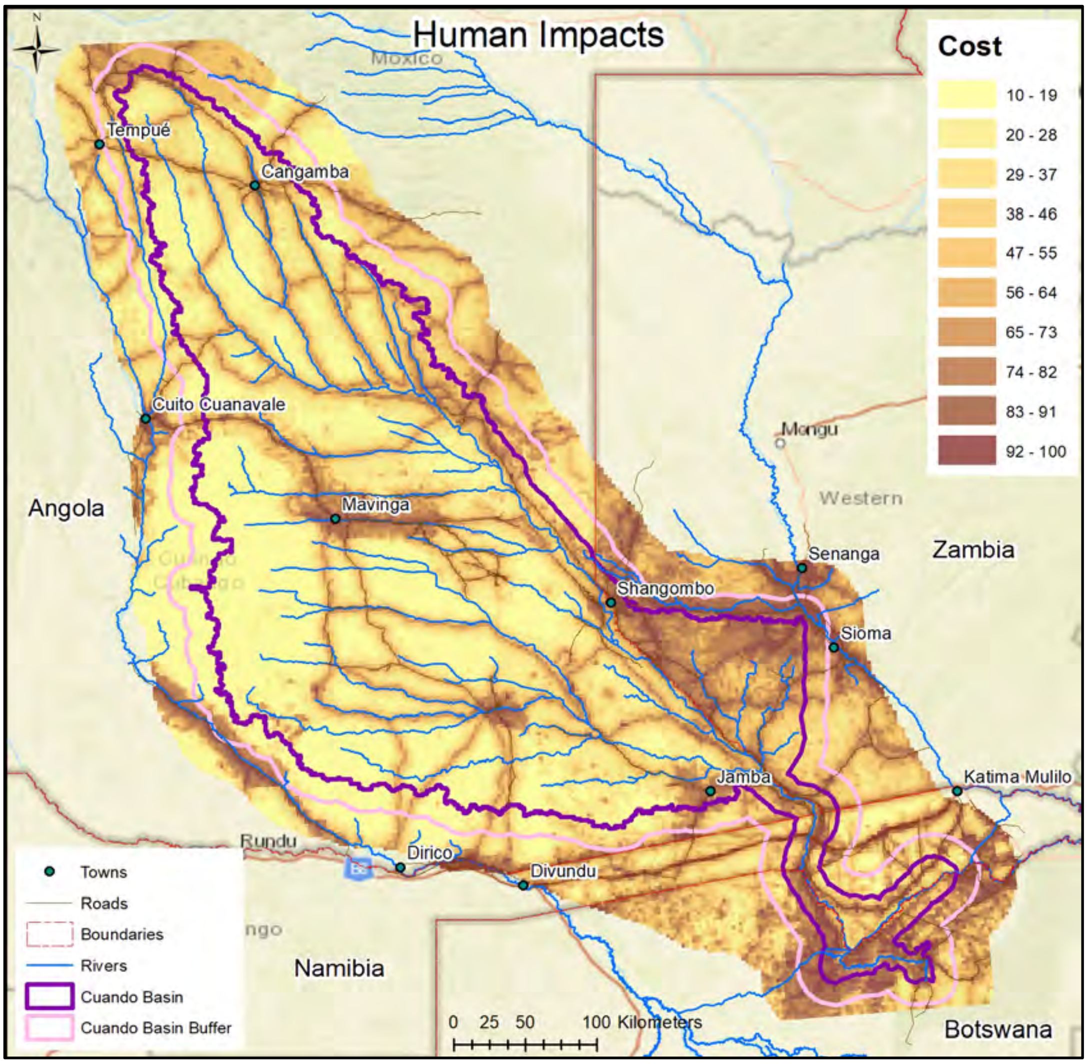


Figure 55: The socio-economic cost layer – human impacts - for the planning domain. Data from the Last of the Wild Project, Version 3 (LWP-3): 2009 Human Footprint, 2018 Release (Venter et al., 2018).

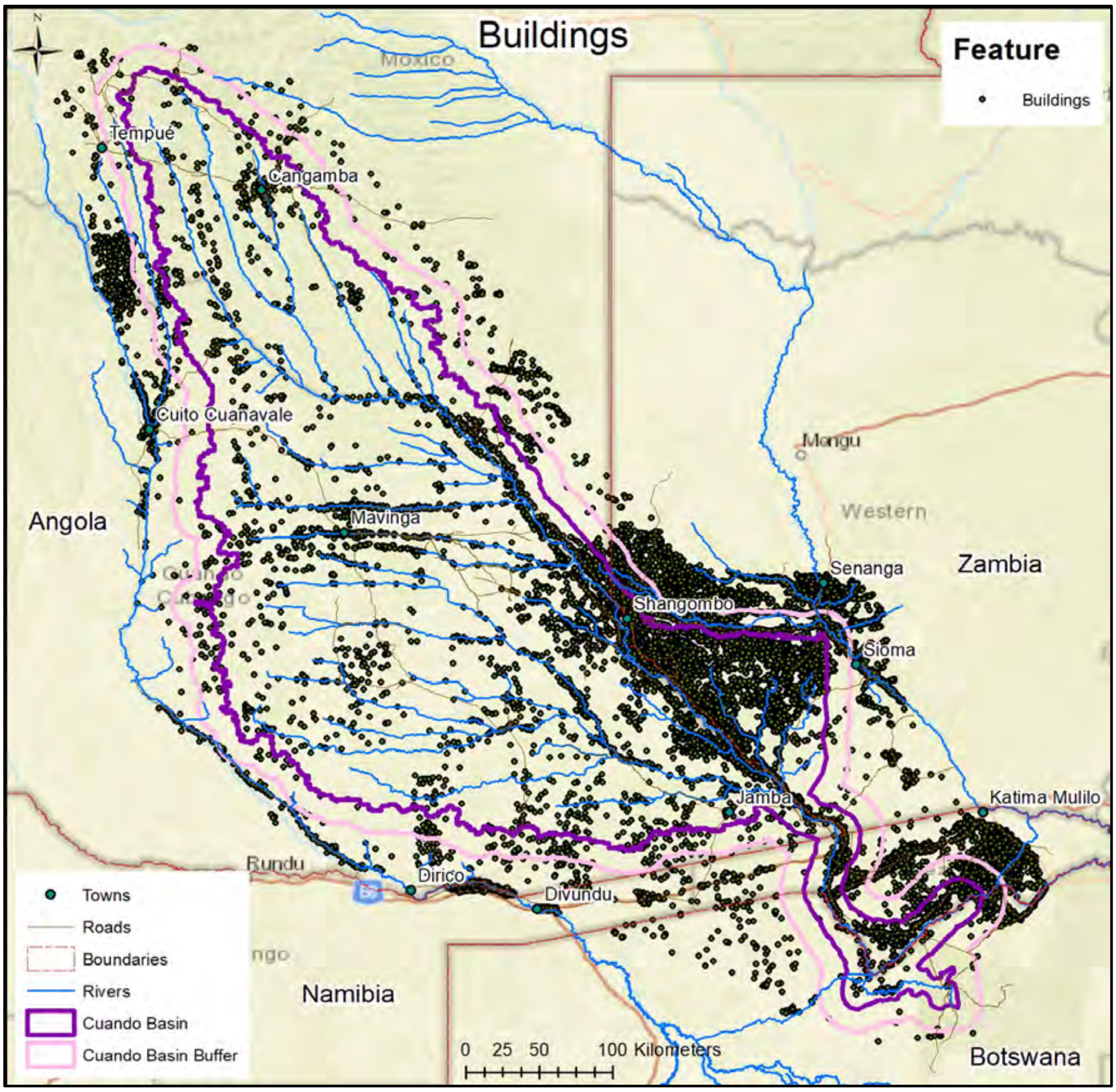


Figure 56: The location of buildings across the planning domain was derived from the 2023 Global Google-Microsoft Open Buildings Dataset. This dataset consolidates Google's V3 Open Buildings and Microsoft's most recent Building Footprints. This was used to develop the building density cost surface shown in Figure 57.

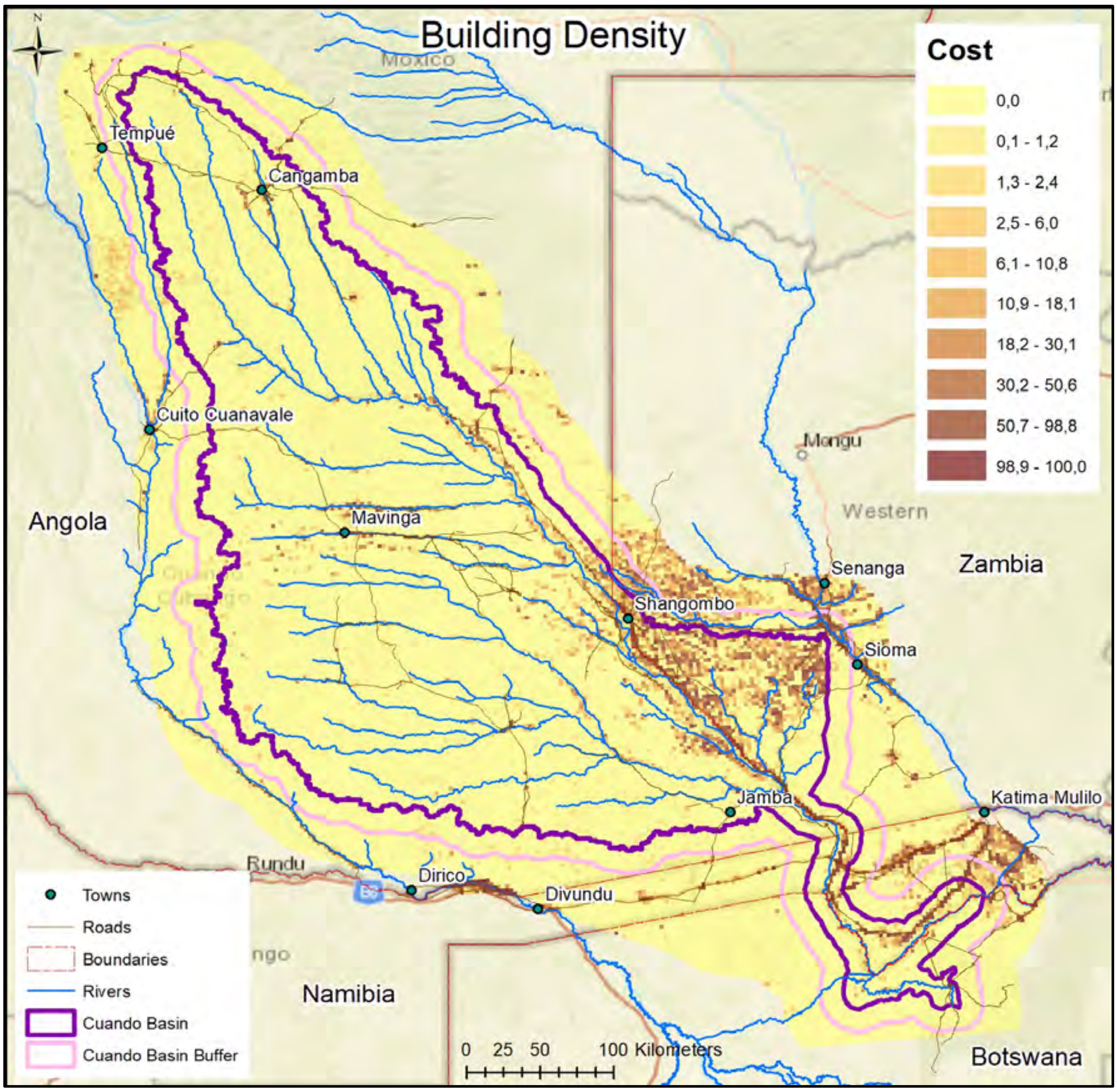


Figure 57: The socio-economic cost layer – building density - for the planning domain. Data derived from the 2023 Global Google-Microsoft Open Buildings Dataset. This dataset consolidates Google's V3 Open Buildings and Microsoft's most recent Building Footprints.

MARXAN Cost Layer

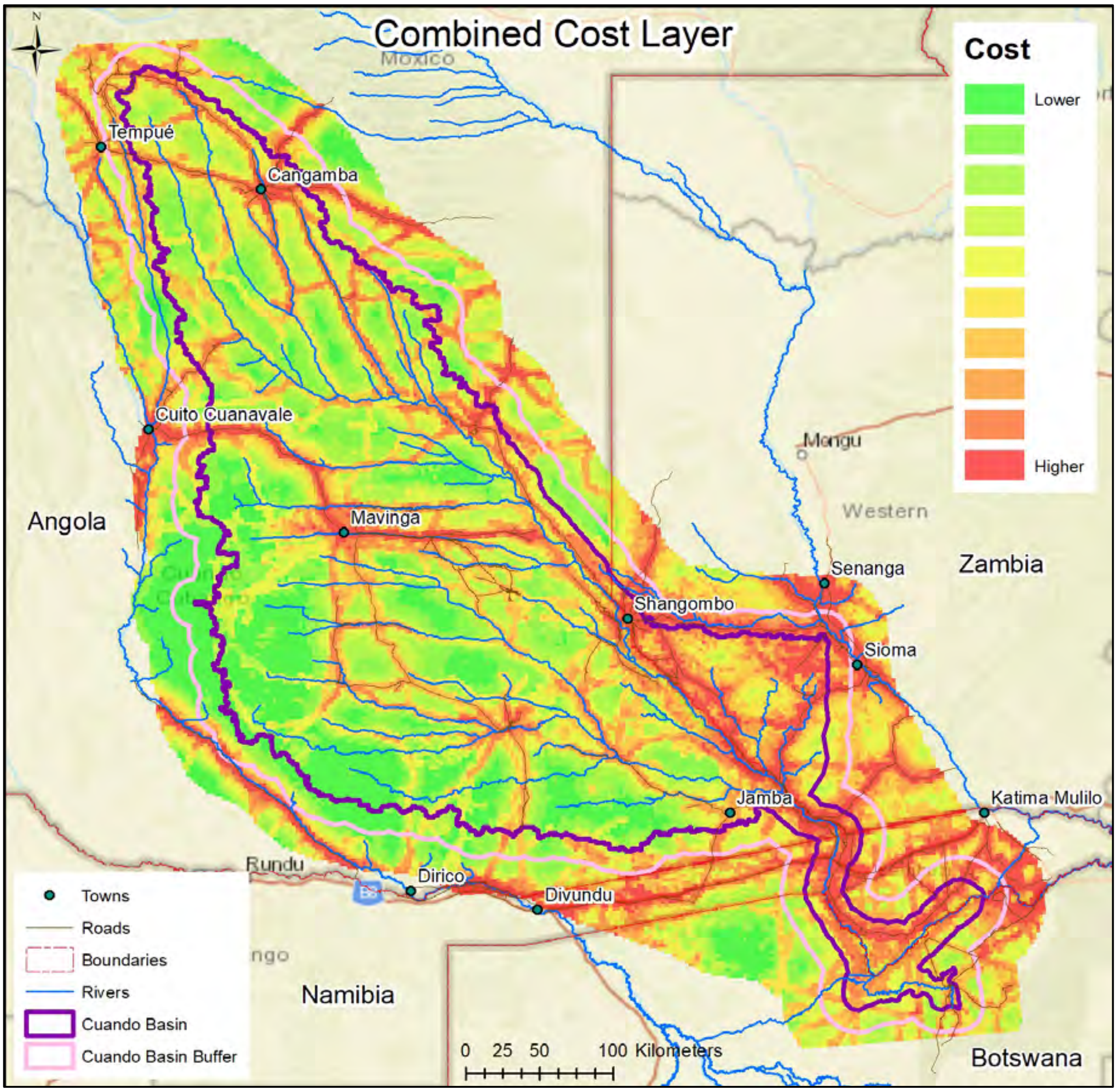


Figure 58: The overall cost surface layer used in the MARXAN analysis for the Cuando Basin planning domain.

Description

A cost surface (Figure 58) was used in the MARXAN analysis in order to ensure an efficient solution and to avoid areas of high socio-economic cost, that are in poor ecological condition or that are used intensively by activities that are largely incompatible (at least at higher intensities) with maintaining areas in a natural or semi-natural state. We used the available data on proximity to larger roads, access by any road or track, average distance to roads, proportions of transformed landcover types (i.e. cropland and settlements), areas with the lowest wilderness characteristics, accessibility to urban centres, and building density which is a proxy for human population. See the previous section for the detailed description of the underlying data layers used in the cost surface.

Overview of data sources and incorporation into planning

As described in the previous section, each of the input layers was scaled from 0-100. This allows layers to be easily combined. After some experimentation, the simplest method for combining the data was chosen, and an equal weighted approach was used. Note that after initial MARXAN calibration runs, each cost surface input value was multiplied by 10, to ensure an appropriate balance between these cost elements and the environmental features. The SCP process deliberately used a multi-variate approach with a number of co-varying datasets. This ensured that the final results were driven by overall trends rather than being potentially undermined by local errors in individual datasets. For example, there are known accuracy issues, especially in terms of agricultural fields data.

The cost surface was built up of the following elements detailed in the "Cost Surface" Section:

- Area of the planning unit in hectares.
- Socio-economic data, including:

Data Layer
Proximity to larger roads
Any access by any road or track
Average distance to roads
Proportions of transformed landcover types (croplands and settlements)
Areas with the lowest wilderness characteristics
Access to urban centers
Building density

The final cost surfaces are shown in Figure 48 to Figure 57 above.

Systematic Conservation Planning Results

MARXAN Conservation Prioritizations

The MARXAN process attempts to meet targets for all the features (in this case ecological and sustainable use features) in areas that are in the best possible ecological condition (i.e. favouring good and fair condition sites before poor condition sites), in a configuration that minimizes cost and conflict with other users of the region (e.g. cultivation, settlements), and that is spatially connected (i.e. favours selecting coherent areas of adjacent planning units rather than a disconnected scatter of selected planning units) because this is ecologically preferable.

It is easy to assume that there is one single answer to a conservation planning problem, however this is not generally the case. There are numerous issues related to the overall objectives of the planning exercise (e.g. for Protected Area Expansion or for land use controls), the relative balance between different biodiversity features (e.g. different emphases on corridors and connectivity, threatened species or hydrological processes), and the relative ambition of the conservation actions. The current planning process is an initial rapid systematic conservation plan rather than a definitive single blueprint. Because of these issues, it is important that we explore a range of conservation planning scenarios. The scenarios approach that we have taken involves:

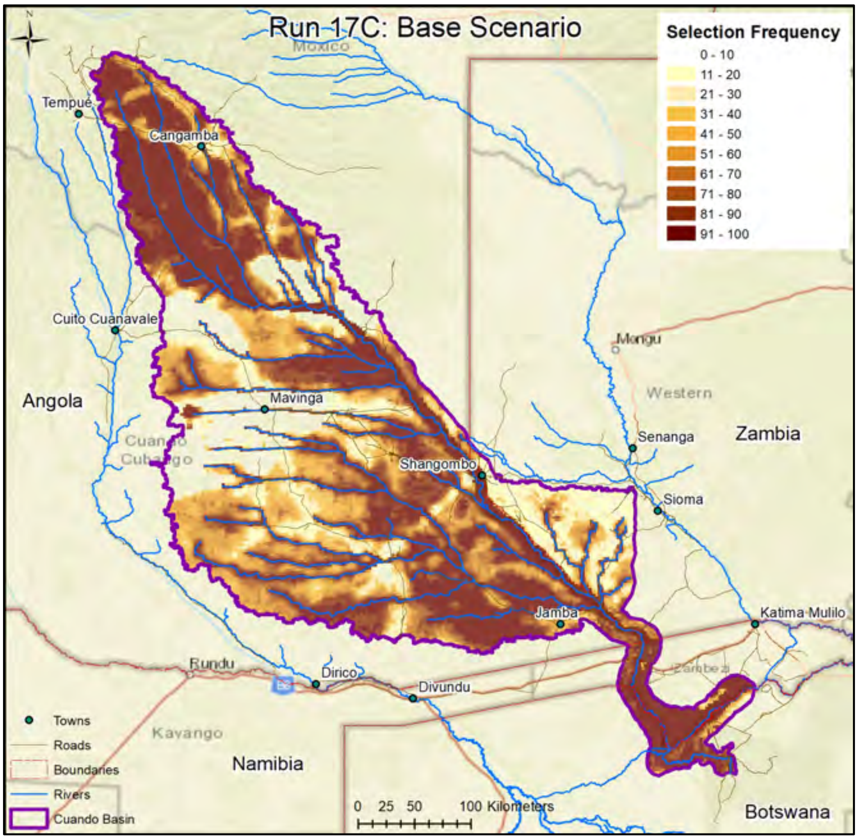
- Building a basic SCP framework that includes all relevant and available biodiversity data and socio-economic cost data.
- Using different target combinations to influence the relative balance between different elements:
    - Ecosystems Species.
    - Landscape connectivity.
    - Hydrological features.
    - The level of land hungriness of conservation planning results.
    - The relative focus on landscape connectivity.
    - The relative focus on existing protected areas and other conservation areas.
    - The relative focus on terrestrial versus aquatic features.
    - The relative focus on areas with wilderness characteristics versus areas that are under human pressure.
- Undertaking a conservation planning process for each of **seven main conservation scenarios**. The specific targets used for each scenario are detailed in Table 5. The primary result of each MARXAN analysis is a selection frequency surface (Figure 59; maps 1 - 7), i.e., how often a planning unit is selected as part of an efficient solution out of a user-defined number of runs of the scenario. This value indicates the irreplaceability of features within a planning unit, and the output map is usually referred to as an **irreplaceability map or selection frequency map**. The MARXAN selection frequency map shows 10 selection frequency categories (with percentage values of 0% – 100%)., to high selection frequency where a planning unit was selected more than 90% of the time.
- The **seven main conservation prioritizations** for the Cuando Basin planning are:

Scenario	Features / Definitions
Base Case (Run 17c)	Targets of 30-50% were used for most biodiversity features, with higher targets for high conservation value special features (e.g. wetlands, peat wetlands), process areas (e.g. key landscape linkages, floodplains) with lower targets for ecosystem types, species, and areas with wilderness characteristics.

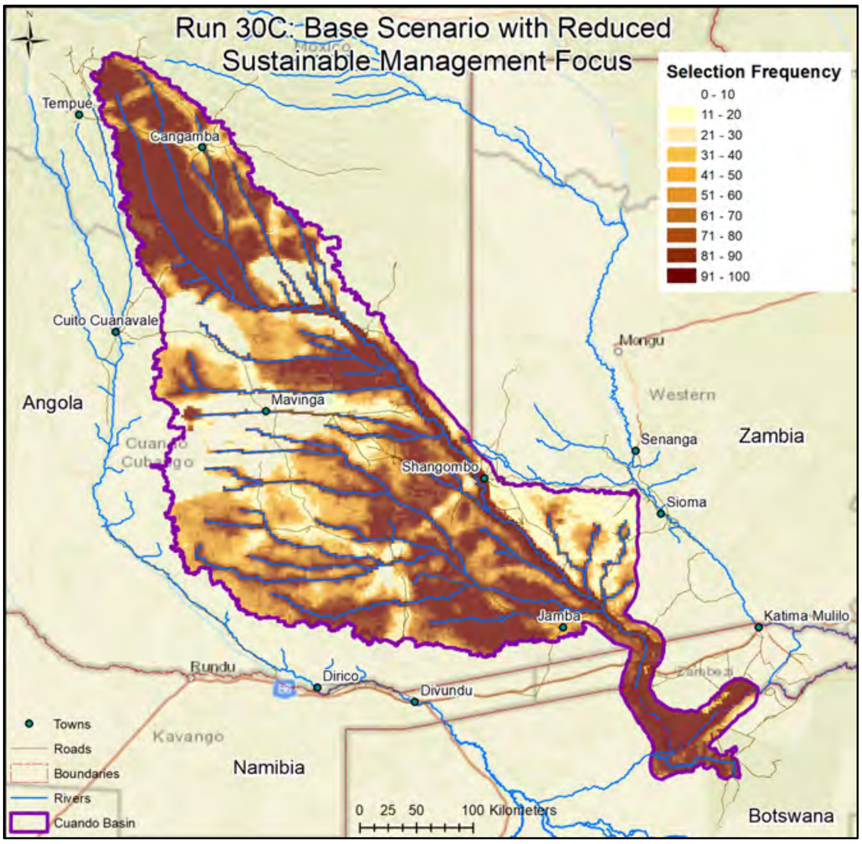
Base with reduced sustainable management focus (Run 30c)	This was as for the base case, but with reduced targets for existing conservation management areas (e.g. the game management area) to avoid forcing selection into some "sustainable management" areas which actually have relatively high levels of human impact.
Areas outside existing Protected Areas (Run 31)	Targets and cost surfaces were as per the base case, but formal Protected Areas were hardwired into the results. This run allowed us to identify features of high importance that were largely outside of the PA network. It however deprioritizes the portions of features that are outside of PAs, where large areas are already inside PAs, even if these features are important.
Species focused scenario (Run 28C):	Higher conservation targets for identified priorities for species.
Hydrologically Focused Scenario (Run 25C):	Higher targets for hydrological linked features – wetlands, rivers, discharge, important catchment areas etc.
Natural Landscape Focused Scenario (Run 26):	Targets as for the base case, but significantly higher cost values, and consequently with much stronger avoidance of human impacted landscapes.
Wilderness and connectivity (Run 27b):	Higher targets for wilderness and connectivity linked features, with strong avoidance of human impacted landscapes Existing Protected Areas were also strongly favoured.

- The results of the seven prioritizations for the region were then integrated into a single overall prioritization (Figure 60). The results are covered in the next section.

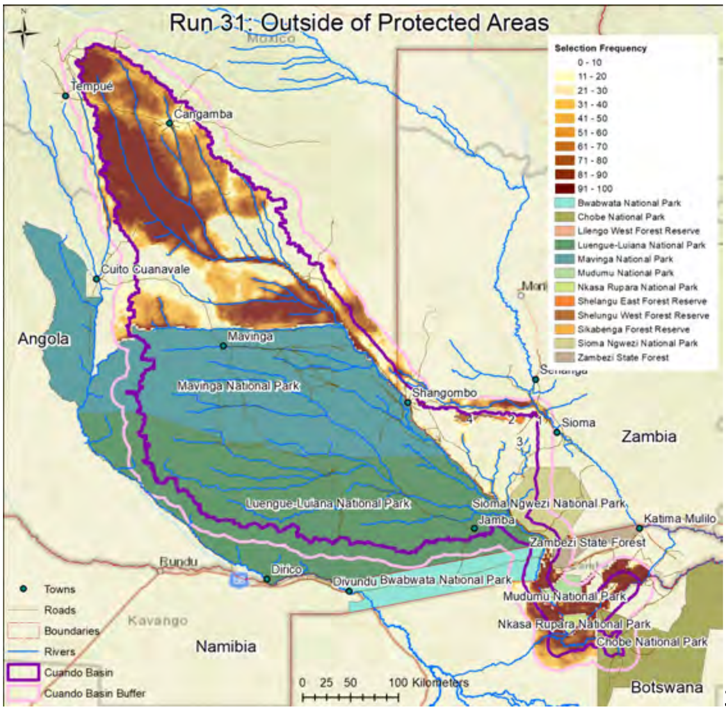
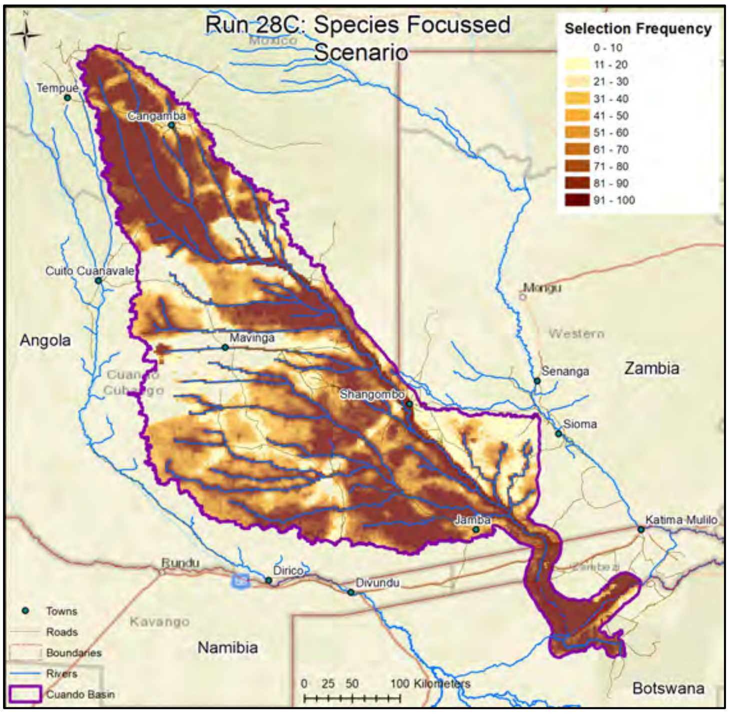
MARXAN Spatial Prioritizations (Selected) 1 - 7



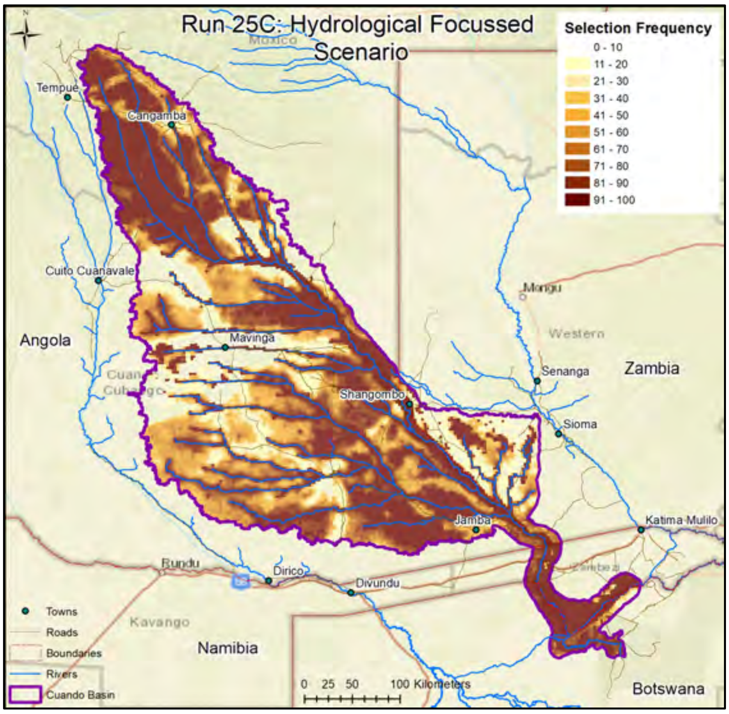
1



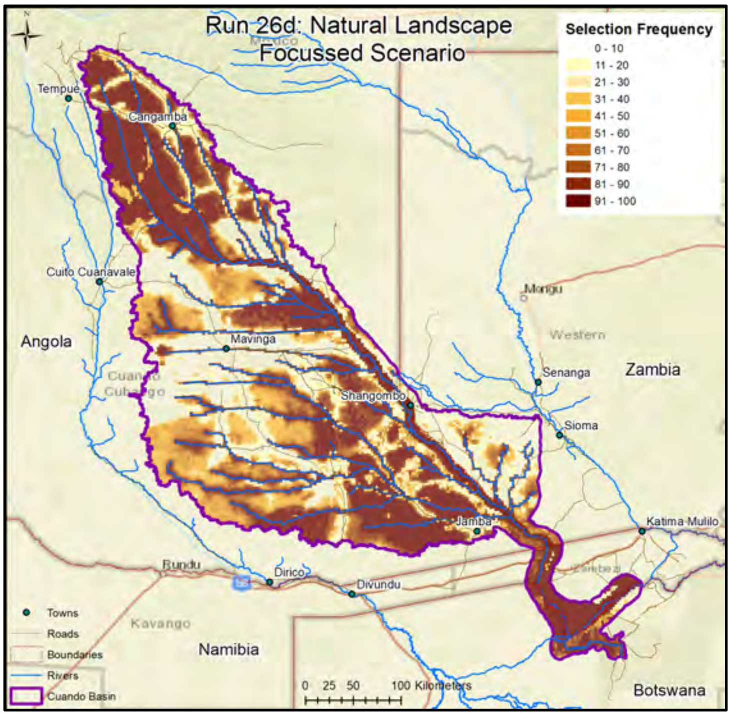
2

MARXAN Spatial Prioritizations (Selected) 1 - 7
 3
 4

MARXAN Spatial Prioritizations (Selected) 1 - 7

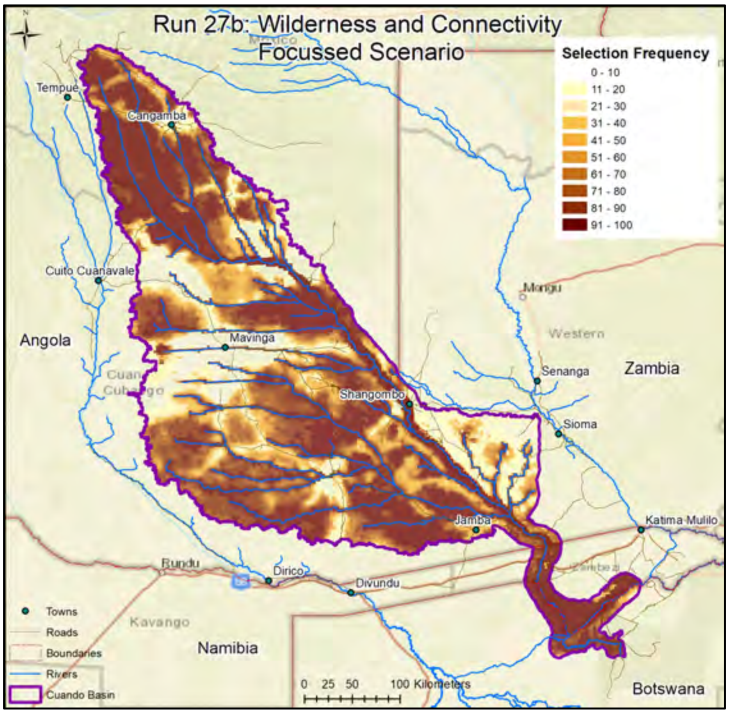


5



6

MARXAN Spatial Prioritizations (Selected) 1 - 7



7

Figure 59: MARXAN Selection Frequency for the seven conservation planning scenarios derived for the Cuando River Basin rapid systematic conservation plan.

Integrated Prioritization

The various conservation planning runs showed strong overall patterns / similarities. Key differences included the level of focus on existing conservation initiatives, connectivity areas, wetlands and wilderness areas. However, given that the overall scenarios had strong similarities in selection areas, we have developed an integrated layer based on the mean selection frequency for individual planning units across the seven scenarios. The **Integrated Marxan Results Layer** was recommended for the final conservation prioritization plan for the region (Figure 60). This was based on a review of the selected areas and the view that this was most closely linked to the purpose of the planning process. A limited review process was undertaken to confirm selection areas and ensure alignment with the SEA objectives.

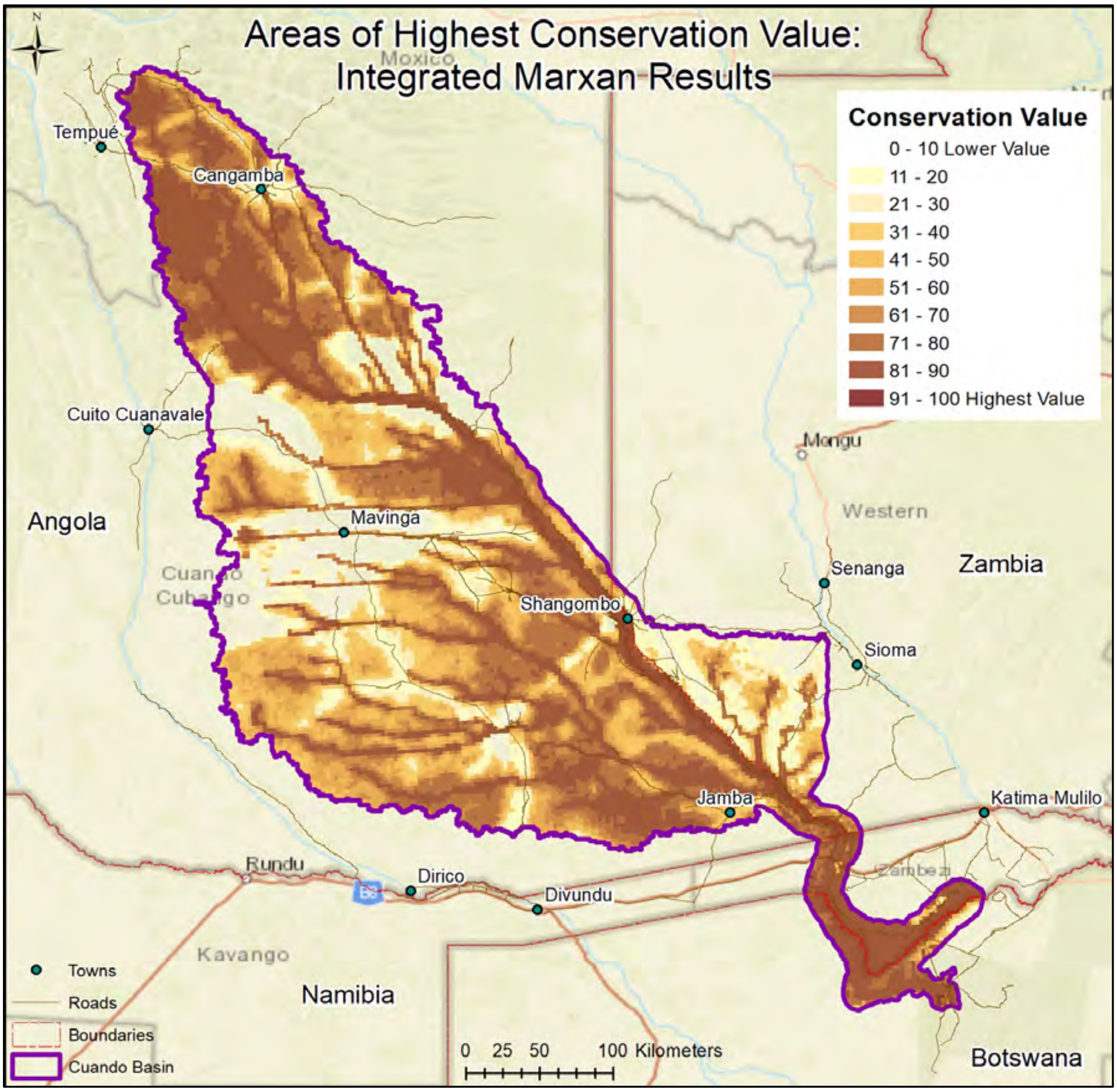


Figure 60: Areas of Highest Conservation Value were identified based on the mean selection frequency across the seven favoured Marxan scenarios. This integrated prioritization was used as the basis for identifying landscape categories for inclusion into the SEA, and guide catchment sustainability and conservation actions.

Areas of Highest Sustainable Management and Conservation Value

The rapid Systematic Conservation Plan (SCP) for the Cuando River Basin was used to identify areas of highest value for sustainable management and conservation actions aligned with the VECs identified in the SEA (SAIEA, 2024). The categorisation of the landscape was done on the basis of the integrated summary of conservation priority (i.e. the mean selection frequency across the seven favoured Marxan scenarios)(Figure 60). An iterative approach was used to allow the identification of thresholds for categories:

- **Critical Areas** – These areas are irreplaceable or practically irreplaceable (i.e. required to meet targets under almost all circumstances and scenarios). These sites had mean Marxan irreplaceability values (or selection frequencies) across the seven scenarios of 90%-100%, which means that they are almost always required to meet targets. These areas are most strongly linked to the VECs.
- **High Value Areas** – These areas have mean selection frequencies of between 70% and <90%. Although it may still be possible to meet targets if some of these areas are lost, in practice these area areas of very high value. If some of these areas are lost then alternate spatial scenarios are likely to be much less efficient. Even limited losses of these areas are likely to result in other sites with similar features immediately becoming "irreplaceable", as they would be identified as being required to meet targets if a new Marxan planning process was undertaken. These areas are strongly linked to the VECs.
- **Medium Value Areas** – These areas have irreplaceability values of between 30% and <70%. They include many high value areas for ecosystem targets, landscape connectivity and wilderness characteristics. Although some specific areas could be lost without necessarily compromising the ability to meet targets, a key issue is the pattern of loss. Fragmentation of these areas could rapidly reduce their value for supporting landscape processes, and could undermine the integrity of linked Critical and High Value Landscape Areas. These areas can be considered to be "ecological support areas" and are important for the overall function of landscape processes which underpin the VECs.
- **Lower Value Areas**- These areas have lower selection frequency of < 30%. However, given the high overall value of the Cuando River Basin, they are still of significant value for supporting overall landscape function and integrity. Significant portions of these areas are directly required to meet targets, but there is some flexibility in the landscape about where the targets are met.

These landscape categories are mapped in Figure 61 and summarised in Table 9. **Critical Areas** cover 4 492 405ha or 36.7% of the Cuando River Basin. Importantly, almost exactly half of these Critical Areas are outside of existing Protected Areas. **High Value Areas** cover an additional 1 856 976ha or 15.2% of the Cuando River Basin. A higher portion of these areas are inside of existing PAs, but nevertheless a substantial area of 755 399ha or 6.2% of the total Cuando River Basin are outside of existing Protected Areas. Together, the **Critical Areas** and the **High Value Areas**, include the most important VECs and areas supporting VECs, and should be a clear focus of conservation and landscape management practices supporting sustainability. Combined, these areas are of highest value as potential protected areas sites for conserving biological diversity, and are highlighted as the most important for immediate conservation actions. The **Medium Value Areas** cover 3 281 823ha or 26.8% of the basin. They are generally less fragmented, have overall higher irreplaceability values than the remainder of the basin, and represent areas with strong wilderness and connectivity characteristics (where these have not already been included in the Critical or High Value categories). These areas are important for overall landscape linkages. Their loss would result in a significant decrease in landscape connectivity. Retaining the overall connectivity and function of these areas should be a focus for landscape management activities. The remaining **Lower Value Areas** cover 21,4% of the basin. These areas are of significantly lower value (relative to the rest of the basin) for supporting VECs than the other landscape categories. However, given the high value of the basin as a whole, on a national or regional scale these sites would undoubtedly be identified as valuable. Significant loss of these areas could undermine the overall integrity of the Cuando River Basin and its VECs.

Table 10 summarises the characteristics of the four spatial planning categories (Critical Areas, High Value Areas, Medium Value Areas and Lower Value Areas), along with the key tools and mechanisms to achieve landscape sustainability and conservation outcomes. The table provides guidance for incorporation into the Draft Strategic Environmental Monitoring Framework (SEMF) for the Cuando River Basin (CURB) set out in the SEA (SAIEA, 2024).

Table 9: The MARXAN irreplaceability analysis for the Cuando River Basin was used to identify areas of highest value for sustainable management and conservation actions aligned with the VECs identified in the SEA. The basin was divided into four categories, which were also stratified according to their location inside or outside of Protected Areas.

Landscape Category	Inside Protected Areas		Outside Protected Areas		Cuando Basin Total	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Critical Areas	2 233 833	18.2%	2 258 572	18.4%	4 492 405	36.7%
High Value Areas	1 101 578	9.0%	755 399	6.2%	1 856 976	15.2%
Medium Value Areas	2 044 634	16.7%	1 237 189	10.1%	3 281 823	26.8%
Lower Value Areas	1 387 156	11.3%	1 236 873	10.1%	2 624 030	21.4%
Grand Total	**6 767 200**	**55.2%**	**5 488 033**	**44.8%**	**12 255 234**	**100.0%**

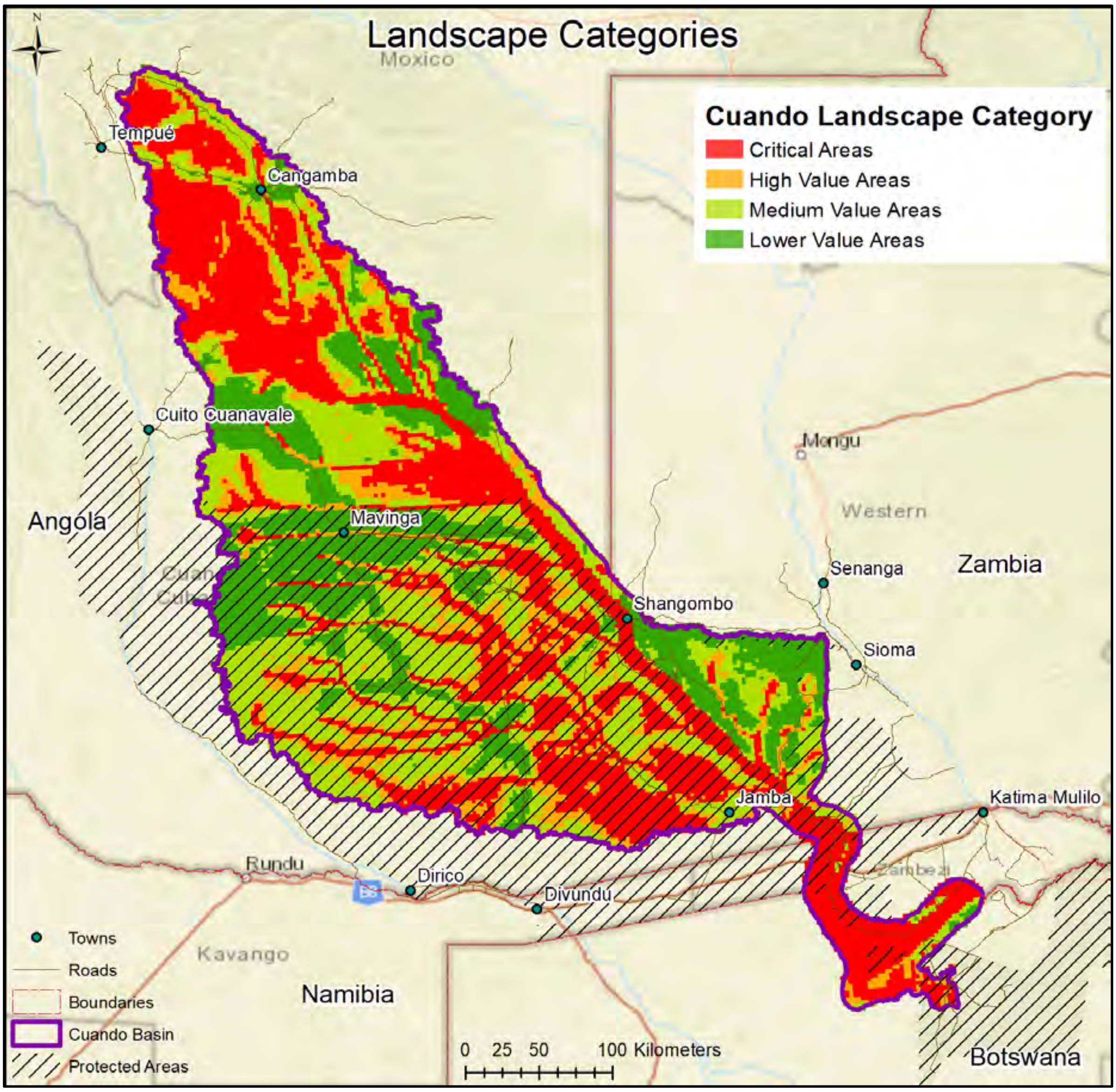


Figure 61: Map of the four landscape categories for sustainable management and conservation actions aligned with the VECs identified in the SEA identified in the MARXAN analysis.

Table 10: Summary definitions of the four landscape categories as depicted in the planning scenarios, with key tools and mechanisms for achieving landscape management and conservation outcomes.

Category	Description	Mechanisms
Critical Areas	• These areas are irreplaceable or practically irreplaceable (i.e. required to meet targets under almost all circumstances and scenarios). These sites had mean Marxan irreplaceability values (or selection frequencies) across the seven scenarios of 90%-100%, which means that they are almost always required to meet targets. These areas are highlighted as the most important for immediate conservation actions and have overall higher irreplaceability values. • These areas are most strongly linked to the VECs. • Biodiversity values are typically the highest. • These areas are most important for overall landscape linkages, and loss of these areas would result in a significant decrease in landscape connectivity. • These areas also tend to have the strongest wilderness characteristics, and are most suitable for strict conservation mechanisms (inclusion in PA or in strict zone with a PA). • They are generally less fragmented, and relative to other areas, the lowest levels of human impacts occur.	• Critical Areas outside of existing PAs are a logical focus for expansion of Protected Areas, especially in the headwaters of the Cuando Basin. These areas would ideally be included in formal protected areas such as national parks and nature reserves. • These areas also tend to have the strongest wilderness characteristics and would be sensible focus areas for declaration of strict protected areas (e.g. national park or equivalent). • Where these areas are already within designated Protected areas, the focus should be on ensuring that the PAs are fully implemented and well managed. Protected area downgrading, downsizing, and degazettement (PADDD) events should be strictly avoided. • Where it is not possible to strictly secure these areas, these areas benefit from mechanisms focused on sustainable use such as Community Forest Reserves. • These areas should be carefully managed to ensure that their biodiversity values (and value as VECs) are not undermined. • Activities that promote and secure wilderness characteristics such as low impact ecotourism. Tourism should be carefully managed to avoid impacts on these areas. • Maintain hydrological functioning and water quality of key river areas and permanent swamps, by avoiding loss of floodplain, strictly managing offtake and avoiding dams and impoundments. This is particularly important in the upstream catchment areas. • Actively protect (especially) the riparian woodland by whatever means possible, especially enforcing a ban on logging within the CURB, curtailing slash-and burn farming, and preventing fires. Maintain integrity of riparian fringe. Avoid clearing of riparian habitat for agricultural or any other form of land use and implement rehabilitation of already impacted areas. • These areas should be appropriately secured in multi-sectoral spatial planning processes and be subject to the strictest possible land use controls. • These areas are likely suitable as offset receiving areas (e.g. to mitigate residual mining impacts).

		• Restore connectivity, by reducing barriers that prevent wildlife from moving through the and between neighbouring systems. The barriers of concern are inappropriately aligned fences and human settlements. Fences (or critical sections) should be removed, and corridors kept open in the gaps between human settlements and fields. These corridors must correspond with known wildlife movement paths, and the gaps need to be wide enough so that they are used. • Focus CBNRM strengthening projects in these areas. • Avoid allocating exploration or mining/petroleum licenses. • These areas should be the focus for monitoring and spatial reporting on VECs and their condition, associated biodiversity values, and implementation of land uses planning processes etc. • Remove existing fences wherever possible to support landscape level wildlife movement. • Habitat loss, especially in the riparian fringe, woodlands and forest, due to agricultural expansion (including shifting agriculture) and hot and/or frequent fires should be minimized. • Minimize human-wildlife conflicts by locating fields away from prime wildlife areas, including migration routes. • Reverse declines of indicator species and maintain viable populations of endemic, rare and endangered species. Initiatives should include land protection, poaching reduction and avoiding/controlling alien invasive species. • Limit livestock to rangelands further away from key biodiversity areas (e.g. avoid the riparian fringe).
High Value Areas	• These areas have mean selection frequencies of between 70% and <90%. Although it may still be possible to meet targets if some of these areas are lost, in practice these area areas of very high value. If some of these areas are lost, then alternate spatial scenarios are likely to be much less efficient. Even limited losses of these areas are likely to result in other sites with similar features immediately becoming “irreplaceable”, as they would be identified as being required to meet targets if a new Marxan planning process was undertaken. • These areas are strongly linked to the VECs. • Together, with the Critical Areas these areas include the most important VECs and areas supporting VECs and should be a clear focus	• Focus areas for mechanisms focused on sustainable use such as Community Forest Reserves, and other community-based conservation initiatives. • May also be suitable for large formal protected areas such as national parks and nature reserves. • Multi-sectoral spatial planning. • Land use controls. • Activities that promote and secure wilderness characteristics such as low impact ecotourism. • Avoid allocating exploration or mining/petroleum licenses. • Focus CBNRM strengthening projects in these areas. • Remove existing fences wherever possible to support landscape level wildlife movement.

	of conservation and landscape management practices supporting sustainability. • Biodiversity values are usually rather lower than the Critical Areas (but these may also be isolated high value areas). • There are typically higher relative levels of human impact than the critical areas.	• Habitat loss, especially in the riparian fringe, woodlands and forest, due to agricultural expansion (including shifting agriculture) and hot and/or frequent fires should be minimized. • Minimize human-wildlife conflicts by locating fields away from prime wildlife areas, including migration routes. • Reverse declines of indicator species and maintain viable populations of endemic, rare and endangered species. Initiatives should include land protection, poaching reduction and avoiding/controlling alien invasive species. • Limit livestock to rangelands further away from key biodiversity areas (e.g. avoid the riparian fringe). • Where possible any mechanism highlighted for the Critical Areas, would be beneficial in these High Value Areas.
Medium Value Areas	• These areas have irreplaceability values of between 30% and <70%. • They include many high value areas for ecosystem targets, landscape connectivity and wilderness characteristics. • Although some specific areas could be lost without necessarily compromising the ability to meet targets, a key issue is the pattern of loss. Fragmentation of these areas could rapidly reduce their value for supporting landscape processes and could undermine the integrity of linked Critical and High Value Landscape Areas. These areas can be considered to be "ecological support areas" and are important for the overall function of landscape processes which underpin the VECs. • Areas that are natural and semi-natural areas surrounding the core areas but could also include addition separate high value areas which may be protected in the future. These are additional areas of conservation importance; but may be of lower significance. • They are often slightly more fragmented and have lower irreplaceability values than the Critical and High Value Categories.	• Land use controls to avoid habitat loss and especially fragmentation. • Community based conservation initiatives. These would focus on potential sustainable use landscapes suitable for community-based conservation initiatives. Areas suitable for potential community forest reserves are also be included in this category. • CBNRM processes which support landscape connectivity and function should be prioritised in these areas. • Support for sustainable farming practices, and sustainable mixed uses. • Collaboration and awareness. • Avoid allocating exploration or mining/petroleum licenses • Remove existing fences wherever possible to support landscape level wildlife movement. • Habitat loss, especially in the riparian fringe around smaller rivers, woodlands and forest, due to agricultural expansion (including shifting agriculture) and hot and/or frequent fires should be minimized. • Minimize human-wildlife conflicts by locating fields away from prime wildlife areas, including migration routes. • Reverse declines of indicator species and maintain viable populations of endemic, rare and endangered species. Initiatives should include land protection, poaching reduction and avoiding/controlling alien invasive species. • Limit livestock to rangelands further away from key biodiversity areas (e.g. avoid the riparian fringe).

Lower Value Areas	• These areas have lower selection frequency of < 30%. However, given the high overall value of the Cuando River Basin, they are still of significant value for supporting overall landscape function and integrity. • Significant portions of these areas are directly required to meet targets, but there is some flexibility in the landscape about where the targets are met. • These are the multi-use areas which have greater levels of human impact and are the focus for many economic activities, but which nevertheless have remaining ecological value especially for overall functioning of the landscape.	• Ensure appropriate land management and land use controls are in place to avoid largescale habitat loss, urban and peri-urban sprawl, linear development and landscape fragmentation. • Promote climate-smart agriculture, so that people can grow crops and raise livestock in an ecologically appropriate way and so that the best possible yields can be eked out of the marginal soils and rangelands on offer. • Avoid allocating exploration or mining/petroleum licenses.

Key remaining issues not dealt with in the current study

The current SCP study attempted to be as comprehensive as possible. However, there were some issues which we could not address due to limits in project scope, resources or timing. Key issues were:

- Due to timing issues, final prioritise were not yet available from the TNC terrestrial planning on the Cubango Okavango (TNC, 2024) and the WWF-US freshwater/hydrology focussed SCP in South East Angola (WWF, 2023).
- There is potential to improve the landcover used in the costs surface. The transformed landcover classes were derived from the 2016 European Space Agency CCI 20m Africa static Landcover data. There are known accuracy issues, especially in terms of agricultural fields data north and south-east of Licua. These areas are likely to be natural woodlands of high conservation value. We did not alter the analysis as these areas were already included as priorities, and alterations would have required a complete re-analysis which was beyond the scope of the project.
- Confirmation of the value of the source lakes is required. In the current study it is assumed that they are important, but they may be over-rated as they may be relatively sparse in biodiversity value, and may not actually be sources of the rivers, but rather simple impoundments near the sources. Nevertheless, the broader areas of the Angola Highlands Water Tower, inclusive of the source lakes and the specific 5km buffer that were included as features in the Systematic Conservation Plan, are clearly of great importance to the hydrological functioning of the Cuando Basin (Lourenco and Woodborne, 2023). The areas are also identified as important in the SCP by the NatGeo / Wild Bird Trust for the Okavango Zambezi Water Tower (Wild Bird Trust, 2022; Wild Bird Trust National Geographic Okavango Wilderness Project, 2024).
- Detailed spatial data on soils phosphorous, nitrogen, cation exchange capacity should be included in future planning.
- Species distribution modelling from the TNC (TNC, 2024) and WWF-US (WWF, 2023) should be fully validated. When we were undertaking the current SCP, these products were not yet fully validated, and were still subject to revision and finalization. Some species data could be further refined (e.g. aquatic mammals) and actual presence and distribution of species should be confirmed with detailed field surveys.
- Additional species data from Panthera and KAZA elephant tracking could be included in future iterations.

Conclusions

This rapid Systematic Conservation Plan (SCP) for the Cuando River Basin is part of the Strategic Environmental Assessment undertaken for the basin by the Southern African Institute for Environmental Assessment for WWF-Namibia on behalf of ZAMCOM. The purpose of the Systematic Conservation Plan (SCP) is to guide zonation of key and important biodiversity areas and ecological corridors in the basin.

The SCP was designed to integrate the Valued Ecosystem Components (VECs) identified for the Cuando River Basin:

- **VEC 1 – The Angolan Highlands Water Tower and perennial supply of water along the length of the Cuando River.**
- **VEC 2 – The immense area of swamp or reedbeds**.
- **VEC 3 – Linyanti Swamps and Savuti area.**
- **VEC 4 – Western flanks of the Cuando.**
- **VEC 5 – Wildlife corridors and ecological connectivity.**
- **VEC 6 - Cuando aquifers**.

This rapid Systematic Conservation Plan integrates available spatial biodiversity and socio-economic data to identify a robust set of spatial priorities for the Cuando River Basin (CURB), which integrate and support the VECS as well as other important biodiversity and socio-economic features of the basin. Whilst the VECs are ecological, most have profound implications for ecosystem services, the livelihoods of the people dependent on them, and the broader economy. They all contribute to maintaining the functioning and integrity of the Cuando Basin and supporting the small but very important tourism industry.

The rapid Systematic Conservation Plan (SCP) for the Cuando River Basin was used to identify areas of highest value for sustainable management and conservation actions aligned with the VECs identified in the SEA (SAIEA, 2024). The landscape was categorised into four categories:

- **Critical Areas** – These areas are irreplaceable or practically irreplaceable (i.e. required to meet targets under almost all circumstances and scenarios). These sites had mean Marxan irreplaceability values (or selection frequencies) across the seven scenarios of 90%-100%, which means that they are almost always required to meet targets. These areas are most strongly linked to the VECs.
- **High Value Areas** – These areas have mean selection frequencies of between 70% and <90%. Although it may still be possible to meet targets if some of these areas are lost, in practice these area areas of very high value. If some of these areas are lost then alternate spatial scenarios are likely to be much less efficient. Even limited losses of these areas are likely to result in other sites with similar features immediately becoming "irreplaceable", as they would be identified as being required to meet targets if a new Marxan planning process was undertaken. These areas are strongly linked to the VECs.
- **Medium Value Areas** – These areas have irreplaceability values of between 30% and <70%. They include many high value areas for ecosystem targets, landscape connectivity and wilderness characteristics. Although some specific areas could be lost without necessarily compromising the ability to meet targets, a key issue is the pattern of loss. Fragmentation of these areas could rapidly reduce their value for supporting landscape processes, and could undermine the integrity of linked Critical and High Value Landscape Areas. These areas can be considered to be "ecological support areas" and are important for the overall function of landscape processes which underpin the VECs.
- **Lower Value Areas**- These areas have lower selection frequency of < 30%. However, given the high overall value of the Cuando River Basin, they are still of significant value for supporting overall landscape function and integrity. Significant portions of these areas are directly required to meet targets, but there is some flexibility in the landscape about where the targets are met.

Critical Areas cover 4 492 405ha or 36.7% of the Cuando River Basin. Importantly, almost exactly half of these Critical Areas are outside of existing Protected Areas. **High Value Areas** cover an additional 1 856 976ha or 15.2% of the Cuando River Basin. Together, the **Critical Areas** and the **High Value Areas**, include the most important VECs and areas supporting VECs, and should be a clear focus of conservation and landscape management practices supporting sustainability. Combined, these areas are of highest value as potential protected areas sites for conserving biological diversity, and are highlighted as the most important for immediate conservation actions. The **Medium Value Areas** cover 3 281 823ha or 26.8% of the basin. They are generally less fragmented, have overall higher irreplaceability values than the remainder of the basin, and represent areas with strong wilderness and connectivity characteristics (where these have not already been included in the Critical or High Value categories). These areas are important for overall landscape linkages. Their loss would result in a significant decrease in landscape connectivity. Retaining the overall connectivity and function of these areas should be a focus for landscape management activities. The remaining **Lower Value Areas** cover 21,4% of the basin. These areas are of significantly lower value (relative to the rest of the basin) for supporting VECs than the other landscape categories. However, given the high value of the basin as a whole, on a national or regional scale these sites would undoubtedly be identified as valuable. Significant loss of these areas could undermine the overall integrity of the Cuando River Basin and its VECs. Key tools and mechanisms to achieve landscape sustainability and conservation outcomes are highlighted for each landscape category, and guidance is provided incorporation into the Draft Strategic Environmental Monitoring Framework (SEMF) for the Cuando River Basin (CURB) set out in the SEA (SAIEA, 2024).

References

Ardron, J.A., Possingham, H.P., Klein, C.J., 2008. Marxan good practices handbook. Pacific Marine Analysis and Research Association, Vancouver.

Ball, I.R., Possingham, H.P., Watts, M., 2009. Marxan and Relatives: Software for Spatial Conservation Prioritisation, in: Spatial Conservation Prioritisation: Quantitative Methods and Computational Tools. pp. 185–195.

Botts, E., Holness, S., Ling, M., Arnell, A., Tayleur, J., 2016. Mapping Biodiversity Priorities: A practical, science-based approach to national biodiversity assessment and prioritisation.

Computational Biology Facility, University of Liverpool, 2022. Condatis: bigger, better and more joined-up habitat networks.

Dottori, F., Alfieri, L., Salamon, P., Bianchi, A., Feyen, L., Hirpa, F., 2016. Flood hazard map of the World–100-year return period, European Commission, Joint Research Centre (JRC)[data set].

Dottori, F, Salamon, P., Bianchi, A., Alfieri, L., Hirpa, F., Feyen, L., 2016. Development and evaluation of a framework for global flood hazard mapping. Adv. Water Resour. 94, 87–102.

Ebrahim, G., Magombeyi, M., 2022. Hotspots for Groundwater Development in Kwando River Basin and Wildlife Dispersal Area (Final Report). Sustainable Groundwater Development and Management for Humans, Wildlife, and Economic Growth in the Kavango Zambezi Transfrontier Conservation Area.

Erdelen, W.R., 2020. Shaping the fate of life on Earth: The post 2020 global biodiversity framework. Glob. Policy 11, 347–359.

Gumbricht, T., Román-Cuesta, R.M., Verchot, L.V., Herold, M., Wittmann, F., Householder, E., Herold, N., Murdiyarso, D., 2017a. Tropical and Subtropical Wetlands Distribution version 2. https://doi.org/10.17528/CIFOR/DATA.00058

Gumbricht, T., Román-Cuesta, R.M., Verchot, L.V., Herold, M., Wittmann, F., Householder, E., Herold, N., Murdiyarso, D., 2017b. Tropical and Subtropical Wetlands Distribution. https://doi.org/10.17528/CIFOR/DATA.00058

Hodgson, J.A., Thomas, C.D., Dytham, C., Travis, J.M.J., Cornell, S.J., 2012. The Speed of Range Shifts in Fragmented Landscapes. PLOS ONE 7, e47141. https://doi.org/10.1371/journal.pone.0047141

Hodgson, J.A., Wallis, D.W., Krishna, R., Cornell, S.J., 2016. How to manipulate landscapes to improve the potential for range expansion. Methods Ecol. Evol. 7, 1558–1566. https://doi.org/10.1111/2041-210X.12614

Jennings, M.K., Zeller, K.A., Lewison, R.L., 2021. Dynamic Landscape Connectivity Special Issue Editorial. Land.

Justen, H., Lee-Yaw, J.A., Delmore, K.E., 2021. Reduced habitat suitability and landscape connectivity in a songbird migratory divide. Glob. Ecol. Biogeogr. 30, 2043–2056.

Kavango Zambezi - Peace Parks Foundation, 2018. URL https://www.peaceparks.org/tfcas/kavango-zambezi/, https://www.peaceparks.org/tfcas/kavango-zambezi/ (accessed 5.6.24).

Laliberte, J. and St-Laurent, M-H., 2020. Validation of functional connectivity modeling: The Achilles' heel of landscape connectivity mapping. Landscape and Urban Planning 202. 103878.

Lehner, B., Verdin, K., Jarvis, A., 2006. HydroSHEDS technical documentation. World Wildl. Fund US Wash. DC 5.

Lourenco, M., Fitchett, J.M., Woodborne, S., 2022. Angolan highlands peatlands: Extent, age and growth dynamics. Sci. Total Environ. 810, 152315.

Lourenco, M., Woodborne, S., 2023. Defining the Angolan Highlands Water Tower, a 40 plus-year precipitation budget of the headwater catchments of the Okavango Delta. Environ. Monit. Assess. 195, 859. https://doi.org/10.1007/s10661-023-11448-7

Maiorano, L., Chiaverini, L., Falco, M., Ciucci, P., 2019. Combining multi-state species distribution models, mortality estimates, and landscape connectivity to model potential species distribution for endangered species in human dominated landscapes. Biol. Conserv. 237, 19–27.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253.

Mendelsohn, J., 2022. The Angolan Catchments of Northern Botswana's Major Rivers: The Cubango, Cuito, Cuando and Zambezi Rivers, in: Eckardt, F.D. (Ed.), Landscapes and Landforms of Botswana, World Geomorphological Landscapes. Springer International Publishing, Cham, pp. 15–36. https://doi.org/10.1007/978-3-030-86102-5_2

Mendelsohn, J., Martins, A., 2019. River catchments and development prospects in south-eastern Angola.

Ministry of Environment, Forestry and Tourism, 2021. Wildlife corridors of the Zambezi Region - "A Strategy for their Maintenance, Conservation, Socio-Economic Development and Human Wildlife Conflict Management". Namibia.

Ministry of Lands and Resettlement, 2015a. Integrated Regional Land Use Plan for the Zambezi Region, Namibia (Volume 2). Prepared by Stubenrauch Planning Consultants & Africa Planning Forum for the Ministry of Lands and Resettlement (ML&R), Namibia.

Ministry of Lands and Resettlement, 2015b. Baseline Report for the Zambezi Integrated Regional Land Use Plan, Namibia (Volume 1), Ministry of Lands and Resettlement (ML&R). 2015.

Nicholson, E., Watermeyer, K.E., Rowland, J.A., Sato, C.F., Stevenson, S.L., Andrade, A., Brooks, T.M., Burgess, N.D., Cheng, S.-T., Grantham, H.S., 2021. Scientific foundations for an ecosystem goal, milestones and indicators for the post-2020 global biodiversity framework. Nat. Ecol. Evol. 5, 1338–1349.

Pallett, J., Guillemin, I., Mendelsohn, J., 2022. Cuando River - State of the Basin Report. https://doi.org/10.13140/RG.2.2.26500.33926

SAIEA, 2024. Strategic Environmental Assessment for the Cuando River Basin.

Sayre, R., Karagulle, D., Frye, C., Boucher, T., Wolff, N.H., Breyer, S., Wright, D., Martin, M., Butler, K., Van Graafeiland, K., 2020a. An assessment of the representation of ecosystems in global protected areas using new maps of World Climate Regions and World Ecosystems. Glob. Ecol. Conserv. 21, e00860.

Sayre, R., Martin, M., Karagulle, D., Frye, C., Breyer, S., Wright, D., Butler, K., VanGraafeiland, K., Boucher, T., McGowan, J., 2020b. World terrestrial ecosystems. Encycl. World's Biomes 31–34.

Sayre, R.G., Comer, P., Hak, J., Josse, C., Bow, J., Warner, H., Larwanou, M., Kelbessa, E., Bekele, T., Kehl, H., 2013. A new map of standardized terrestrial ecosystems of Africa. Afr. Geogr. Rev.

TNC, 2024. Terrestrial species models for Angola, Namibia, Zambia and Botswana.

Tootchi, A., Jost, A. and, Ducharne, A., 2019. Multi-source global wetland maps combining surface water imagery and groundwater constraints. Earth Syst. Sci. Data 11, 189–220. https://doi.org/10.5194/essd-11-189-2019.

Trigg, M.A., Birch, C.E., Neal, J.C., Bates, P.D., Smith, A., Sampson, C.C., Yamazaki, D., Hirabayashi, Y., Pappenberger, F., Dutra, E., Ward, P.J., Winsemius, H.C., Salamon, P., Dottori, F., Rudari, R., Kappes, M.S., Simpson, A.L., Hadzilacos, G., Fewtrell, T.J., 2016. The credibility challenge for global fluvial flood risk analysis. Environ. Res. Lett. 11, 094014. https://doi.org/10.1088/1748-9326/11/9/094014

UNEP-WCMC, I., 2020. Protected Planet: the World Database on Protected Areas (WDPA), the Global Database on Protected Areas Management Effectiveness (GD-PAME). UNEP-WCMC and IUCN, Cambridge, UK. www. prote ctedp lanet. net.

Wallis, D.W., Hodgson, J.A., 2015. Condatis; software to assist with the planning of habitat restoration v0.6.0. https://doi.org/10.5281/zenodo.13951

Weiss, D.J., Nelson, A., Gibson, H.S., Temperley, W., Peedell, S., Lieber, A., Hancher, M., Poyart, E., Belchior, S., Fullman, N., 2018. A global map of travel time to cities to assess inequalities in accessibility in 2015. Nature 553, 333.

Wild Bird Trust, 2022. Ramsar Information Sheet Lisima Water Tower (Lisima Lya Mwono).

Wild Bird Trust National Geographic Okavango Wilderness Project, 2024. Rapid Systematic Conservation Plan for the Okavango Zambezi Water Tower (OZWT), Angola.

WWF, 2023. Southeast Angola Freshwater Systems Mapping Initiative: A Multi-scale GeoSpatial Data Infrastructure encompassing GeoDatabases & Datasets, Cartographic Resources, and Auxiliary Files, Version 01A-Feb/23.

WWF, 2020. Strategic wildlife corridors in the Zambezi Region and recommendations for their maintenance v.0.4.

WWF Namibia, 2022. A Rapid Systematic Conservation Plan for the Zambezi and Kavango East Regions of Namibia. Unpublished report by Southern Connections NPC, Port Elizabeth.