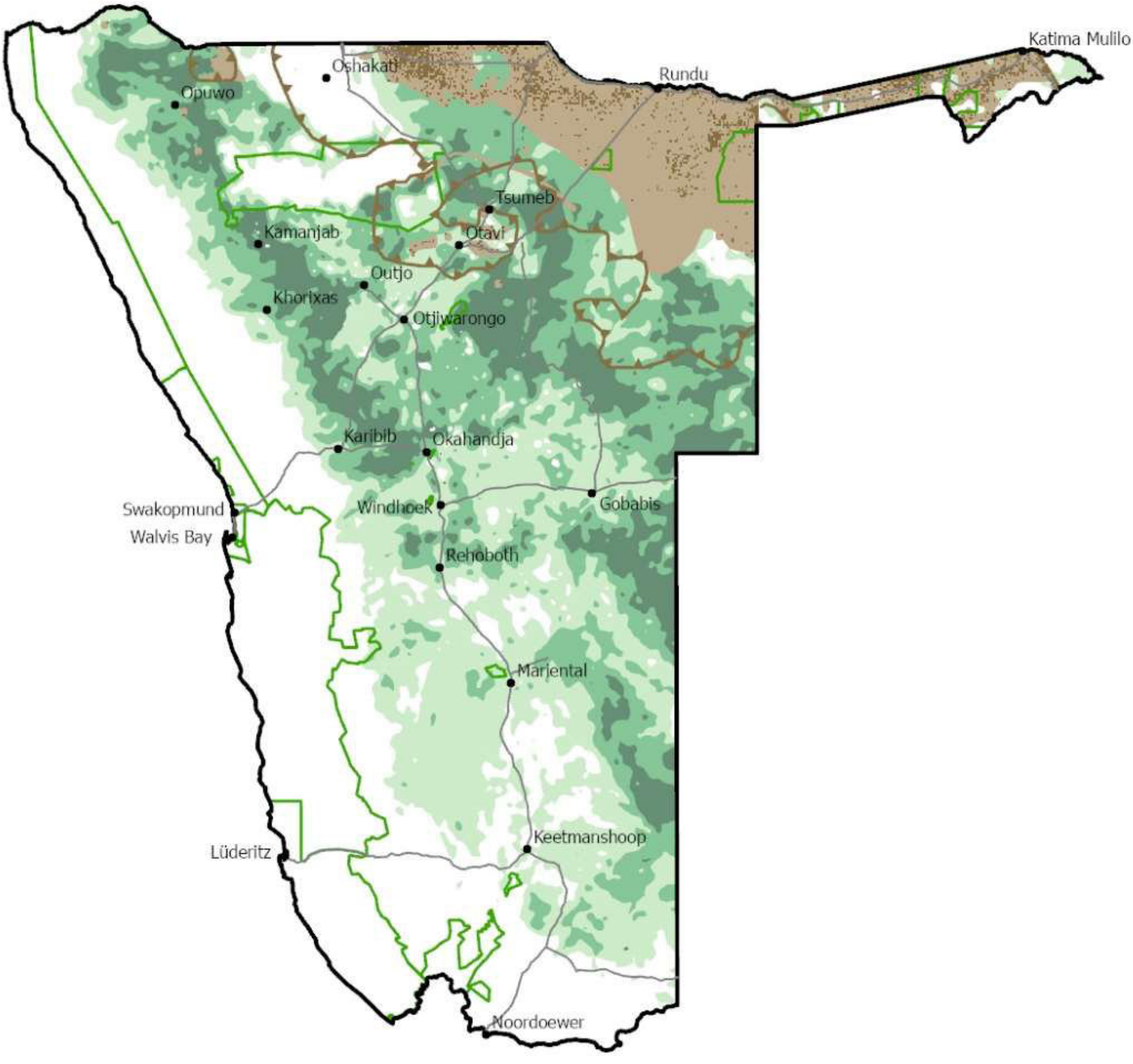
Final Report on Bush Maps Project

# Review and Consolidation of Namibia’s Bush Thickening Maps

*17 April 2024*

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***Cover Page Photo: Bush Thickening Across Namibia***

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# Executive Summary

Bush thickening (also referred to as bush encroachment), reduces ecosystem services such herbaceous forage production, biodiversity of many organisms and ground water recharge over vast tracks of land in Namibia, which impacts ecosystems and people's livelihoods negatively. The most used map is the one produced and agreed upon during the drafting of the 2016 "*Strategic Environmental Assessment of Large-Scale Bush Thinning and Value Addition Activities in Namibia*" led by the Southern African Institute for Environmental Assessment (SAIEA). While the above-mentioned map was largely based on consensus among experts and different available datasets, in 2018 the Bush Information System (BIS) was developed, constituting a remote sensing-based national map layers on bush cover and biomass in the country. There has however not been any effort to update the national overview maps with data from the BIS or other new data since then.

Reviewing the extent of bush thickening in Namibia is critical for several reasons including: 1) Environmental Conservation, 2) Rangeland Management, 3) Climate Change Mitigation and Adaptation, 4) Research and Monitoring, 5) Permitting and 6) Community and Stakeholder Engagement. The review and monitor the extent of bush thickening is essential to address a range of environmental, agricultural, and socio-economic challenges as it provides a valuable tool for informed decision-making, conservation efforts and sustainable land management practices.

The overall aim of this assignment was to make updated and consolidated national overview maps on bush thickening available. To manage this problem quantitative data are required about the extent, severity and encroacher species involved.

The mapping approach followed analysed bush thickening in the context of long-term rainfall, which ultimately limits woody plants where no additional runoff or sub-irrigation (e.g., along streams and rivers) is experienced (Sankaran et al. 2004; 2005). This allowed us to also map bush thickening in especially the southern parts of Namibia. From the new map, it is estimated that about 46 million ha are to some agree affected by bush thickening in non-forest areas. Our estimate agrees with the previous estimate of 45 million ha (SAIEA, 2016) done about 8 years ago. The very different approaches used to calculate the total area affected, however, negate any direct comparison. Considerable bush control and harvesting also took place since then, which the current map does not incorporate fully.

The new map suggests that in terms of extent, the Otjozondjupa, Omaheke and Khomas regions are the most affected. Our estimate of 8.9 million ha affected in the Otjozondjupa region is less than the 10.5 million ha estimated by Hengari (2018) but is partly due to the exclusion of areas considered as a high likelihood of forest occurring. These high likelihood forest areas probably include bush thickened wooded areas not classified as forests. Similarly, were large parts of the Zambezi, Ohangwena and Kavango East and West regions excluded from the extent calculations, resulting in low areas mapped as bush thickened. These regions have substantial areas denoted as Forest or High likelihood of Forest, which affects these figures. This is in agreement with the SAIEA (2016) map where the Ohangwena and Zambezi regions had no thickening.

It is recommended that the maps are frequently reviewed as new information and technology become available and given the extent and importance of bush thickening in Namibia.

# Table of Contents

# List of Abbreviations

| | |
|---|---|
| BCBU | Bush Control and Biomass Utilisation |
| BE | Bush Encroachment |
| BIS | Bush Information System |
| CAoN | Charcoal Association of Namibia |
| CBNRM | Community-Based Natural Resource Management |
| DoF | Department of Forestry |
| DRFN | Desert Research Foundation of Namibia |
| FG | Focus Group |
| GIS | Geographic Information System |
| GIZ | Gesellschaft für Internationale Zusammenarbeit |
| GHG | Greenhouse Gas |
| KBA | Key Biodiversity Areas |
| IUCN | International Union for the Conservation of Nature |
| MCA | Millenium Challenge Account |
| MAWLR | Ministry of Agriculture, Water and Land Reform |
| MEFT | Ministry of Environment, Forestry and Tourism |
| NACSO | Namibian Association of CBNRM Support Organisations |
| NBiG | Namibia Biomass Industry Group |
| NBRI | Namibia Botanical Research Institute |
| NCA | Northern Communal Areas |
| NDPBR | National Dialogue Platform on Bush Resources |
| NDC | Nationally Determined Contributions |
| NNF | Namibia Nature Foundation |
| NUST | Namibia University of Science and Technology |
| PN | Project Number |
| PCT | Perivoli Climate Trust |
| PRI | Perivoli Rangeland Institute |
| SOC | Soil Organic Carbon |
| SAIEA | Southern African Institute for Environmental Assessment |
| SASSCAL | Southern African Science Service Centre for Climate Change and Adaptive Land Management |
| TE | Tree Equivalents |
| TE/ha | Tree Equivalents per Hectare |
| ToR | Terms of Reference |
| UNAM | University of Namibia |

# List of Maps



# List of Figures



# List of Tables

# 1. Project Overview

Bush thickening (also referred to as bush encroachment), reduces ecosystem services such herbaceous forage production, biodiversity of many organisms and ground water recharge over vast tracks of land in Namibia, which impacts ecosystems and people's livelihoods negatively. Conversely, bush constitutes a natural resource that can be harvested, generating income and job opportunities. Harvesting the bush resource can help subsidize rangeland restoration, provided that good practises and sufficient aftercare of the post-harvest land are adhered to. To estimate the impact of bush thickening on ecosystem services and take stock of the bush resource, various maps displaying the extent of Namibia's bush thickening have been attempted in the past. These depict the spatial distribution and total area affected, both for bush thickening overall and for selected species. The most used map is the one produced and agreed upon during the drafting of the 2016 "*Strategic Environmental Assessment of Large-Scale Bush Thinning and Value Addition Activities in Namibia*" led by the Southern African Institute for Environmental Assessment (SAIEA). While the above-mentioned map was largely based on consensus among experts and different available datasets, in 2018 the Bush Information System (BIS) was developed, constituting a remote sensing-based national map layers on bush densities in the country. There has however not been any effort to update the national overview maps with data from the BIS or other new data since then.

## 1.1. Project Importance

Reviewing the extent of bush thickening/encroachment (we use these terms as synonyms) in Namibia is critical for several reasons including:

1) Environmental Conservation: expansion of woody vegetation into grasslands and savannas, can have detrimental effects on Namibia's ecosystems. Reviewing the extent of thickening will help identify areas where this phenomenon is occurring and allow for targeted management and conservation efforts.

2) Rangeland Management: thickening can negatively impact rangeland productivity and quality, which is crucial for livestock farming in Namibia. A better understanding of the extent can guide policy development and help farmers to make informed decisions on land management practices.

3) Climate Change Mitigation and Adaptation: understanding the extent of bush thickening is essential for calculating the carbon sequestration potential of Namibia's landscapes. This information is valuable in the context of global efforts towards adaptation and mitigation.

4) Research and Monitoring: Regularly updating and reviewing these types of maps allow researchers to track changes over time and understand the dynamics of bush thickening. This data can inform scientific studies, which may lead to better strategies for managing this phenomenon.

5) Permitting: as bush-biomass utilisation expands and upscales across different value chains, there is an increased need to define the key areas affected by bush thickening as well as priority areas for restoration areas, informing permit decision-making processes by the Directorate of Forestry.

6) Community and Stakeholder Engagement: Involving local communities and stakeholders in the review of the bush encroachment map can lead to more inclusive and effective conservation and land management initiatives. It allows for the integration of indigenous knowledge and ensures that the interests and concerns of local people are considered.

In summary, reviewing and monitoring the extent of bush thickening is essential to address a range of environmental, agricultural, and socio-economic challenges. It provides a valuable tool for informed decision-making, conservation efforts and sustainable land management practices.

## 1.2. Study Objectives and Terms of References

The overall aim of this assignment is to make updated and consolidated national overview maps on bush thickening available. As per the terms of reference:

> **"This assignment requires the consultant to convene a group of experts for the purpose of reviewing the existing maps on the extend of bush thickening in the country and producing a set of consolidated and updated maps."**
>
> **"The overall aim of this assignment is to make updated and consolidated national overview maps on bush thickening available."**

In summary, the purpose was the reviewing and monitoring of the extent and severity of bush thickening, as an essential perspective to address a range of environmental, agricultural, and socio-economic challenges. It provides a valuable tool for informed decision-making, conservation efforts and sustainable land management practices.

The consultancy had the following agreed objectives:

1. Considering and reviewing all existing maps and relevant datasets related to bush thickening in Namibia.
2. The reviewed maps rely as much as possible on remote sensing and actual validation data, although it is acknowledged that this will be at best only an approximation and dependent on how thickening is defined.
3. The final maps are based on consensus reached among experts from various fields including environmental, rangeland and forestry management and the spatial sciences. The incorporation of inputs and guidance from key experts at the Directorate of Forestry/ National Botanical Research Institute is a priority.
4. The maps and relevant statistics should consider as far as is feasible in the consultancy timeframe the following: 1) total area affected, 2) vulnerability zones, 3) encroacher species distributions, 4) land tenure systems, 5) biodiversity hotspots vulnerability, and 6) socio-economic impacts. The final list of these maps and data will be negotiated during the inception phase of this assignment.
5. The new maps estimate the total area affected and therewith provide an update to the 45 million hectares of the 2016 SAIEA map.

The definition of "*Bush Encroachment*" is clearly articulated in the *National Strategy on the Sustainable Management of Bush Resources 2022-2027* (MEFT, 2022) on Page 11 as:

> ***"Bush encroachment is a global phenomenon. Across different bioclimatic zones, woody plants have displaced grasses. While trees dominate humid regions, unpalatable shrubs proliferate in arid regions. This is considered a type of degradation (Archer et al., 2017). In Southern Africa, it is commonly referred to as "bush encroachment", although the term "bush thickening" is more appropriate since it involves indigenous woody species in their natural environment (Smit et al., 2015)."***

To manage this problem quantitative data are required about the extent, severity and encroacher species involved. Various maps were used in the past to display the extent of Namibia's bush. These depict the spatial distribution and total area affected, both for bush thickening overall and for selected species. The most used map is the one produced and agreed upon during the drafting of the 2016 Strategic Environmental Assessment, led by The Southern African Institute for Environmental Assessment (SAIEA, 2016). Whereas this map was largely based on consensus among experts and different available datasets, in 2017 the Bush Information System (BIS) was developed, constituting remote sensing-based national map layers on bush densities in the country. There has however not been any effort to update the national overview maps with data from the BIS or other new data since then.

# 2. Literature Review

The available literature was reviewed according to the following topics relevant to the current project:

## 2.1. Definition of Bush Encroachment for Mapping Purposes

To map the extent and severity of BE, it is important that consensus is reached how BE is defined. In their review of bush encroachment in southern Africa, O'Connor et al. (2014) defined BE as "***as a directional increase in the cover of indigenous woody species in savanna***…" and differentiate BE from the establishment of indigenous woody elements in the formerly treeless grassland biome of southern Africa, which they termed "***bush invasion***". Turpie et al. (2019) considered BE as "…***entails increased abundance of indigenous woody vegetation in the grassland and savanna biomes***…", in a South African policy brief.

For this project the definition of bush thickening as stated in the National Strategy on the Sustainable Management of Bush Resources (NSSMBR) 2022-2027 was adopted, who defined BE as:

> ***"…the invasion and/or thickening of aggressive undesirable woody species, resulting in an imbalance of the grass: bush ratio, a decrease in biodiversity, a decrease in carrying capacity and concomitant economic losses…".***

In addition, the NSSMBR considers BE to occur in savannas and wooded areas and exclude forest ecosystems[1] as defined by the FAO, although it acknowledges that in special cases BE can occur in forests. BE areas are subsequently considered as:

> ***"…woodland areas with more than 0.5 ha that are thickened against the capacity defined by the local conditions which have a relative over abundance (80-90%) of species identified as encroaching and would not develop into a forest under the given circumstances".***

Other definitions have been formulated for defining bush thickening. In their review of bush encroachment in southern Africa, O'Connor et al. (2014) defined BE as

> ***"…as a directional increase in the cover of indigenous woody species in savanna" and differentiate BE from the establishment of indigenous woody elements in the formerly treeless grassland biome of southern Africa, which they termed 'bush invasion".***

Also, in a South African policy brief, Turpie et al. (2019) considered BE as:

> ***"…entails increased abundance of indigenous woody vegetation in the grassland and savanna biomes."***

## 2.2. Approaches to Map Bush Encroachment

### 2.2.1. Quantifying the Imbalance in the Grass: Bush Ratio

Above a certain threshold, the increase in woody cover increasingly degrades ecosystem services such as the grazing capacity of an area, the biodiversity of certain taxa and reduce hydrological processes

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[1] FAO definition of Forest: Land spanning more than 0.5 ha with trees higher than 5 meters and a canopy cover of more than 10 %, or trees able to reach these thresholds in situ.

such as recharge of ground water sources and increase rainwater run-off. Several approaches have been suggested to quantify the BE threshold as a rule of thumb. These are based on the long-term rainfall of area because more woody plants can be tolerated in a wet area than an arid area without affecting herbaceous productivity (Smit et al., 2015). De Klerk (2004) considers BE to have occurred where the density of Tree Equivalents (defined as a bush 1.5 m high) per hectare exceeds twice the long-term annual rainfall of an area. Smit et al. (2015), in a more refined approach, propose that negative effects due to BE emerge where the median number of Evapo-Transpiration Tree Equivalents (ETTE) per ha exceeds 10 times the mean annual rainfall of an area. The ETTE is a standardized woody leaf volume unit that provides an index of the competitiveness of the woody layer acting upon the grass layer (Smit et al. (2015). Although simplifications, these offer a means to quantitatively determine the severity of BE based on the long-term rainfall an area can expect. Usually, field measurements of the woody layer are carried out to determine the TE/ha or ETTE/ha, which is then related to the long-term rainfall of the area to determine the severity of BE. In southeast Namibia, Lubbe (2013) determined the density of encroacher bush (*Rhigozum trichotomum* and others) in transects spaced roughly 20km apart. A density map was created after interpolating the measured densities in a GIS.

### 2.2.2. Remote Sensing

For mapping BE at a national or continental scale, remote sensing approaches are commonly used. Remote sensing approaches can essentially be divided in satellite (or aircraft) derived optical and synthetic aperture radar methods, or a combination of the two. Optical remote sensing gathers information about the earth's surface using electromagnetic radiation in the visible, near infrared, and shortwave infrared regions of the electromagnetic spectrum. This method relies on sensors (e.g., on-board satellites) that capture sunlight reflected or emitted by the Earth's surface, atmosphere, and objects. Optical remote sensing data are used in different ways to map BE. In their study of woody cover changes in sub-Saharan Africa, Venter et al. (2018) utilized Landsat surface reflectance data from 1986 to 2016 and extracted time-series spectral metrics, including vegetation indices derived from reflectance bands, to map fractional woody cover per year. To train the model, Google Earth imagery in random sampling quadrates were manually classified according to the level of bush cover observed in quadrates. Lastly, the increase or decrease in woody cover between 1986 and 2016 (slope of the linear regression between fractional woody cover and year) was determined and mapped for the African continent at a 30m spatial resolution (Venter et al., 2018). A statistically significant increase in woody cover from 1986 to 2018 indicates BE.

Synthetic Aperture Radar (SAR) methods are also used to map woody resources and has the advantage of penetrating cloud cover, which obscures optic methods. The SAR instruments mounted on satellites emit microwave pulses toward the Earth's surface and record the backscattered signals, which are sensitive to vegetation structure and biomass. By analysing the SAR data, biomass and forest cover can be accurately assessed, once calibrated. For mapping woody vegetation, longer radar wavelengths such as the L-band (23 cm) are best. In Namibia the Bush Information System (BIS) was largely based on L-band SAR data. Synthetic Aperture Radar data has also been successfully used in South Africa to map woody resources (Urbazaev et al., 2015; Naidoo et al., 2016). L-band SAR data are suited to the estimation of above-ground biomass of woody plants up to 100 ton/ha (Bouvet et al., 2018), after which it saturates and becomes less accurate. This is not a problem in Namibia where woody biomass tends to be much lower due to the arid climate. The SAR estimates the cover or biomass of the woody layer but does not indicate the level of BE in an area. It does offer, however, the potential to map BE if threshold values are known.

# 3. Methodology

## 3.1. Review of Available Data, Information and Maps

The spatial and validation datasets deemed relevant to the project was initially reviewed and are listed in the table below. The table also indicate how the datasets were used in the project.

| | Dataset and source | How it was used in the project |
|---|---|---|
| Bush Encroachment Related Spatial Datasets or Model Input Layers | Map by Bester (1999). | Was acquired and used to validate produced map |
| | Strategic Environmental Assessment by SAIEA (2016). | Was acquired and used to validate produced map |
| | Bush Information System (BIS). This includes the woody cover, mean tree height, biomass, ETTE/ha and encroacher species distribution maps. | The BIS 2018 canopy cover product was used to quantify bush thickening in the higher rainfall vegetation types. The BIS 2018 tree height product was used to determine additional forest patches. |
| | The bush encroachment data layers developed by Zander Venter and team, which mapped bush encroachment (1984 to 2018) over Africa (30m spatial resolution) using validated remote sensing data (Venter et al., 2018). | These maps were acquired and used to validate the bush thickening map layer, particularly the western boundary of thickening. |
| | Recent Synthetic Aperture Radar (most important variable used in the BIS maps). The most recent data available is for 2022. | The data were acquired and processed and were used to validate specific areas on the bush thickening map, e.g., feedback from focus group members. |
| Ground Truthing and Validation Datasets | Biomass Quantification Tool data collected and supplied by DoF/NBRI, N-BiG | Not used. The analysis was based on canopy cover data and not biomass or forms of tree equivalent data. |
| | Land Degradation Neutrality regional assessment data. | Not used, because the data were not compatible with the canopy cover approach followed |
| | Measured woody cover - EU funded Rangeland Early Warning System (2015-2018) | Data were used to analyse the rainfall-woody cover relationship. |
| | Measured woody cover - State of Rangeland project (2018) | Data were used to analyse the rainfall-woody cover relationship. |
| | Woody biomass - GIZ SOC study (2023) | Were used to explore the relationship between Tree equivalents and long-term rainfall. |
| | GIZ F4Resilience Rangeland Management Plan datasets | Was acquired but not used, because it covers only small areas |
| | Woody measurements from other scientists, e.g., BECVOL assessments, NamPower Bush to Energy project. | Some data were acquired but not used, because it was decided not to use biomass data, but canopy cover of the woody layer. |

| | | |
|---|---|---|
| Biodiversity And Endemism Spatial Data (Atlas of Namibia Database) | State protected areas, | Data were included in the map. |
| | Tourism concession areas, | The data were included in the map. |
| | Core wildlife areas and corridors in conservancies, | The data were not used because it was deemed too much detail for the scale of the map. |
| | Community forest areas | The data were displayed on the map. |
| | Wetlands and RAMSAR sites, | Wetland data were included in an insert map, but the inclusion of RAMSAR sites was deemed too much detail for the map. |
| | Key Biodiversity Areas (KBAs) as identified by the IUCN | The data were not used because it was deemed too much detail for the scale of the map. |
| | Sensitive areas as mapped by SAEIA 2015: Review of the current Social and Environmental status, regulatory and institutional frameworks governing the extractive industry in Namibia. | This data was deemed too detailed for inclusion in the final map or as an insert map. |
| Encroacher Species Distribution | BIS encroacher species probability of occurrence datasets for encroacher species. | The probability of occurrence data formed the basis of the encroacher species distribution augmented with actual occurrence data from various sources and experts. |
| | iNaturalist data. | Data for the encroacher species were extracted and used to validate and adapt the distribution maps. |
| | National Phytosociological Database (Strohbach & Kangombe 2012). | The data were used to validate and refine the encroacher species distribution maps. |
| | Tree Atlas data. | The data were used in the forest mapping and species distribution analyses. |
| Other Data Layers or Sources | Department of Forestry's Forest Cover (DoF Forest Cover) | Was the base data set used to derive a layer that represents the areas with high likelihood forest and a layer that represents the maximum extent line of high value timber species |
| | Google Earth Pro | Was used to validate specific areas in the forest and bush thickening layers, respectively. |
| | Land cover data to mask out urban and build up build-up, water bodies, etc. (Global products) | The European Space Agency 's 10m land cover product for 2021 was used to model shrub cover in the lower rainfall vegetation types. |
| | Vegetation types (Atlas of Namibia Team, 2022) | The modelled bush thickening used different approaches for higher and lower rainfall vegetation types. |
| | Altitude and slope derived from digital elevation models. | Slope data were used in modelling the bush thickening and are included as a layer in the final map. |
| | Land tenure (NSA data portal) | Was included as an insert map. |
| | Long-term rainfall (Atlas of Namibia Team, 2022) | Was used to establish the relationship between woody cover and rainfall, as well as in modelling bush thickening severity from the BIS 2018 canopy cover data. |
| | Global Tree Cover Potential (WWF Globil) (Bastin et al., 2019) | Was used in the process to derive a layer that represents the areas with high likelihood forest |
| | Geographical distributions of *Pterocarpus angolensis*, *Burkea africana* and *Schinziophyton rautaneni* (De Cauwer, 2014) | Was the base data set used to derive a layer that represents the areas with high likelihood forest and a layer that represents the maximum extent line of high value timber species |

## 3.2. Data Processing and Mapping

During the first stakeholder engagement the proposed methodology and draft products were presented, and feedback received. further identification of potential datasets as well as potential final map products. Promising datasets based on spatial analysis and modelling by the team *a priori* will be displayed during this workshop. These datasets were derived primarily derived from remote sensing products or data (e.g., BIS, Venter et al., 2018, SAR) and adjusted according to expert input.

### 3.2.1. Bush Thickening Severity and Extent Mapping

In savanna ecology, the maximum tree cover is believed to be limited by water availability and competition between trees (Sankaran et al., 2004). Disturbances such as fire and large herbivores keep the tree cover at a lower level, releasing the grass layer from the competition of woody plants. This has been demonstrated in an African dataset where measured woody cover was indeed bound by mean annual rainfall up to about 650mm/year (Sankaran et al., 2005; Bond, 2008) (Figure 1).

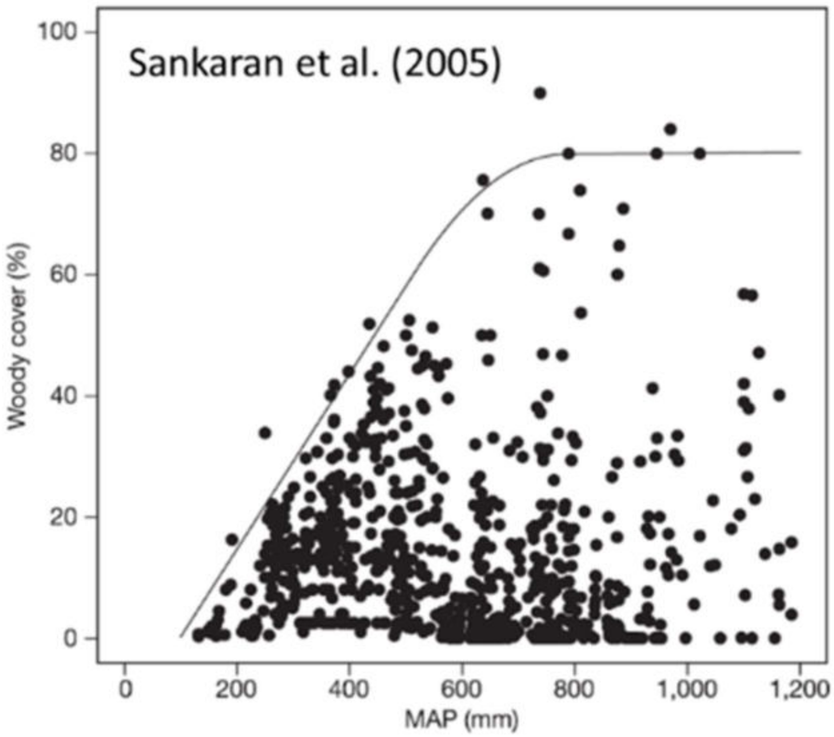


***Figure 1: Woody cover in Relation to Mean Annual Precipitation in African savannas.***

Beyond 650mm/year Mean Annual Precipitation, woody cover flattens out as canopy closure is approached. Most sites, however, occurred at lower cover values which were related to various factors including fire frequency, presence of mega herbivores such as elephants, land use change, etc. (Sankaran et al., 2005).

A similar pattern was observed in Namibia where 569 woody cover plots (measured in 100 or more descending points per plot) were plotted against long-term mean annual rainfall extracted from long-term rainfall data (Atlas of Namibia Team, 2022). Quantile regression (R, quantreg package) was used to describe the upper limit as the 99$^{th}$ percentile for the woody cover measured in field plots scattered over Namibian rangelands. This line describes a line where 99% of woody cover values falls below the line. In addition, the 25th percentile line was calculated and was arbitrarily chosen as the threshold above which encroachment increasingly occur. Cover values at or below the 25th percentile line therefore was assumed to indicate situations where the net effect of woody cover on ecosystem services (herbaceous production, biodiversity, ground water recharge) are not restrictive. Woody cover above the 25th percentile line was interpreted to indicate increasing negative impacts on ecosystem services as the upper limit is approached.

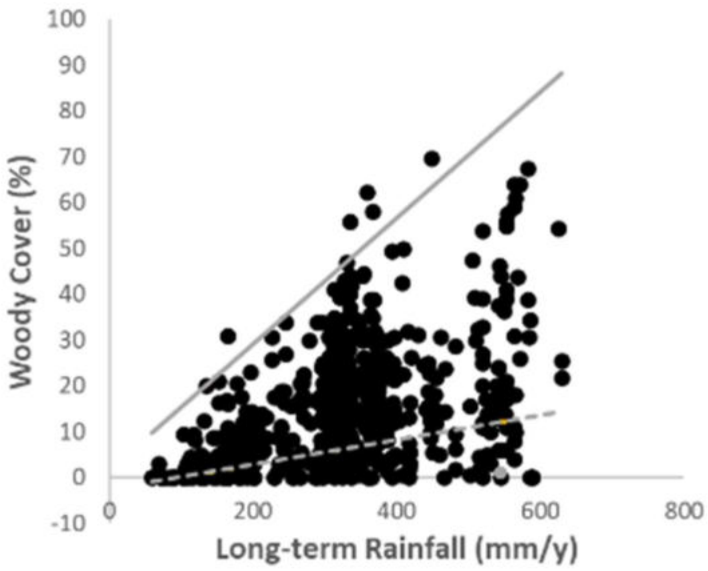


***Figure 2: Actual Woody Cover vs Long-Term Rainfall in Namibian Rangelands.***

*The line indicates the 99th percentile and the broken line the 25th percentile.*

This approach is analogue to the rule-of-thumb that thickening severity scales with rainfall, e.g., the threshold where bush thickening effects starts to manifest occurs where the number of Tree Equivalents/ha equals or surpass two times the long-term annual rainfall (NSSMBR, 2022).

Using the long-term annual rainfall map of Namibia (Atlas of Namibia Team, 2022), the 25th percentile woody cover threshold was calculated using the quantile regression formula established for the field woody cover - long-term rainfall data (Figure 2). To map bush thickening in Namibia, the Bush Information System's Canopy Cover product for Namibia (2018) was expressed as a percentage of the 25th percentile map. This means that a positive percentage deviation from the threshold indicates bush thickening. A further refinement was to exclude thickening in areas with slopes of more than 12.5 %, because mountainous areas often have naturally higher woody cover than expected for the rainfall received and because the bush harvesting regulations of the MAWLR (2017) prohibit wood harvesting on steep slopes. In addition, the BIS canopy cover predictions are based on Synthetic Aperture Radar, which is known to be affected by topography and surface roughness (Wessels et al., 2018). The slope corrected map was then generalized in a Geographic Information System (GIS) and classified according to arbitrarily chosen thickening severity classes as indicated in Table 1.

*Table 1: Estimated Bush Thickening Values for Statistical Analysis*

| Bush Thickening Class | Central, North and Northwest | South and far West |
|---|---|---|
| | *Rainfall and slope corrected BIS bush thickening map values used in the central, north and northwestern parts.* | *Slope corrected and aggregated ESA shrub cover bush thickening map used in the south and far western parts.* |
| None or very localized | Negative values - 150 | 0 – 0.12 |
| Light or localized | 150 - 250 | 0.12 – 0.38 |
| Moderate | 250 - 330 | 0.38 – 0.7 |
| Severe | 330 - infinity | 0.7 – 1.0 |

Feedback from focus group members indicated that the BIS approach was less suitable for the southern parts of Namibia, where underestimations were reported. A different approach was therefore employed in the southern and far western vegetation types (Atlas of Namia Team, 2022) as delineated in Map 1. These include the Western highlands, Central-Western Escarpment and Inselbergs, Northwestern Escarpment and Inselbergs, Desert-Dwarf Shrub Transition, Dwarf Shrub Savanna, Karas Dwarf Shrub Savanna, Dwarf Shrub – Southern Kalahari Transition and Southern Kalahari vegetation types (Atlas of Namibia Team, 2022). No thickening was mapped in the Namib Desert vegetation types. In these areas bush thickening was based on the shrub cover estimated by the European Space Agency's land cover 2021 map, which is available at 10m spatial resolution. The shrub cover class was extracted and all shrub values that coincided with slopes steeper than 12.5 % was transformed to 0 to exclude potential high shrub cover associated with mountainous areas for reasons described above. The slope-corrected shrub cover was then aggregated to a pixel size of approximately 500 x 500 m by averaging shrub presence in the original 10 x 10m pixels. A value of 1 indicates that all 250 pixels contained in the aggregated 500 x 500 m pixel were covered by shrub while a value of 0 indicates that none were covered by shrub. The data was generalized and classified in increasing bush thickening severity classes according to the values indicated in Table 1. The high bush density areas identified in the digitized bush density map produced by Lubbe (2013) for the southeastern parts was also incorporated in the shrub cover map.

*Map 1: Regional Difference in Data Source*

*In the southern and far western vegetation types (yellow shaded areas), bush thickening was based on land cover data.*

The BIS based and ESA shrub cover based maps were merged and vectorized in a GIS. Adjustments were subsequently made to the consolidated map based on feedback from focus group members, land users, visual assessments (only western and central areas) and spot checks using Google Earth imagery and the JAXA SAR data for 2022 (horizontal-vertical polarization). The latter SAR data is the same source and polarization that was used for producing the BIS canopy cover data.

### 3.2.2. Bush Encroacher Species Distribution Maps

In the Namibian landscape, forests are generally deciduous with few evergreen species. They are characterised with open canopy that allows sufficient sunlight to reach the groundcover to allow for the development of grass layers (Oliveras and Malhi ,2016, De Cauwer et al., 2018).

It is known that conventional remote sensing techniques fail to distinguish forest and bushland in Namibia's woodlands, unless ground truthing data or LiDAR data are available (Wessels et al., 2019). To disassociate forests from bush encroached areas, a forest cover data layer would be beneficial. To this end, the Department of Forestry (DoF) from Namibia's Ministry of Environment, Forestry and Tourism (MEFT) made available the Forest Cover data set, derived from GEDI (Global Ecosystem Dynamics Investigation) and other satellite products.

### 3.2.3. Forest Cover Maps

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#### 3.2.3.1. Forest Definition

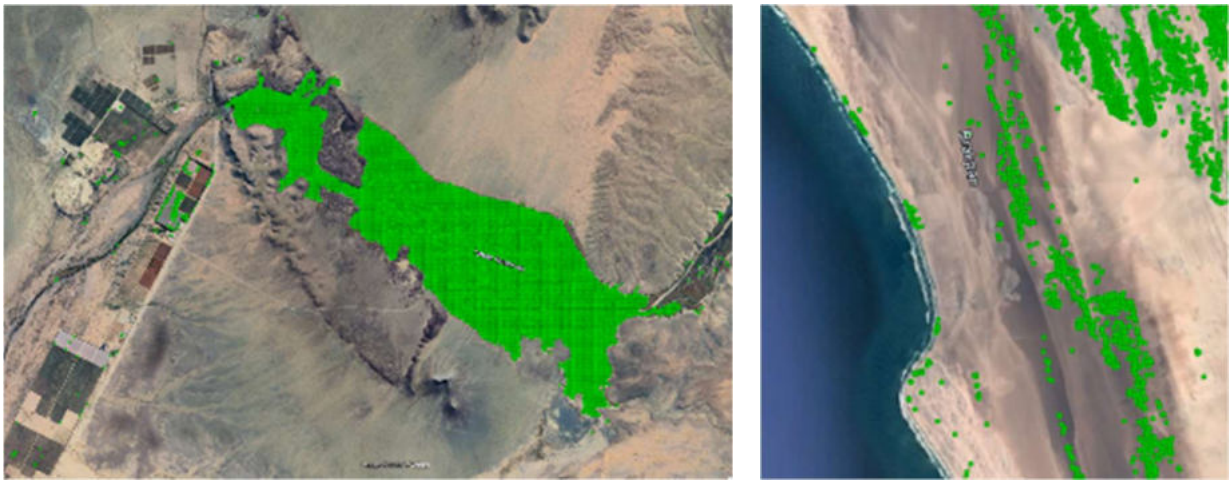
The forest cover data set provided by the DoF was generated according to the definition of the FAO (Food and Agriculture Organization of the United Nations). The FAO defines a forest as "***...land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 %, or trees able to reach these thresholds in situ...***" (FAO, 2000). Notably, the FAO defines other wooded land, as an area with "***...the canopy cover of trees in between 5 and 10 percent, trees should be higher than 5 meters or able to reach 5 meters in situ...***" or "***...the canopy of trees is less than 5 percent, but the combined cover of shrubs, bushes and trees is more than 10 percent, includes areas of shrubs and bushes where no trees are present...***" (FAO, 2000).

The High Likelihood Forest Area was derived from the Namibia's Ministry of Environment, Forestry and Tourism (MEFT) Department of Forestry (DoF) forest cover layer, which was derived from GEDI (Global Ecosystem Dynamics Investigation) and other satellite products. The Namibian Tree Atlas (Curtis & Mannheimer, 2005), *Pterocarpus rotundifolius*, *Pterocarpus angolensis*, *Guibourtia coleosperma*, *Burkea africana* and *Baikiaea plurijuga*, the modelled geographical distributions of *Pterocarpus angolensis*, *Burkea africana* and *Schinziophyton rautaneni* (De Cauwer 2014), from which above 60% probability was extracted, and the high probability tree cover was extracted from the Global Tree Cover Potential data set (WWF Globil) (Bastin et al., 2019), in order to eliminate false positives from the DoF tree cover layer. The resulting layer was subjected to several cartographic refinements to create a generalised data layer. The final layer was adjusted according to expert opinion input.

#### 3.2.3.2. Quality assessment

According to the data set's associated report produced by the DoF, a validation was conducted on the data for the Zambezi region. Overall map accuracy was found to be 81.5%.

An assessment of the data quality beyond the Zambezi region, in particular in areas not likely to have forest cover in Namibia, established that extensive false positives (misclassifications of forest cover) existed, in particular; water bodies, shaded areas, soil with dark signatures and steep slopes.



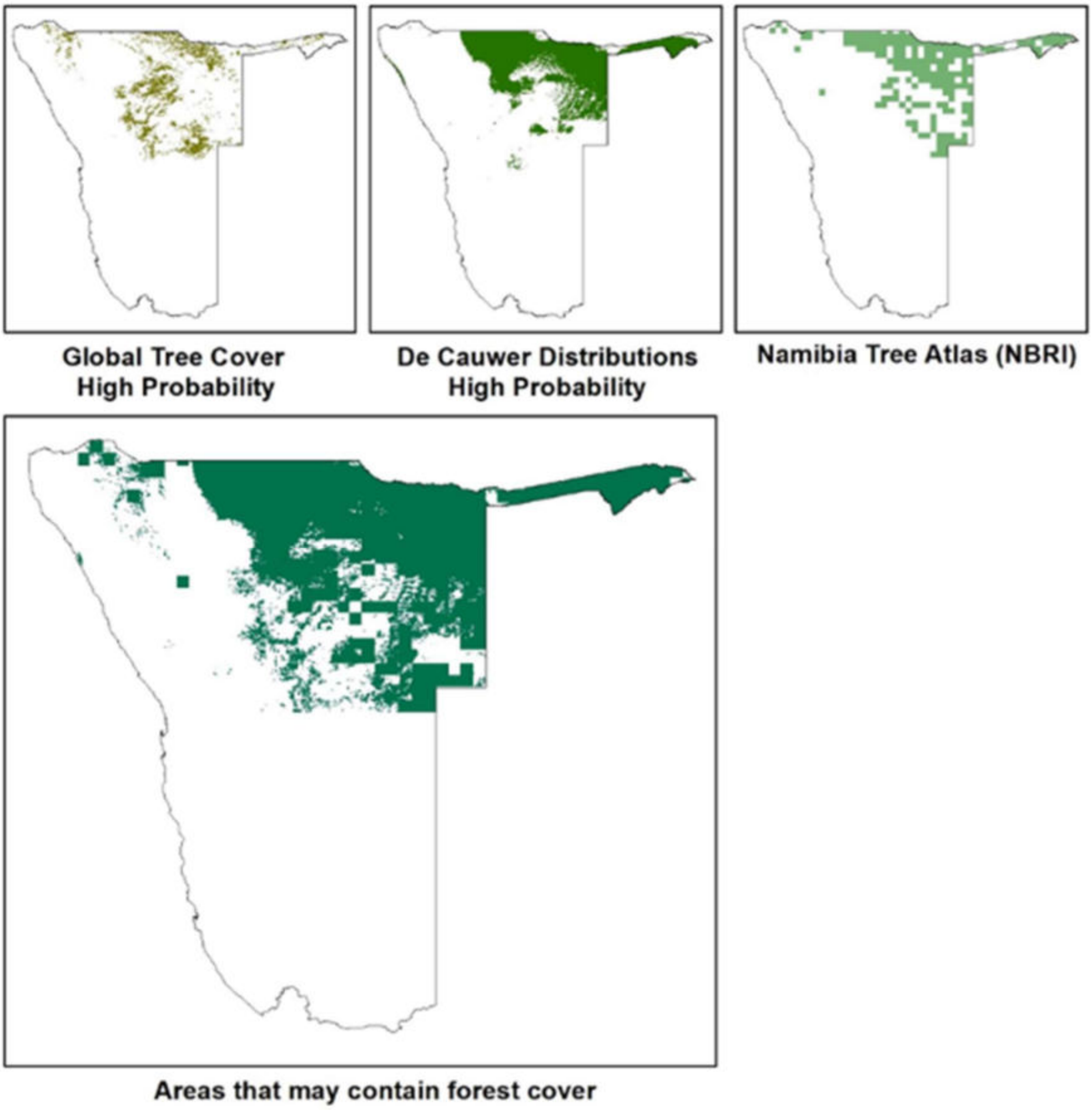
***Map 2: Examples of False Positives from DoF's Forestry Dataset***

*Left: The entire Naute dam's water surface is incorrectly classified as forest cover. Right: The northwestern Namibian coast shows sand discoloration wrongly classified as forest cover.*

#### 3.2.3.3. Cleaning the Forest Cover Data Set

The DoF's forest cover data set was subjected to several spatial processes to solve challenges with false positives. To this end, a filter was built from, according to expert opinion, three reliable data sources to ascertain where, in Namibia, there is consensus on forests' existing, or which represent the likely maximum spatial extent of forests in Namibia. Areas outside these areas were deemed as false positives:

6. From the Namibian Tree Atlas (Curtis & Mannheimer 2005), *Pterocarpus rotundifolius*, *Pterocarpus angolensis*, *Guibourtia coleosperma*, *Burkea africana* and *Baikiaea plurijuga* were used.
7. Dr Vera De Cauwer provided the modelled geographical distributions of *Pterocarpus angolensis*, *Burkea africana* and *Schinziophyton rautaneni* (De Cauwer 2014), from which above 60% probability was extracted.
8. Tree Cover with high probability was extracted from the Global Tree Cover Potential data set (WWF Globil) (Bastin et al 2019).

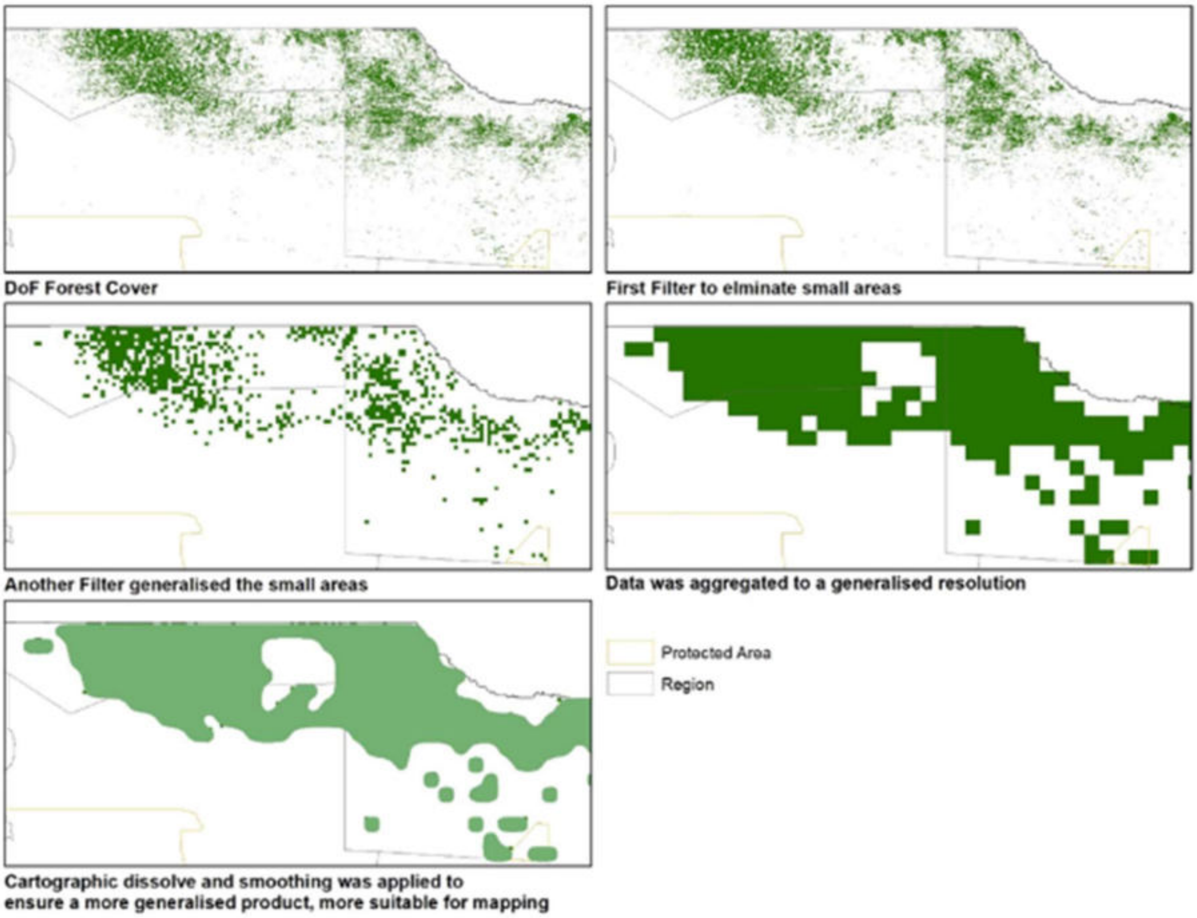



***Map 3: Initial Project Forest Cover Data Set***

*The Global Tree Cover High Probability layer, De Cauwer's tree distributions with high probability and data from the Namibian Tree Atlas were used to create a data layer in which forest may occur in Namibia.*

#### 3.2.3.4. Cartographic Intervention

In view of the scale of the final bush thickening map envisaged for this project, the cleaned forest cover data set was subjected to a number of cartographic generalization functions in order to produce a cleaner final forest cover data set, that represents the high likelihood of forest cover, as derived from forest cover and tree species distributions, available to this project (Map 4).




***Map 4: Insights into Project Forest Cover Data Processing***

*The diagrams give insight into the cleaning, filtering and aggregation process to derive a forest cover layer more suitable for mapping.*

### 3.2.3.5. Expert Intervention

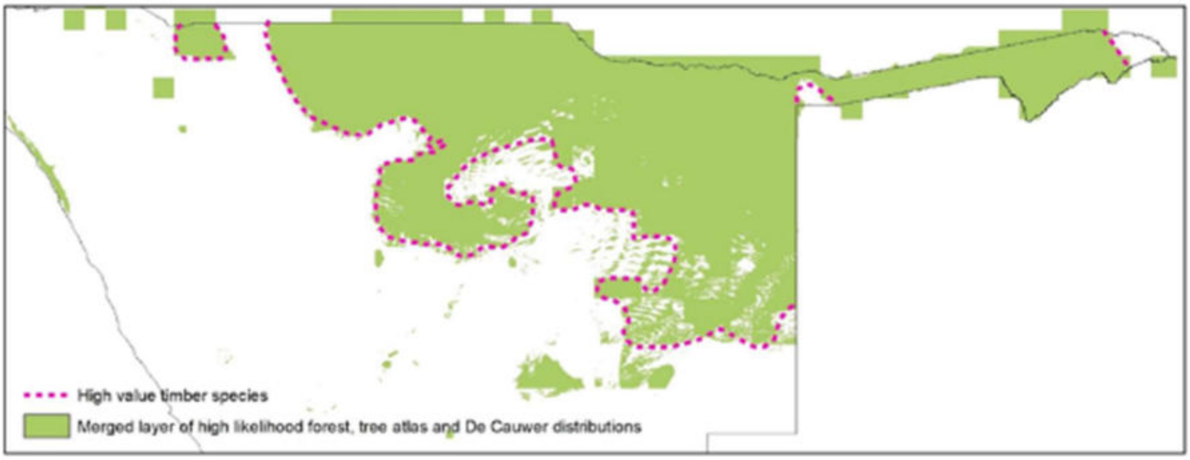
The derived data layers were perused by expert opinion and three amendments were conducted:

1. Prof Vera de Cauwer from NUST pointed out a forest cover area east of Opuwo, which was not present in the data layer. This area was added, by extracting a suitable area from the BIS canopy cover layer and refining it with areas where the soil sand content is bigger than 76%.
2. Mr Peter Erb from the NNF pointed out four distinct areas close to Outjo and south of Otjiwarongo, which are not forest cover areas. These were consequently removed.
3. Prof. Ben Strohbach proposed expansion of the southern boundary, which was accordingly incorporated.

#### 3.2.3.6. High Value Timber Species Line

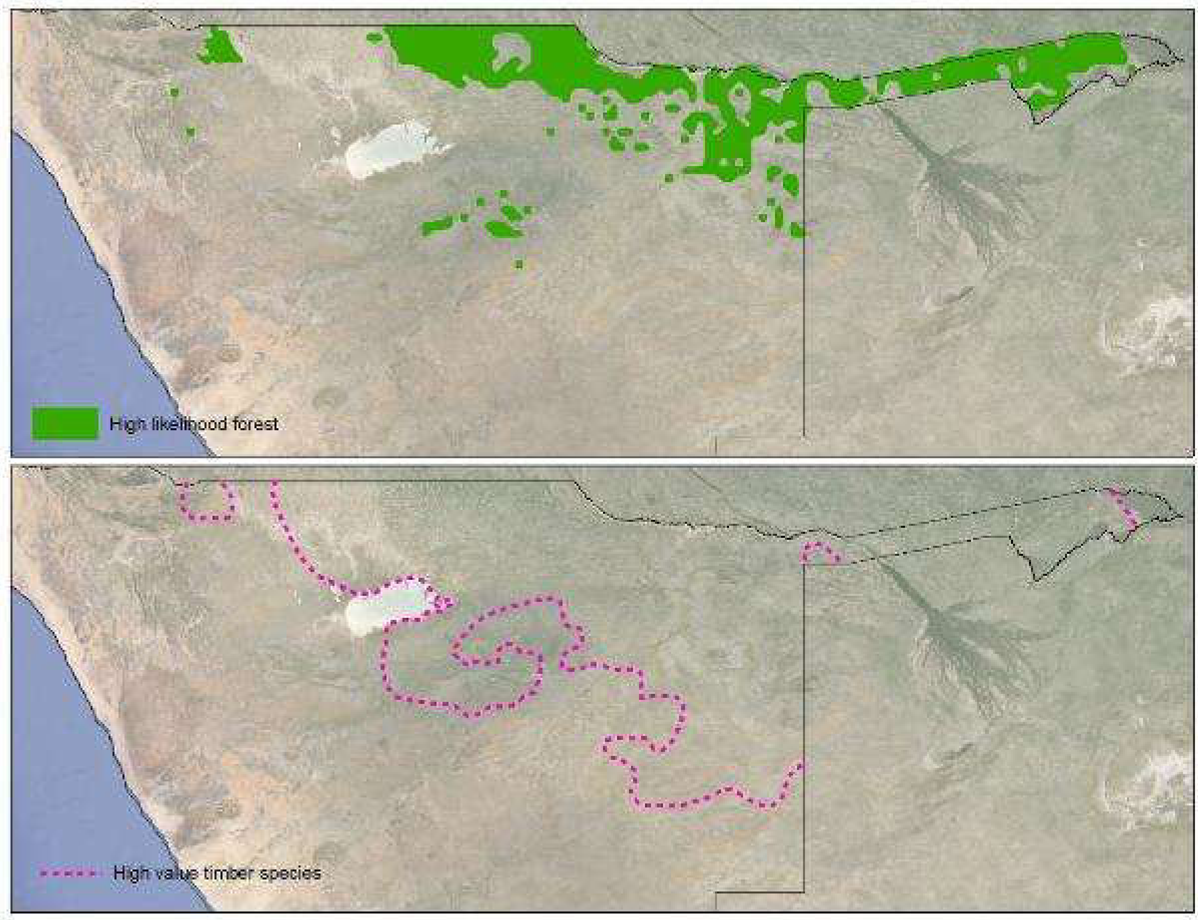
In addition to the High Likelihood Forest area, was a High-Value Timber Species maximum extent boundary included in the map. This boundary was derived from the High Likelihood Forest Area layer, the De Cauwer and the Tree Atlas tree distributions, to ascertain a possible maximum extent for high-value timber species. Notably, field and ground truthing data were not used to assess the final derived data layer. In a data derivation process, this would still be a desirable step to ensure an accurate representation of Namibia's forest cover but moreover, to provide a quality assessment report of the final data layers. Similarly, for the High Value Timber Species layer.

Using the same data as for the high likelihood forest cover data set, the respective Tree Atlas distributions and the distributions provided by Prof De Cauwer, however, excluding the distribution of the commonly occurring *Burkea africana*, a high value timber line was derived, representing the probable area of high value timber species occurring (Map 5).




***Map 5: Maximum Likelihood of High Value Timber Species***

*The high value timber species maximum likelihood line was derived from a merged area of the high likelihood forest, the respective tree atlas layers and the distributions provided by Prof De Cauwer.*




***Map 6: Likelihood of Forest Cover and High Value Timber Species***

*The final high likelihood forest cover area and the high value timber species line, as derived from the available forest cover and tree species data.*

#### 3.2.4. Consensus Building Process

This consultancy had to reach wide consensus about the layout and contents of the maps. Consensus means that "We agree that the presented information is the best possible interpretation and outcome considering the given dataset" accepted by the majority. The process of reaching consensus is divided in several steps: A Project kick-off meeting was held with the client on 16 January 2024 with the purpose to get more clarity on the job at hand and to ensure a smooth start.

1. Three working group meetings with experts in the field of vegetation mapping were held where inputs were received. During these meetings the latest products were presented, discussed and consensus reached on the way forward. These meetings took place on 2 April, 1 and 15 March 2024.
2. Several questionnaires were sent out to selected people clarifying issues of format, layout and contents.
3. Individual contacts were made with selected experts and farmers to get feedback on the correctness of the maps.
4. After the second workshop a presentation was made to the management of the MEFT on the maps and supporting text and feedback was incorporated.

# 4. Results & Discussion

## 4.1. Bush Thickening Extent and Severity

The spatial extent of bush thickening in increasing severity classes in non-forest areas of Namibia is shown in Annexure B.

The area estimated to be affected by bush thickening is summarized in

Table 2. It is estimated that about 46 million ha are to some agree affected by bush thickening in non-forest areas. Our estimate agrees with the previous estimate of 45 million ha (SAIEA, 2016) done about 8 years ago. The very different approaches used to calculate the total area affected, however, negate any direct comparison. Considerable bush control and harvesting also took place since then, which the current map does not incorporate fully.

A complication with the calculation of area affected is that the "light or localized" class include areas where bush thickening occur patchily at too fine scales for mapping at national scale. Examples are thickened dune streets but where the dune crests themselves are unaffected in the Kalahari vegetation types, yet the entire area is counted as bush thickened. This overestimation is to some degree offset by the localized thickening in the "None to very localized" class, which were not considered in calculations, as well as thickening in the High likelihood Forest areas, which were also not counted.

***Table 2: Summary of Area Affected By Bush Thickening***

| | Bush Thickening Severity Class Excluding Forest Areas (Million Ha) | | | | |
|---|---|---|---|---|---|
| **Region** | **Light Or Localized** | **Moderate** | **Severe** | **Total Area Affected** | **% Area Of Region** |
| !Karas | 3.9 | 1.0 | 0.3 | 5.2 | 32 |
| Erongo | 0.6 | 0.8 | 0.7 | 2.1 | 32 |
| Hardap | 5.0 | 1.7 | 0.3 | 7.0 | 64 |
| Kavango East | 0.1 | 0.0 | 0.0 | 0.1 | 22 |
| Kavango West | 0.1 | 0.2 | 0.0 | 0.3 | 55 |
| Khomas | 2.1 | 0.9 | 0.2 | 3.1 | 85 |
| Kunene | 1.9 | 2.6 | 1.9 | 6.4 | 56 |
| Ohangwena | 0.1 | 0.1 | 0.0 | 0.2 | 23 |
| Omaheke | 2.3 | 3.5 | 2.6 | 8.4 | 99 |
| Omusati | 0.6 | 0.6 | 0.2 | 1.4 | 52 |
| Oshana | 0.2 | 0.0 | 0.0 | 0.2 | 25 |
| Oshikoto | 0.7 | 1.3 | 0.5 | 2.5 | 66 |
| Otjozondjupa | 2.4 | 4.0 | 2.5 | 8.9 | 92 |
| Zambezi | 0.2 | 0.0 | 0.0 | 0.2 | 13 |
| **Total Namibia** | **20** | **16.7** | **9.3** | **46** | **56 % of Namibia's Land Surface** |

The recent map suggests that in terms of extent the Otjozondjupa, Omaheke and Khomas regions are the most affected. Our estimate of 8.9 million ha affected in the Otjozondjupa region is less than the 10.5 million ha estimated by Hengari (2018) but is partly due to the exclusion of areas considered as a high likelihood of forest occurring. These high likelihood forest areas probably include bush thickened wooded areas not classified as forest. Similarly, were large parts of the Zambezi, Ohangwena and Kavango East and West regions excluded from the extent calculations, resulting in low areas mapped as bush thickened (Table 2). These regions have substantial areas denoted as Forest or High likelihood of Forest, which affects these figures. According to the SAIEA (2016) map the Ohangwena and Zambezi regions had no thickening.

The mapping approach followed analysed bush thickening in the context of long-term rainfall, which ultimately limits woody plants where no additional runoff or subirrigation (e.g., along streams and rivers) are experienced (Sankaran et al. 2004; 2005). This allowed us to also map bush thickening in especially the southern parts of Namibia.

## 4.2. Encroacher Species Distribution

The bush encroacher species distribution maps (probability of occurrence in four classes) are shown in Annexure B.

The bush encroacher species distribution maps attempted to improve on the previous Tree Atlas distribution maps, which provides occurrence information at a Quater Degree Square scale by incorporating environmental suitability modelling, accurate occurrence data and expert opinion. These maps do not indicate the density of the species, only where the probability for occurrence in an area is. The BIS encroacher species distribution maps, used as the starting point in this project, were not previously validated and this project allowed for validation with extensive field observation data and expert opinion adjustment of the current distribution ranges, thus is considered a substantial improvement on previous distribution maps.

It was decided to merge the *Vachellia luederitzii* and *V. reficiens* maps, because of the difficulty distinguishing these species in the field (Mannheimer & Curtis, 2018) and to simplify the information included on the final map.

## 4.3. Project Constraints

The short duration of the project and the limitation imposed to preferably make only use of available data sources placed constraints on the accuracy and detail included in the maps. For example, the most recent BIS layers, used to map most of the higher rainfall areas, were based on 2018 data, thus more than 5 years old. We attempted to rectify this deficiency by incorporating expert opinions and validation using recent SAR 2022 data and Google Earth imagery. The southern and far western parts were, whoever, based on the 2021 land cover classification, thus reflects more recent patterns.

Distinguishing between forests, woodlands and savannas was problematic and several stakeholders raised the issue about how these vegetation types are defined and quantitively mapped. Some of the confusion emerge because of different viewpoints between forester and rangeland scientists, which tend to view the value of the land, degradation and how to restore the land through the lens of their respective disciplines. We attempted to accommodate both viewpoints, but this remains a contentious issue, not the least because changes from savannas to woodland/forest is often gradual in reality.

# 5. Conclusion & Recommendations

The previous bush thickening map for Namibia (SAIEA 2016) was updated and an information poster created that provides additional information related to bush control and utilization, including updated distribution maps of the main encroacher species, sensitive areas and general information and regulations that applies in Namibia. The main thickening map extent and severity was based on existing remote sensed data layers, which were adjusted manually with input from experts and limited field verification carried out.

## 5.1. Recommendations

1. Central database related to bush related datasets hosted by a reputable organisation. A range of historic field datasets were identified, which were hosted by various institutions or individuals. Creating a central database where field data, photos and other bush related data and information can be stored and easily retrieved will be valuable for future research and updates. Organizations or data portals that may be suitable for hosting such a data compilation include N-BIG, Perivoli Rangeland Institute and the Environmental Information System. Redundancy will be preferable.
1. Review bush thickening map every 3-5 years.
2. Revisit definitions of bush thickening and forest every 3-5 years. Early discussions with stakeholders showed that the current definitions are ambiguous and not easily quantifiable, a requirement for mapping exercises.
3. Stimulate or request research with regards to ecosystem service responses to a gradient of bush thickening levels, repeated over various environmental conditions including rainfall and soil texture.
4. Regularly updating woody cover and biomass layers, using approaches such as the BIS or Venter et al. (2018) is urgently needed to obtain detailed information of changes at 30-50m spatial resolution for monitoring and inventory purposes. Such data layers will be the logical inputs for future updates of the bush thickening maps in future.
5. Undertake a field and ground truthing exercise of the final High Likelihood Forest Cover layer to ensure an accurate representation of Namibia's forest cover but moreover, to provide a quality assessment report of the final data layers. Similarly, for the High Value Timber Species Line.

## 5.2. Disclaimer

The new maps detailing bush thickening in Namibia serve as a comprehensive visual representation of the extent of bush thickening across the different regions and biomes of the country. These maps offer valuable insights into the ecological phenomenon of bush thickening, including species distribution. When making use of the maps, either for own purposes or by re-producing it in reports or similar works, the following limitations are important to take into consideration:

1. Data sources: the maps are exclusively based on aggregated secondary data (e.g., from the Bush Information System and Land Degradation Neutrality Reports) and thus do not represent new national spatial dataset. The maps were further refined through open stakeholder workshops and expert consultation, factoring in a large amount of field data from localised vegetation assessments, which had previously not been available for bush thickening maps. The maps thus represent aggregated data of various sources, qualities and collection methods. The reliability of the information displayed can thus differ geographically.
2. Static nature of maps: The resulting maps are static and illustrate the best possible information at the point of drafting, based on the consensus of the involved experts. Due to the dynamic nature of bush thickening and bush control measures, the information displayed can quickly be outdated, especially at specific sites. The maps are thus not be used for site-specific decision-making.
3. Comparability with other maps: the new maps follow the idea and general concept of previous efforts to map bush thickening in Namibia, like the maps of Bester (2004) and SAIEA (2016). However, methods and data sources will differ between the different mapping exercises, especially because technology for data collection is evolving rapidly. The maps are thus not directly comparable. Differences in the total areas size displayed as affected by bush encroachment, are thus not to be understood to accurately reflect the actual expansion or reduction of bush encroachment.

Potential uses include the integration into academic and non-academic reports, as well as the usage of information poster for capacity development measures and general public information. The maps do not allow for location-specific (e.g., farm level) vegetation assessments and biomass quantification. For decision-making on targeted interventions, such as bush harvesting and respective permitting, localised assessments will be required.

Neither the Ministry of Environment, Forestry and Tourism and its implementation partners, nor the authors of the map and consulted experts, can be held responsible for conclusions derived from the maps.

# Appendix A: References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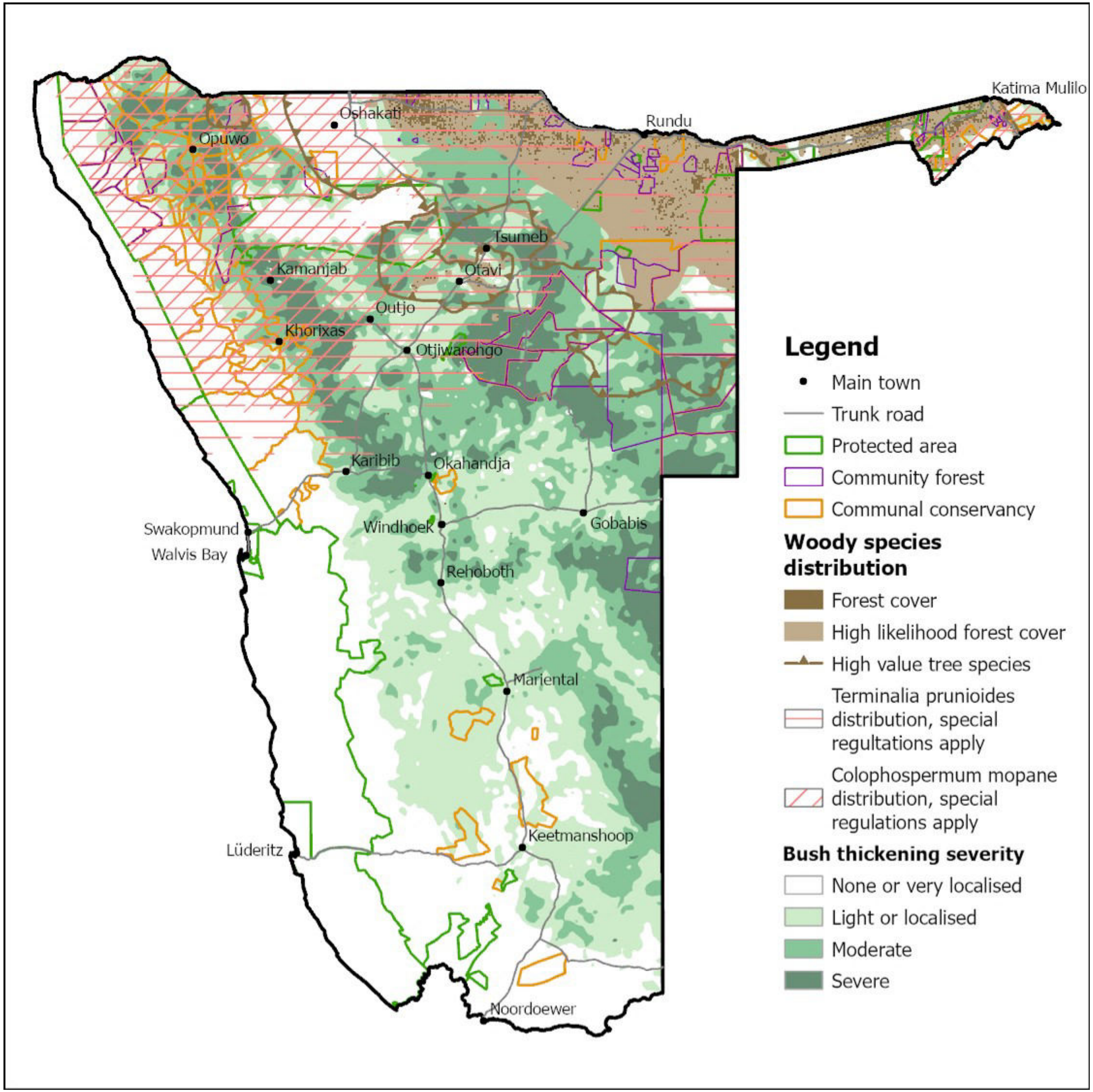
# Appendix B: Revised Bush Maps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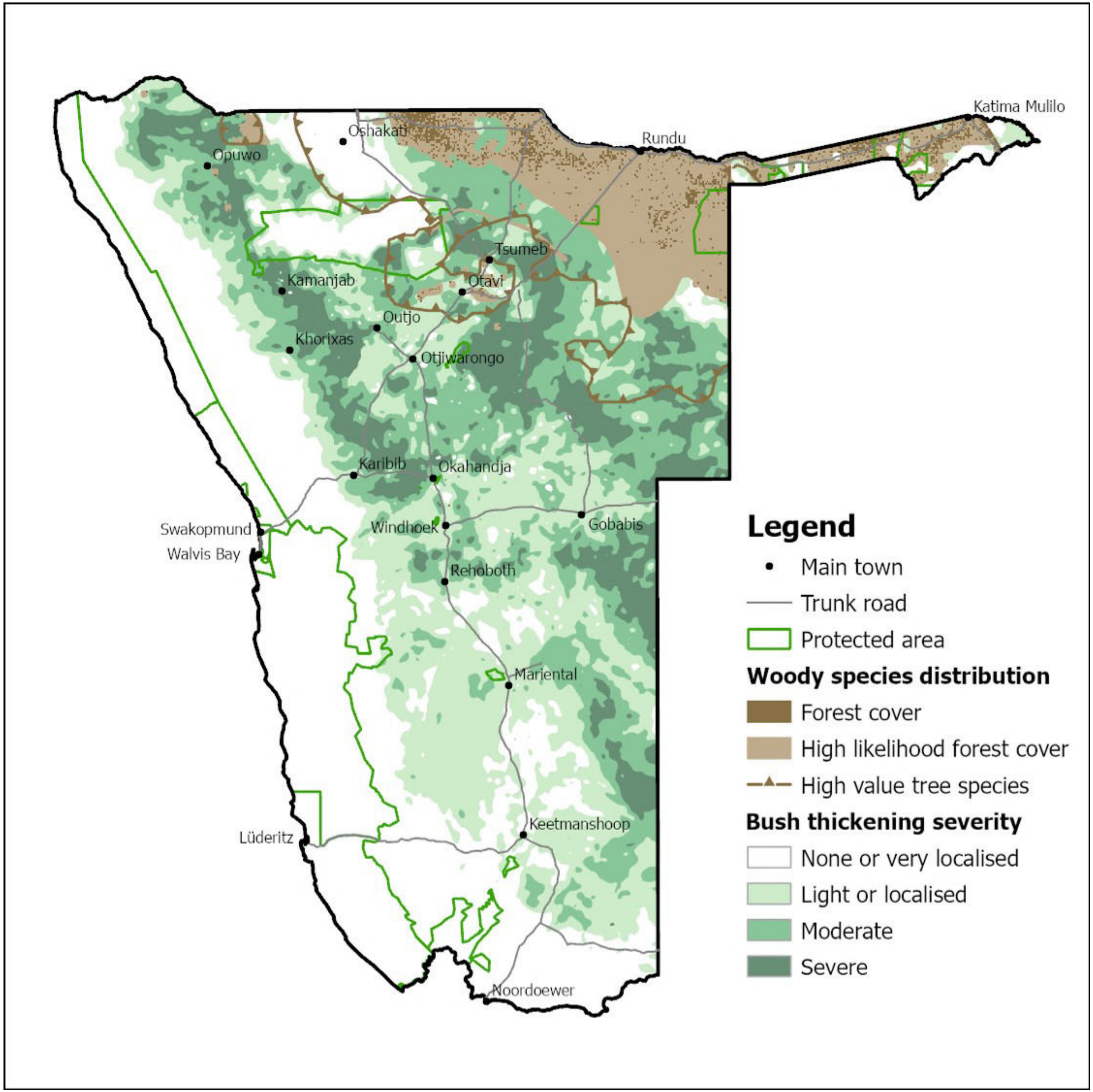
Swakopmund
Walvis Bay
Windhoek
Gobabis
Rehoboth
Mariental
Keetmanshoop
Lüderitz
Noordoewer
Legend
Main town
Trunk road
Protected area
Community forest
Communal conservancy
Woody species distribution
Forest cover
High likelihood forest cover
High value tree species
Terminalia prunioides distribution, special regultations apply
Colophospermum mopane distribution, special regulations apply
Bush thickening severity
None or very localised
Light or localised
Moderate
Severe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Windhoek
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Rehoboth
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Lüderitz
Keetmanshoop
Noordoewer
Legend
Main town
Trunk road
Protected area
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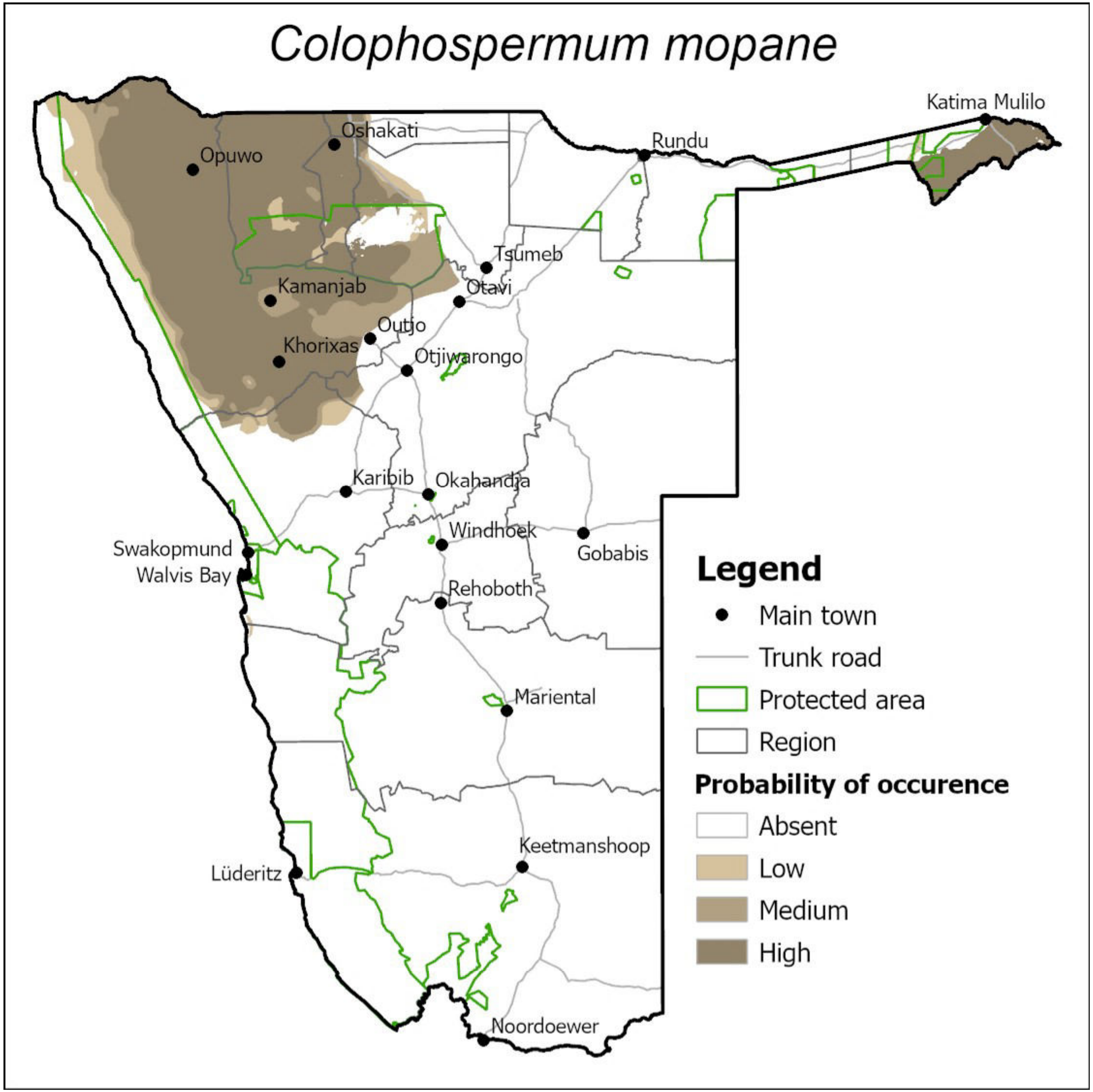
Forest cover
High likelihood forest cover
High value tree species
Bush thickening severity
None or very localised
Light or localised
Moderate
Severe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Okahandja
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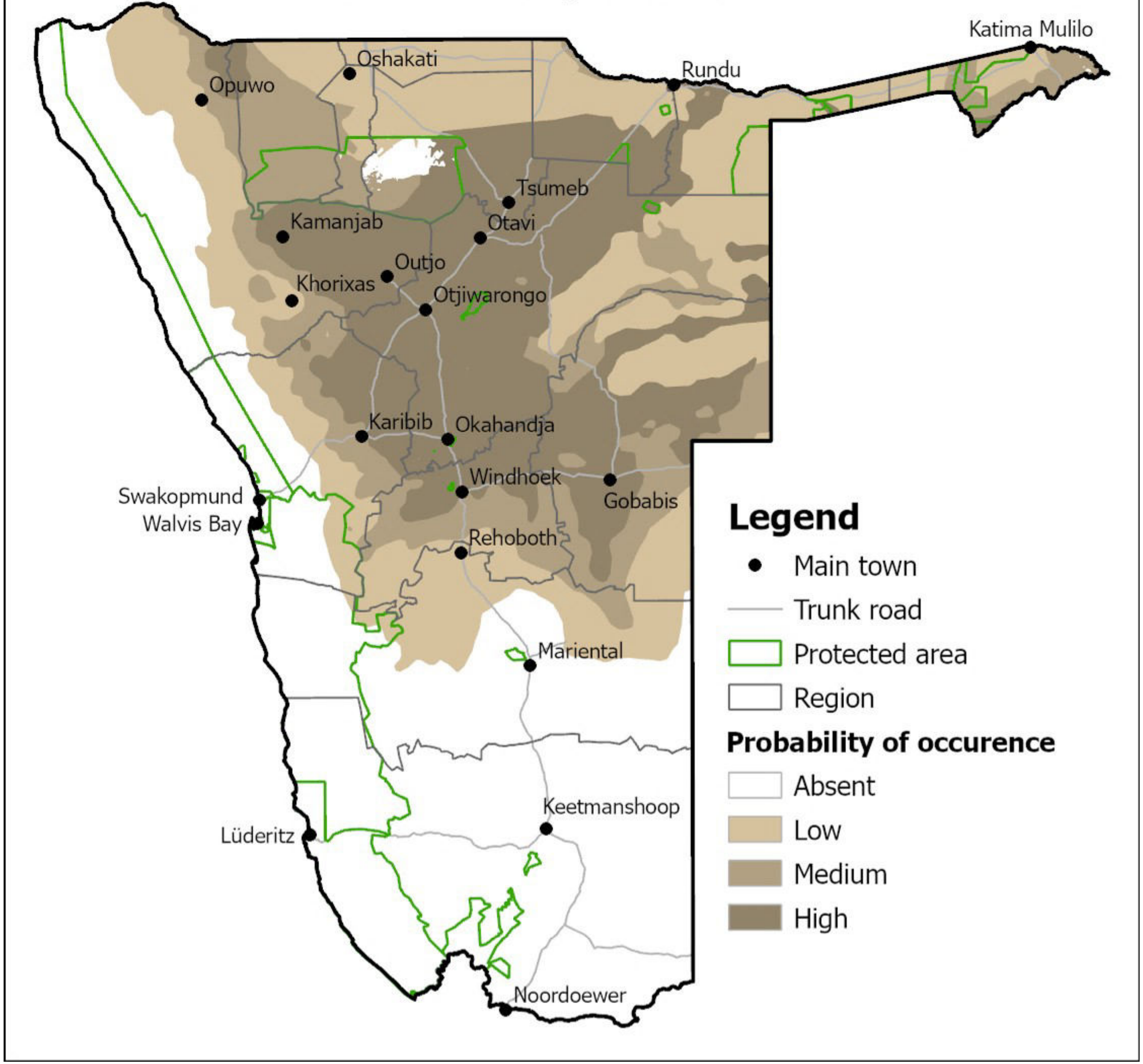
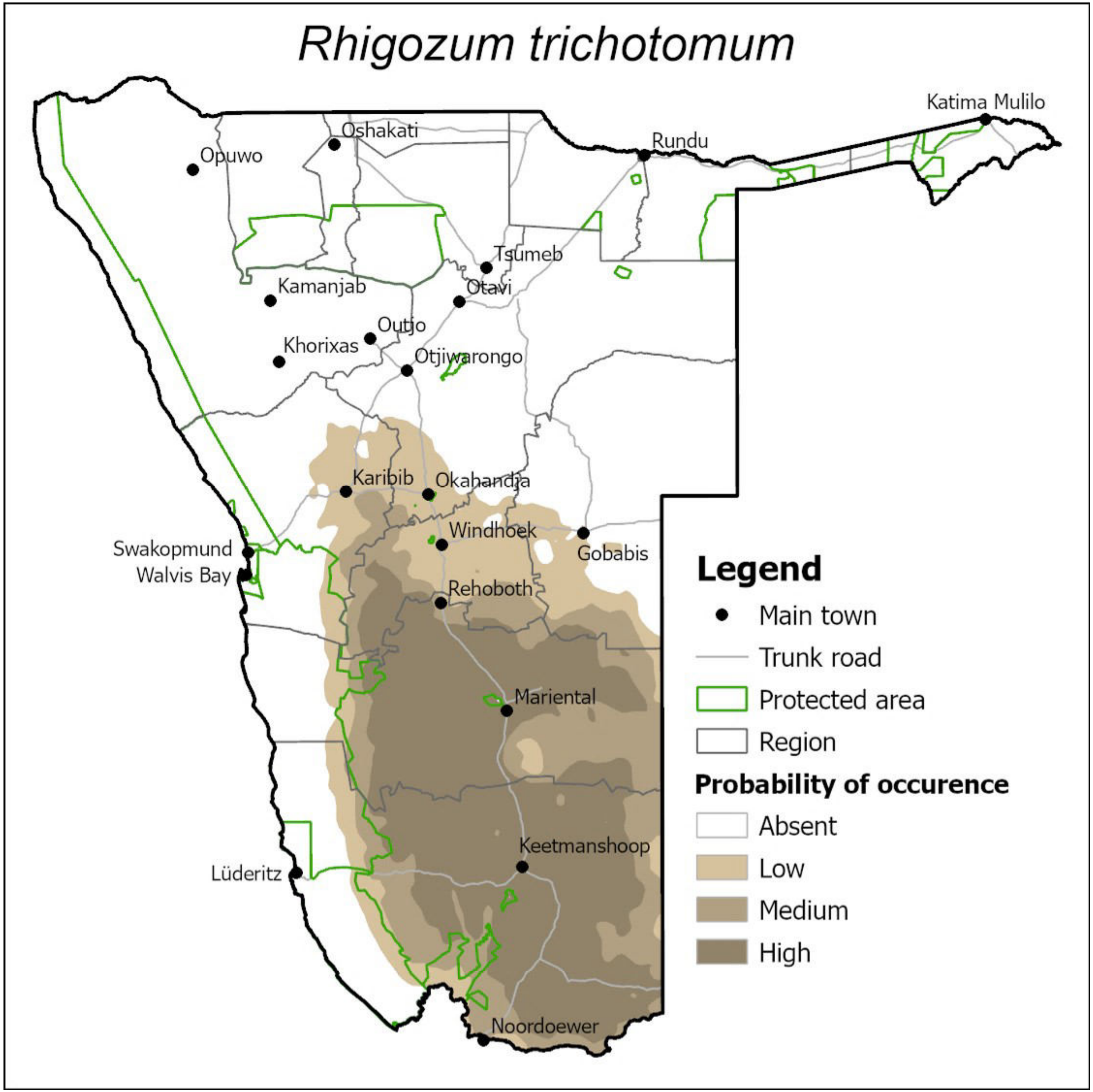
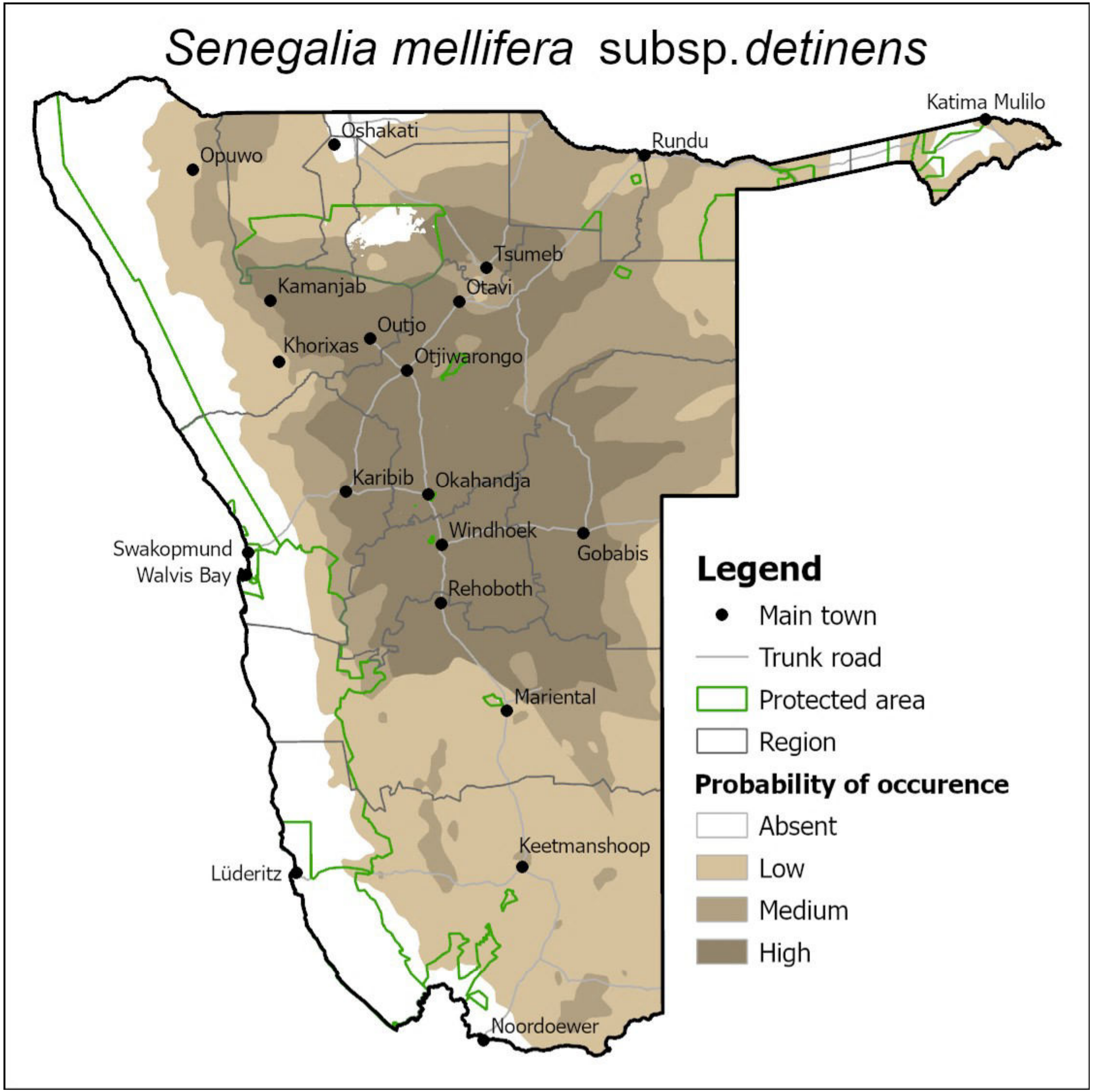
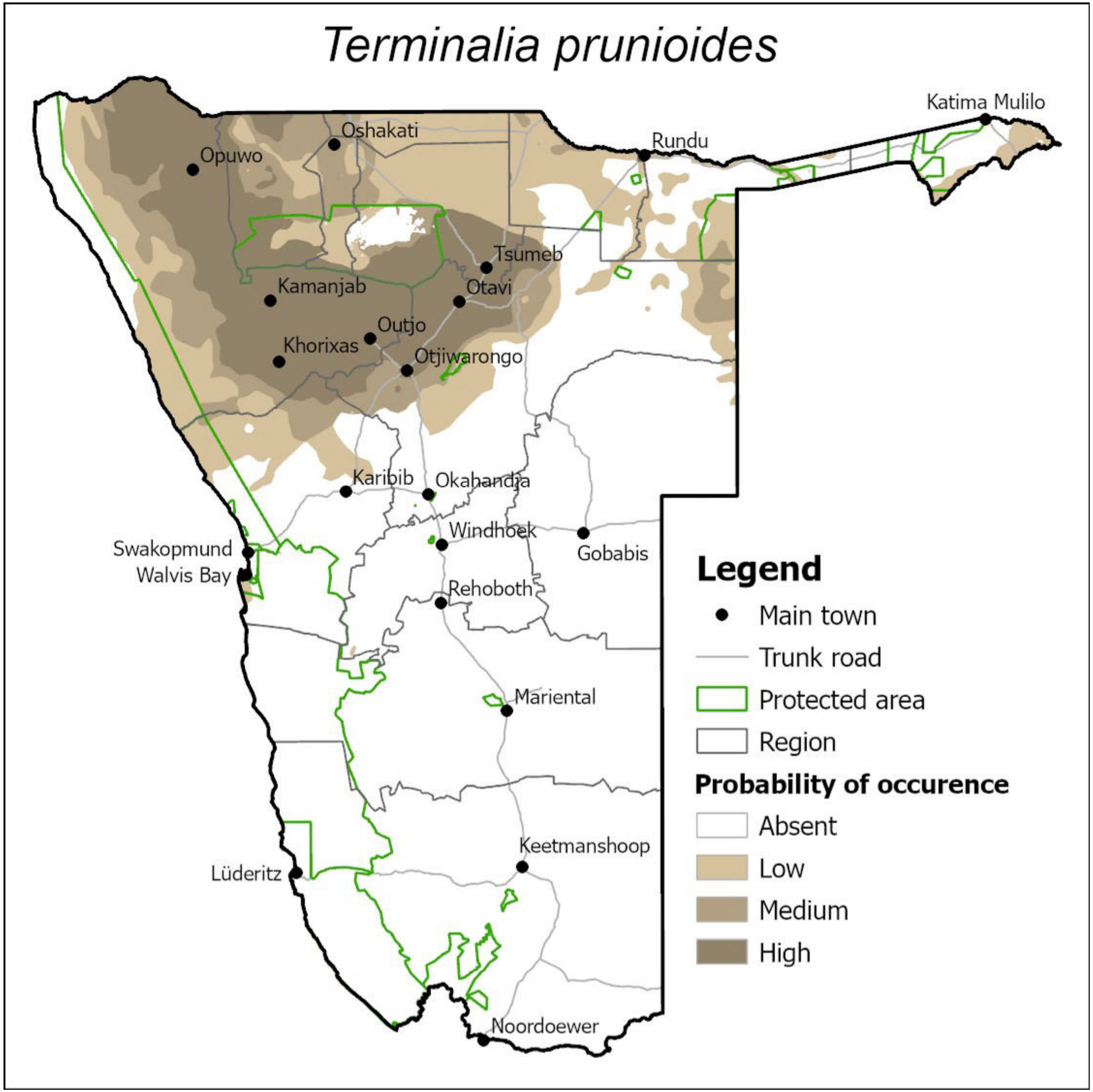
Swakopmund
Walvis Bay
Rehoboth
Mariental
Keetmanshoop
Lüderitz
Noordoewer
Legend
Main town
Trunk road
Protected area
Region
Probability of occurence
Absent
Low
Medium
High

# *Dichrostachys cinerea*

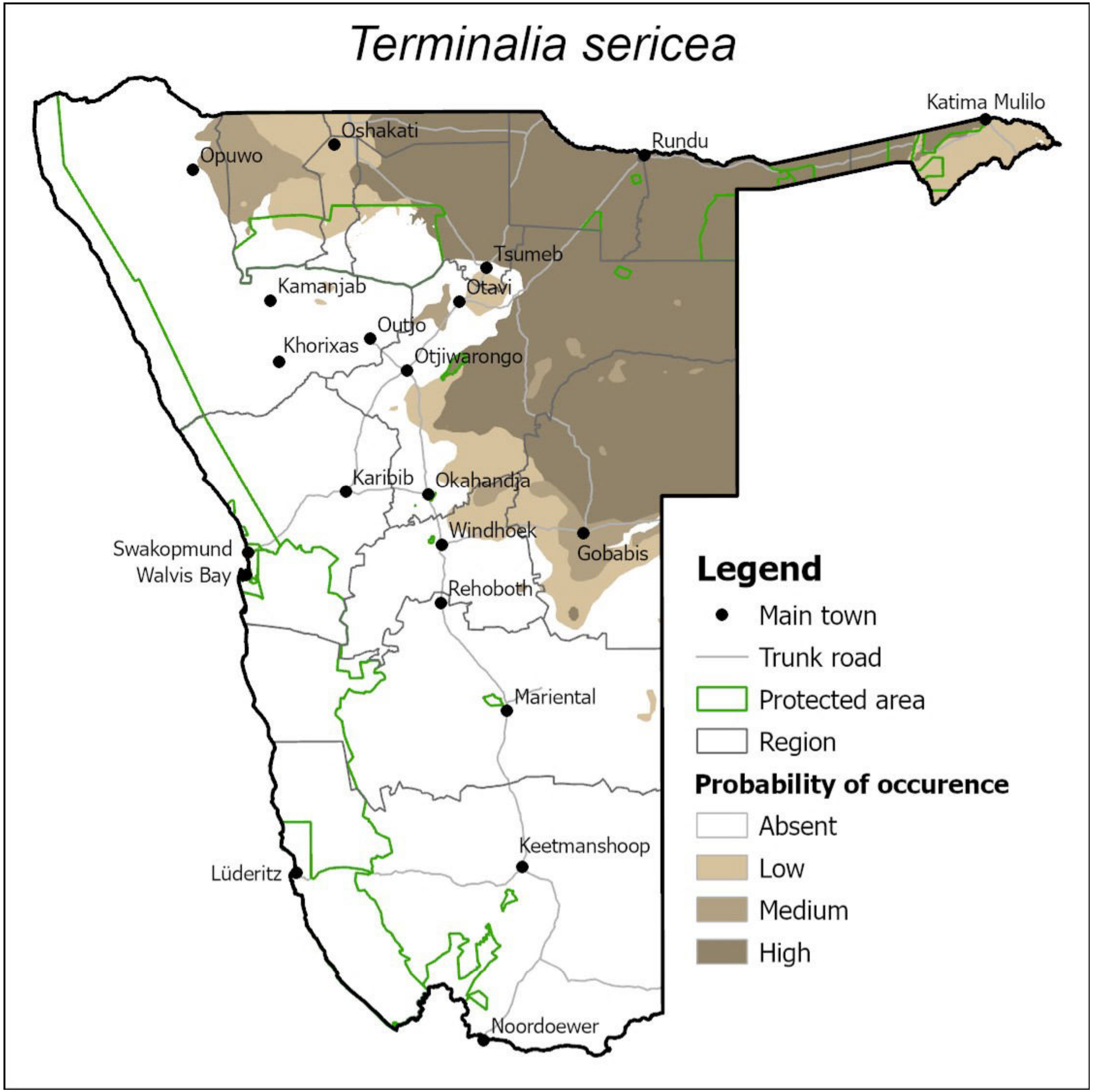



Rhigozum trichotomum
Katima Mulilo
Rundu
Oshakati
Opuwo
Tsumeb
Otavi
Kamanjab
Outjo
Khorixas
Otjiwarongo
Karibib
Okahandja
Windhoek
Gobabis
Swakopmund
Walvis Bay
Rehoboth
Mariental
Keetmanshoop
Lüderitz
Noordoewer
Legend
Main town
Trunk road
Protected area
Region
Probability of occurence
Absent
Low
Medium
High

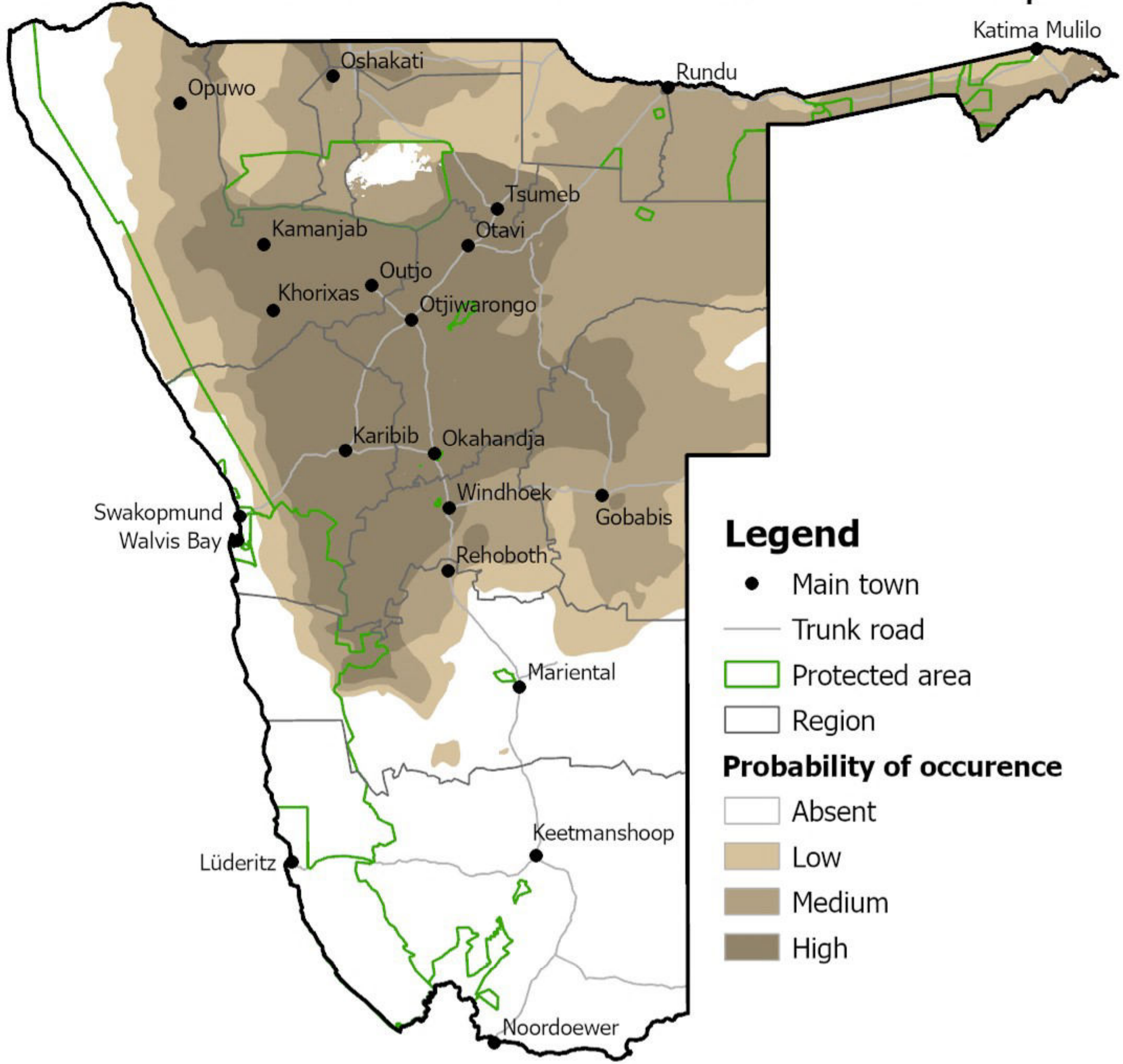

Senegalia mellifera subsp.detinens
Katima Mulilo
Oshakati
Rundu
Opuwo
Tsumeb
Kamanjab
Otavi
Outjo
Khorixas
Otjiwarongo
Karibib
Okahandja
Windhoek
Gobabis
Swakopmund
Walvis Bay
Rehoboth
Mariental
Keetmanshoop
Lüderitz
Noordoewer
Legend
Main town
Trunk road
Protected area
Region
Probability of occurence
Absent
Low
Medium
High



Terminalia prunioides
Katima Mulilo
Rundu
Oshakati
Opuwo
Tsumeb
Otavi
Kamanjab
Outjo
Khorixas
Otjiwarongo
Karibib
Okahandja
Windhoek
Gobabis
Swakopmund
Walvis Bay
Rehoboth
Mariental
Keetmanshoop
Lüderitz
Noordoewer
Legend
Main town
Trunk road
Protected area
Region
Probability of occurence
Absent
Low
Medium
High


Terminalia sericea
Katima Mulilo
Oshakati
Rundu
Opuwo
Tsumeb
Kamanjab
Otavi
Outjo
Khorixas
Otjiwarongo
Karibib
Okahandja
Windhoek
Gobabis
Swakopmund
Walvis Bay
Rehoboth
Mariental
Keetmanshoop
Lüderitz
Noordoewer
Legend
Main town
Trunk road
Protected area
Region
Probability of occurence
Absent
Low
Medium
High

# *Vachellia luederitzii - Vachellia reficiens* complex



# *Vachellia nilotica*