Photo: St John Wilson

ASSESSMENT OF LAND USE CHANGE & ECOSYSTEM SERVICES

ZIMBABWE

Emma Underwood, Beth Hahn, Allan Hollander

United States Forest Service Assessment

December 2020

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Victoria Falls, Zimbabwe by helicopter
Photo: Jason Zhao on Unsplash

ACRONYMS AND ABBREVIATIONS

EPOs	Exclusive prospecting orders
FTLRP	The Fast Track Land Reform Program
GDP	Gross Domestic Product
JRC	Joint Research Council
IPIS	International Peace and Information Service
MODIS	Moderate Resolution Imagine Spectroradiometer
NGO	Non-Governmental Organization
NTFPs	Non-Timber Forest Products
SEOSAW	Socio-Ecological Observatory for the Southern African Woodlands
SWAT+	Soil and Water Assessment Tool
USFS	United States Forest Service
USDA	United States Department of Agriculture
USAID	United States Agency for International Development
ZELA	Zimbabwe Environment Law Association

Community members outside a commercial mining equipment depot, Mashonaland East Province.

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Native tree nurseries and planting in communal areas can provide provisioning services for rural communities, as well as contribute to regulating services through carbon storage; Matabeleland North Province.

1.0 EXECUTIVE SUMMARY

The Republic of Zimbabwe has diverse and productive natural resources. Its native ecosystems provide habitat to globally significant megafauna including black rhinoceros and African elephant. Woodlands and grasslands with high conservation value species such as teak and mahogany dot the landscape.

Zimbabwe's natural resources are a critical source of subsistence and income for rural communities who practice smallholder agriculture, livestock rearing, and artisanal mining. These intensive land use practices—combined with increasing population, a warmer climate, weak natural resource governance, and an ongoing economic crisis—threaten the country's natural capital, which is the stock of ecosystems from which Zimbabweans derive services, for example, soil, water, and timber. Ecosystem services can also be resilience to climate change or resources and areas that attract tourism and recreation.

Agricultural development, mining, urbanization, altered fire regimes, and climate change all threaten ecosystems and the services they provide. Substitutes for ecosystem service can be costly or completely unavailable. Understanding the quantity and spatial distribution of ecosystem services is important for ensuring the long-term provision of essential natural resources, along with broader issues of socio-ecological resilience.

The US Forest Service's International Programs undertook the first national-scale snapshot of ecosystem services in Zimbabwe. The assessment provides a better understanding of the pressures facing Zimbabwe and examines how these pressures might affect the provision of critical ecosystem services from natural landscapes. A particular interest was to assess how pressures and ecosystem services were reflected in patterns of provincial administrative units, and changes in land tenure resulting from the Fast Track Land Reform Program (FTLRP) starting in 2000. To this end, USFS analyzed tree loss, fire, and population data from the past twenty years to detect trends in relation to woody biomass, water, tourism, biodiversity, and non-timber forest products. The USFS team also integrated available data on large-scale and artisanal mining, and commercial timber harvest.

Findings indicated that changes in land tenure and land use were associated with changes in tree loss and fire frequency. Highest tree loss rates were found in the A1 resettlement areas (small plots averaging 5 ha in size) between 2000-2008, which experienced loss rates of up to 6%. Similarly, agricultural land uses had the greatest areas burned, peaking at 19% and 30% for A1 and A2 resettlement areas, respectively, in 2010 (A2 areas included larger, self-contained farming units that averaged 318 ha per farmer). These pressures can be viewed in the context of spatial patterns of ecosystem services, particularly areas of high ecosystem service provision that can be considered as priority areas for future focus. Aboveground woody biomass was highest in the Eastern Highlands and north of Hwange National Park in northwestern Zimbabwe. Similarly, average water balance between 1999-2013 was also highest in landscape units along the northern border, while highest tourism values were concentrated in Victoria Falls and Hwange National Parks, but also around Matopas National Parks, and scattered throughout the Eastern Highlands.

This assessment demonstrated how data on biodiversity, timber, and non-timber forest products can be combined, and we identified four areas important for biodiversity that are currently unprotected: southwest of Gonarezhou National Park, the northern end of the Great Dyke, the area to the east of the Mana Pools, and portions of the Eastern Highlands. Combining all of the ecosystem service analyses, we found only a weak to moderate correlation: some provinces were remarkably balanced such as the Midlands, while others showed one or two dominant services, such as tourism services in the Bulawayo Province.

The assessment identified four areas important for biodiversity that are currently unprotected:

1. Southwest of Gonarezhou National Park

2. The northern end of the Great Dyke

3. The area to the east of the Mana Pools

4. Portions of the Eastern Highlands.

In reviewing the data and findings, it is important to recognize the limitations of national scale analyses, which do not necessarily capture local-scale patterns and are bounded by the selected timeframe. For example, widespread deforestation in Hwange and Gonarezhou National Parks caused by increasing elephant populations is unlikely to be captured in the satellite data utilized. Similarly, widespread loss of trees associated with settlements in the South Eastern Lowveld is likely to have happened prior to our data analysis from 2000 onwards, and again not reflected. We are also aware that our mining data provides only a partial snapshot given the rapid changes in mining activities over time.

Finally, the timing of our assessment was unfortunate. Given the global COVID-19 pandemic, the in-country meetings and workshops were rescheduled as virtual engagements which, in turn, restricted the opportunities for in-person engagement and in-depth data availability discussions. This assessment has nonetheless compiled the best available information to date on pressures to Zimbabwe's natural landscapes since 2000 and reviewed these in terms of administration and land use patterns. This project is also the first national-scale ecosystem service analysis for Zimbabwe, and as such we hope that Zimbabwean stakeholders and decision makers will find these results useful as they balance social, economic, and ecological considerations.

Using this national assessment as a foundation, the USFS's International Programs will next undertake a regional study of the South Eastern Lowveld. The South Eastern Lowveld is one of the priority regions for biodiversity that is also at high risk for drought, as well as climatic and economic shocks, and an area that was repeatedly discussed in our interactions with experts. Focusing on this region will allow ecosystem services to be modeled at a finer spatial scale, thereby increasing their accuracy through incorporating empirical data. It will also allow work at the community scale to better understand the use of non-timber forest products from community forests and in particular, to explore the economic values of selected ecosystem services to highlight the benefits natural landscapes provide.

2.0 ZIMBABWE OVERVIEW

GEOGRAPHY AND ADMINISTRATIVE DIVISIONS	
Total Area	**Total: 390,757 sq km** Land: 386,847 sq km Water: 3,910 sq km
Administrative Divisions	59 districts located within 10 provinces, including two cities with provincial status, the capital, Harare, and Bulawayo
DEMOGRAPHICS	
Population	**Total: 14.5 million (2020)** 0 - 14 years: 38% 15 - 64 years: 57% 65 years and older: 5%
Annual Population Growth Rate	**1.9% (2020)**
Population Density	**38 people per sq km (2020)**
Life Expectancy at Birth	**Average: 62 years** Female: 65 years Male: 60 years
Fertility rate (# births per woman)	**3.93 (2020)**

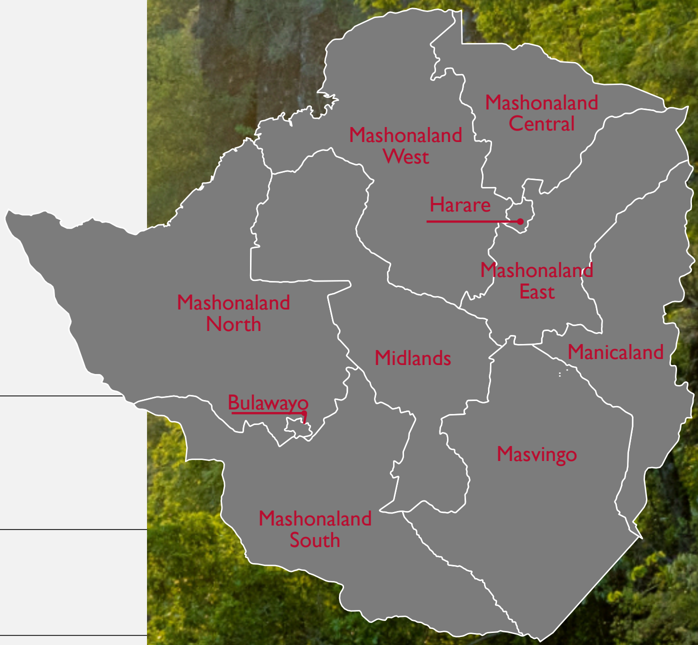


Photo: Tatenda Mapigoti

3.0 BACKGROUND

3.1 RATIONALE AND APPLICATION FOR THIS ASSESSMENT

The forests of Zimbabwe provide important ecosystem services at all scales: from fuelwood and construction materials for local communities, to water supply at the regional level, to carbon storage and biodiversity conservation at national and global scales. In addition, many of the forested ecosystems in Zimbabwe are located in, or near, sites with economically important minerals. Quantifying and identifying important services provided by forests and determining hotspots where multiple services overlap, can inform natural resource decision making and help ensure that critical landscapes and resources are managed sustainably.

Understanding the quantity and spatial distribution of ecosystem services is important for ensuring the long-term provision of services by natural ecosystems, along with broader issues of socio-ecological resilience. This type of information can also be used to influence policy around land management and be used by both government and civil society to help support natural resource decision making. Furthermore, determining the economic value associated with some of the services provided by forests can illuminate their contribution to the national economy, elevating the importance of conserving these resources for future generations. Finally, this can also increase public appreciation of natural landscapes.

Ecosystem services are the suite of natural assets functioning ecosystems provide that are critical to human health and society (Millennium Ecosystem Assessment 2005).

As ecosystems are threatened by agricultural development, urbanization, altered fire regimes, and climate change, this leads to reduced provision of ecosystem services for which substitutes are costly or completely unavailable (Benayas et al. 2009; Bullock et al. 2011).

The areal extent of forests in Zimbabwe has diminished over the past several decades. It is important to determine the links to possible drivers of change, the relationship between changes in land use and land tenure and watershed function, and the impacts to critical ecosystem services in order to help inform forest conservation. After a series of extensive consultations with partners in Zimbabwe about broader natural resource management challenges, in June 2019, the United States Forest Service's International Programs (USFS) undertook a spatial assessment at the national scale to better understand the pressures facing Zimbabwe's natural resources and to examine how these drivers might affect the provision of critical ecosystem services from natural landscapes. A particular interest was to assess how patterns of pressures and services were reflected by provincial administrative units, as well as changes in land tenure resulting from the Fast Track Land Reform Program (FTLRP) starting in 2000. As such, the USFS team analyzed tree loss, fire, and population data from 2000 to 2020 to detect trends in relation to woody biomass, water, tourism, biodiversity, and non-timber forest products. USFS also integrated available data on large-scale and artisanal mining and commercial timber harvest. This effort involved communication with experts and researchers in the fields of ecology, forestry, non-timber forest products, hydrology, and tourism; and, discussions with variety of government and non-government institutions in an effort to understand the current extent of mapping woodlands, land cover and ecosystem services in Zimbabwe (see Appendix 1).

The acquisition of spatial data at the national scale was both time-intensive and challenging, and further compromised by the global COVID-19 pandemic. Nonetheless, this assessment builds on other ecosystem services assessments (e.g., Chawanji et al. 2018) by incorporating a broader suite of services, and provides a sound foundation for undertaking future analyses. Moreover, the process of undertaking the assessment has been equally important in helping to strengthen relationships with existing colleagues while also expanding USFS' network of contacts and stakeholders within Zimbabwe. In November 2020, the USFS team held two virtual workshops to review the data and analyses(Appendix 1), and the insights and feedback shared during those workshops are reflected in this assessment. In short, **this report summarizes the best, readily available data at the national scale, drawing on the strength of established relationships**.

This report, along with the spatial data from this national scale assessment, can be applied in various ways by diverse stakeholders looking to integrate more holistic approaches that balance social, economic, and ecological considerations of land use and natural resource sustainability. For example, these analyses highlight areas within Zimbabwe where there are strongholds or challenges for particular ecosystem services, or potential conflicts among stakeholder uses. Moreover, this national assessment can be supplemented with future regional-scale data to improve accuracy and site-level application.

3.2 UNITED STATES FOREST SERVICE EXPERTISE AND HISTORY IN ZIMBABWE

The USFS manages 78 million hectares of land in diverse ecosystems across the United States on behalf of the American people. These protected areas are managed under a "multiple use" mandate that aims to balance economic, social, and ecological components of natural resource management. USFS International Programs has a long history of collaborating with the U.S. Agency for International Development (USAID) and the U.S. Department of State as a technical implementation partner on natural resource management projects, and the USFS currently works in 90 countries around the world. To accomplish its international programming, the USFS brings technical expertise to in-country partnerships across the region with host country agencies, NGOs, and other partners on build capacity to local natural resource management priorities—such as protected area management, tourism, watershed management, sustainable forestry, disaster management, and conservation crime—while contributing to improving the economic and environmental viability of natural resource-based livelihoods.

USFS has been providing technical assistance in Zimbabwe since 2016. Initial engagement followed a two-week visit that included meeting with representatives from the US Embassy, USAID, and many in-country organizations to explore partnership opportunities. Thematic areas explored during that visit that align with USFS expertise included community-based natural resource management, watershed and rangeland management, youth conservation education and vocational training, community resilience and disaster management, and mining. USFS technical assistance to Zimbabwe is exceptional. Few U.S. Government agencies provide technical assistance in Zimbabwe because of the challenging operating environment, particularly on conservation issues.

To date, USFS projects in Zimbabwe have been modest, with support from USAID/Africa Bureau biodiversity funding. USFS has provided technical assistance to a native tree nursery and reforestation project of TreeEco International in Matabeleland North Province and organizational mentoring and tree nursery equipment to Environmental Buddies Zimbabwe. USFS has also partnered with the Zimbabwe Environmental Law Association on the design and implementation of a capacity building workshop on responsible metals mining for civil society participants working across Zimbabwe. In addition, USFS has hosted 19 Zimbabweans over the years on study tours, international exchange visits and annual natural resource seminars in the United States to build global and regional networks of natural resource practitioners. Participants include staff from USAID and the Embassy, as well as NGO representatives.

Photo: Christine Donaldson

4.0 INTRODUCTION

The woodlands and forests of Zimbabwe cover over 40% of the country and provide a variety of ecosystem services to local and regional communities (FAO, Campbell 1996). There are three main types of woodland in Zimbabwe – miombo, mopane, and montane. Miombo woodlands are dominated by trees belonging to the family *Fabaceae: Caesalpinioideae* and characterized by the genera *Brachystegia* and *Julbernardia*, occurring in the central, mid-altitude areas of the country, while mopane woodlands (*Colophospermum mopane*) characterize the more arid north and south of the country. The relatively rare Afromontane forests occur in the Eastern Highlands. Miombo and mopane woodlands have high levels of diversity and endemism in a number of taxonomic groups, including mammals, birds, amphibians, reptiles, and plants. The forests and woodlands of Zimbabwe provide habitat for a variety of animals, including endangered and charismatic mammals such as African elephants (*Loxodonta africana*) and black rhinoceros (*Diceros bicornis*) (Burgess et al. 2004).

Studies have put a high value on the ecosystem services provided by miombo and mopane woodlands across southern Africa. Provisioning services such as fuelwood, construction materials, charcoal and medicines are estimated to support 100 million rural people and 50 million urban residents, contributing $9 billion a year to rural and urban populations (Ryan et al. 2016, Campbell 1996, Katerere et al. 1999, Dewees et al. 2010). Regulating services provided by Zimbabwe's woodlands are also highly noted, including carbon sequestration and storage, with significantly higher soil organic carbon content under relatively undisturbed woodlands than on cultivated lands (Zingore et al. 2005). Sediment retention and regulation of water is also better under woodland versus cleared woodland (Ryan et al 2015). Finally, cultural services associated with woodlands and forests such as tourism to national parks contribute to the country's Gross Domestic Product (GDP). Tourism is estimated to contribute 7.2% to the GDP and over $1 billion in foreign receipts to the economy, with 18% of tourist arrivals for leisure purposes (Zimbabwe Tourism Authority 2018). In addition, the spiritual role of Zimbabwe's sacred forests, although difficult to put an economic or monetary value on, have long been recognized (Byers et al. 2001).

Miombo and mopane woodlands provide services such as fuelwood, construction materials, charcoal and medicines. They are estimated to support 100 million rural people and 50 million urban residents, contributing $9 billion a year to rural and urban populations.

Similar to other woodlands and forests across southern Africa, Zimbabwe's woodlands have been affected by changing patterns of land use with ramifications on the carbon cycle at regional to global scales (Ryan et al. 2012). An increase in human populations and associated consumption preferences, together with new connections to the global economy, are cited to be the driving forces of this change (McNicol et al 2014). More specifically, widespread deforestation (i.e., the reduction in wooded area) is resulting from agricultural expansion, while degradation (a reduction in woody carbon density in an area that remains woodland) has been caused by fuelwood collection and timber harvesting (Hansen et al. 2013 Ryan et al. 2014).

In Zimbabwe, **land conversion has been particularly marked since 2000**, when the government embarked on its agrarian reform program through the Fast Track Land Reform Program (FTLRP). The resettlement program resulted in the permanent clearing of woodlands and forests for agriculture, reduced fallow periods, and environmental degradation such as soil erosion, overgrazing, and excessive resource extraction (Hamandawana et al. 2005, Jewa et al. 2016). At the same time, the change in land cover resulted in substantial losses of habitat for wild flora and fauna (Matvire et al. 2015), modifications to fire frequency, and threatening the ecosystem services that local and regional communities depend upon for both subsistence and their livelihoods (Campbell and Mapaure 2002).

The 2000 Fast Track Land Reform Program resulted in the permanent clearing of woodlands and forests for agriculture, reduced fallow periods, and environmental degradation, such as soil erosion, overgrazing, and excessive resource extraction.

Changes in land cover resulted in:

- habitat loss for wild flora and fauna
- modifications to fire frequency
- loss of ecosystem services for local and regional populations

4.1 OBJECTIVES

While a number of regional scale analyses of land cover or forest change have been conducted in specific areas, e.g., the Bindura District (Kamusoko and Aniya 2007) or the Mafungabusi forest in the Midlands Province (Mapedza et al. 2002), there have been few assessments of land cover change at the national scale in Zimbabwe. Estimates of the status of Zimbabwe's forests and woodlands from the FAO are concerning; of the 40% (15,624,000 ha) of the country that is forested, only 5% (801,000 ha) is classified as primary forest. Studies have estimated 1.48% (327,000 ha) of forest was lost per year between 1990-2010 (FAO), while Sachikonve (2005) estimated 70,000 ha of forest were lost to agriculture each year. While these statistics are useful, there can be difficulties in interpreting the data, given the various definitions of 'forests' and 'woodlands' and their respective % canopy cover. In our assessment we refer to tree cover and tree loss for simplicity.

We had four primary objectives in undertaking the assessment (Figure 1):

1. To assess how land use has changed since 2000, when the Fast Track Land Reform Program began, and how woodland and forest cover has changed during this time;

2. To explore patterns of fire activity both temporally and spatially, and to determine if there is any alignment with patterns of tree loss;

3. To model and compile data on the ecosystem services associated with woodlands and forests at the national scale and, where possible, to indicate an economic or monetary value associated with the quantity of these services; and,

4. To assemble data on threats that might affect woodlands and forests (hereafter 'tree cover'), and the provision of ecosystem services.

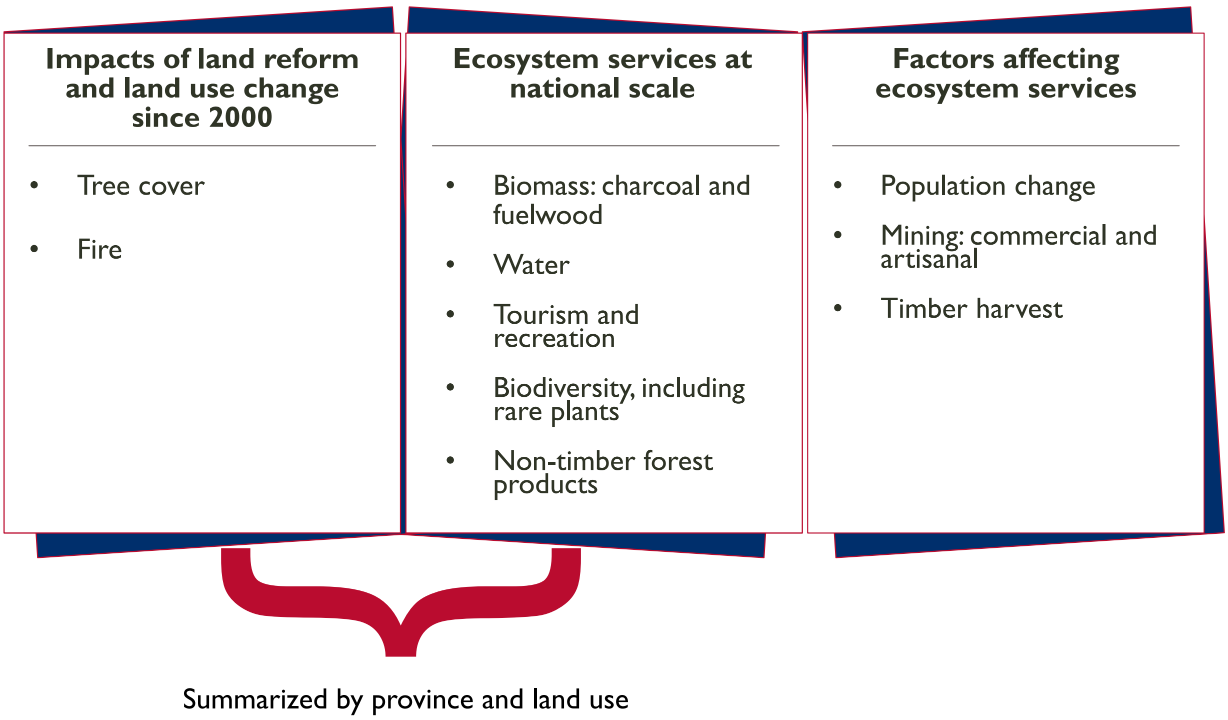


Figure1. Summary of project components, data types and analysis units

5.0 METHODS

5.1 IMPACTS OF LAND REFORM AND LAND USE CHANGE SINCE 2000

The FTLRP has been a major driver of land use-land cover change patterns in Zimbabwe since 2000, when the government sought to acquire 12.4 million ha of large-scale, commercial farms for redistribution among more than 150,000 farmers (FAO report, Mkodzongi and Lawrence 2019, Nyamadzawo et al. 2013). There were two dominant resettlement models that were implemented. Under the A1 resettlement model, small plots averaging 5 ha in size were allocated to landless and poor farmers from 127,192 households for growing crops and grazing land (FAO report). The A2 resettlement model was based on larger, self-contained farming units (average size of 318 ha per farmer) for 12,943 new commercial farmers who had the skills and resources to farm profitably, thereby increasing agricultural productivity (Chimera et al. 2018). Other land tenure classes included communally owned land and state land (Scoones et al. 2010).

The FTLRP had substantial impacts on Zimbabwe's environment and wildlife, which varied by geographic area. A report compiled by the World Wild Fund for Nature (Du Toit 2004) documented these as ranging from fragmentation of the Central Plateau with the growth of small scale and commercial farming; settlement and poaching in the conservancies of the Save-Limpopo Lowveld; over-hunting and illegal hunting in the north-west; and slash and burn clearing of remaining mid- and low-altitude forest in the Eastern Highlands.

One of the objectives of our national-scale analysis was to assess if these patterns of land use were reflected in patterns of tree loss and fire over the last two decades and, finally, how different land-use types compare in terms of their provision of ecosystem services.

TREE COVER

To assess the change in tree cover (i.e., woodland and forest), we compiled available data from the Global Forest Watch tree cover loss database[1], from 2000 to 2018. These data are available as a collection of raster geotiff files (30 m resolution), which include the amount of tree cover (defined as >10% cover) in the year 2000 and a raster indicating if tree cover had been lost or gained in that pixel for each year 2000-2018 (Hansen et al. 2013). To analyze tree loss, we aggregated the tree cover loss data to four-year intervals (2001-2004, 2005-2008, 2009-2012, 2013-2016, and a remaining two-year interval 2017-2018) by combining the binary tree loss data available for each year. We used a threshold of 20% tree cover in a pixel and calculated tree loss as *a fraction of the total area with >20% tree cover in 2000*. As such, estimates of change in tree cover relate to 2000, and consequently any loss of trees before 2000 is not reflected.

We summarized the tree cover data at a variety of scales—nationally, by province, district, and land tenure type—extracting the mean and summed values of the tree data. Within each analysis unit we computed the ratio of the sum of pixels with tree cover loss, or gain, over the four-year interval over the number of pixels in the region with tree cover in the year 2000. We then plotted the time series of tree loss by analysis unit.

FIRE

We obtained fire data from the Global Fire Emissions Database[2] and downloaded from the ORNL Distributed Active Archive Center.[3] This database provides information on individual fires over the period 2003-2016, using 500 m resolution MODIS daily burned area data and including information on the day of the year the fire started. We then converted the day-of-the-year raster layers to binary raster files, indicating for each year between 2003 and 2016 whether a fire occurred in a given 500 m pixel. Again, we summarized the yearly fire data at a variety of scales—nationally, by province, district, and land tenure type—computing the proportion of each class that burned in a given year and plotting the yearly values for the proportion of fire.

[1]Global Forest Watch tree cover loss database https://data.globalforestwatch.org/

[2]Global Fire Emissions Database https://www.globalfiredata.org/

[3]ORNL Distributed Active Archive https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1642

5.2 PATTERNS OF ECOSYSTEM SERVICES AT NATIONAL SCALE

BIOMASS – CHARCOAL AND FUELWOOD

Data on aboveground biomass (or woody carbon density) were generated by researchers at the University of Edinburgh using satellite radar images and in-situ carbon stock estimates for calibration (McNicol et al. 2018). A polarization mosaic product of radar backscatter from the Phased Array L-Band Synthetic Aperture Radar sensor on-board the Japanese JAXA's Advanced Land Observation Satellite (ALOS-PALSAR) was used. These measurements were regressed against field measured carbon stocks at 137 sites across Malawi, Mozambique, and Tanzania from the Socio-Ecological Observatory for the Southern African Woodlands databased (SEOSAW). The study focused on the quantifying changes in aboveground woody carbon stock—deforestation and degradation, as well as gains in biomass—from 2007-2010.

Within the study period, across the woodlands of seven countries in southern Africa, McNicol et al. (2018) found that forest degradation affected 17% of the woodlands, accounting for 55% of biomass loss (−0.075 PgC yr^{-1}); deforestation rates were five time greater than existing estimates and associated gross carbon losses estimated to be 3–6 times higher than previously thought. To put Zimbabwe into context, the study found the region-wide carbon density was 24 MgC ha^{-1}, with the most carbon dense woodlands in the former Katanga province of the Democratic Republic of Congo (mean 28.6 MgC ha^{-1}) and the least dense in Zimbabwe (19.6 MgC ha^{-1}), reflecting the differences between wet and dry miombo ecoregions (Burgess et al. 2004). The study also reported 33% of Zimbabwe as wooded, compared to 55% of Mozambique and Zambia, and 62% of the Katanga area within the Democratic Republic of Congo. However, throughout more remote areas of southern Africa, the authors also determined that some of these losses are offset by previously undetected, but widespread, gains in carbon stocks which might be linked to urban migration and defaunation (Andela et al. 2014).

We used the 2007 biomass estimates from this study which are considered to be final, compared to the 2017 mapping effort using similar methods but still to be validated. We also illustrate how biomass estimates can be converted to provide an indication of charcoal and fuelwood services in communal lands.

WATER

Zimbabwe relies on surface water resources for 90% of its requirements, while groundwater supplies the remaining 10% (Zimbabwe Framework report 2016). A review of groundwater recharge and storage across countries in Africa found Zimbabwe ranked in the middle (MacDonald et al. (2021). We explored the availability of existing hydrological data by contacting researchers in academia and government employees in Zimbabwe. We were provided some historical annual summary tables of surface water and groundwater for each of the seven water catchments that Zimbabwe is typically divided into for hydrological analyses. In the absence of better available data, we undertook water modeling for Zimbabwe using the Soil and Water Assessment Tool (SWAT+) watersheds (Bieger et al. 2017)4. Using input data on landcover (European Space Agency source, 2015), a digital elevation model (WWF Hydrosheds), and soils (FAO soils) SWAT+ created 4,380 hydrological units across the country, which were grouped into 210 larger landscape units.

After an initial test run of SWAT+ using the internal weather generator facility, we carried out a SWAT+ run using an integrated daily precipitation and temperature data model (CFSR) sampled at 500 point locations across Zimbabwe, which allowed us to report annual hydrological data from 1999 to 2013; unfortunately, more recent data are unavailable. To help assess the performance of our hydrological modeling, the SWAT+ output of evapotranspiration (the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants) was cross-referenced to an annual MODIS evapotranspiration product[5] to assess if the values were similar. At this national scale, the overall regression between the SWAT+ output and MODIS (Moderate Resolution Imagine Spectroradiometer) modeled evapotranspiration was fair, with an r^2 value of 0.45. We then repeated this comparison by constricting it to specific land cover types and found the fit ranged from poor to relatively good: for instance, the fit for agricultural land had an r^2 of 0.309 and the fit for brushy rangeland had an r^2 of 0.619 (Figure 2). One caveat to the hydrological modeling is that we did not have stream discharge data to calibrate our SWAT+ outputs; however, we believe our model provides a reasonable starting approximation because of the moderate fit at the national scale with the MODIS evapotranspiration data.

[4]SWAT+ https://swat.tamu.edu/

[5]MOD16A3 https://lpdaac.usgs.gov/products/mod16a3v006/

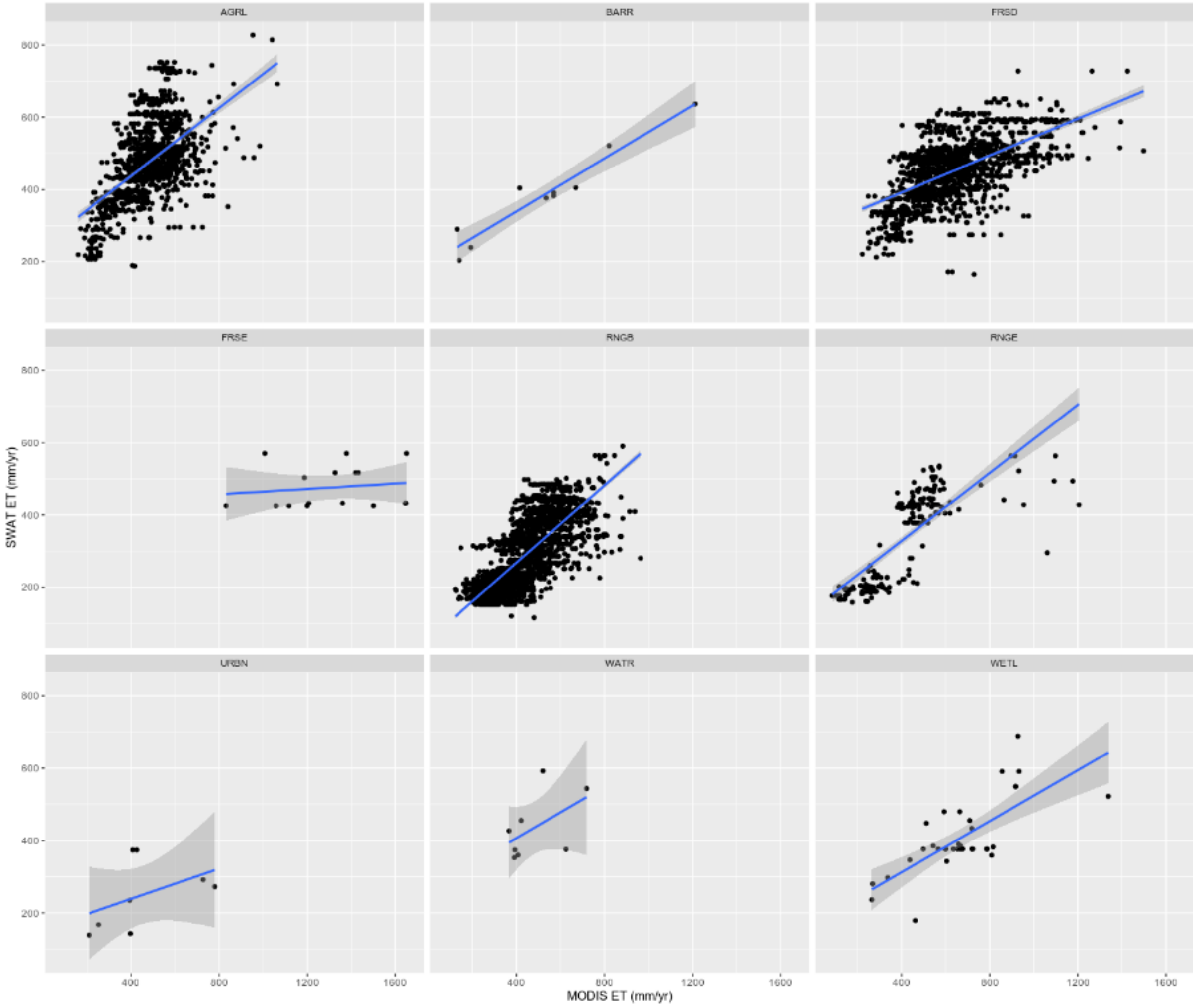


Figure 2. Correlation between SWAT+ modeled evapotranspiration and evapotranspiration derived from MODIS by different SWAT+ defined land cover classes based on 5,000 random points scattered across the hydrological units layer: AGRL=Agricultural, BARR=Barren; FRSD=Forest-deciduous; FRSE=Forest-evergreen; RNGB=Range-Grasses; RNGE=Range-bushland; URBN=Urban; WATR=water; WETL=Wetland. The figure shows which land-use types had tighter relationships with the hydro data.

To highlight the temporal variation in hydrological patterns we compared an unusually wet year, and dry year with the average for all years (1999-2013). We identified the wet and dry years by querying the precipitation data for 1999-2013, and identified 2002 as particularly dry, and 2013 as particularly wet. We present outputs from the SWAT+ model at the national scale for water balance (calculated as precipitation minus evapotranspiration) and sediment yield. To highlight variability at a finer temporal scale, we also present monthly data in streamflow for six major rivers in the Zimbabwe, again using the average across 2000-2013, wet (2013) and dry (2002) years.

TOURISM AND RECREATION

As an indicator of tourism and recreation activity we used the recreation and tourism model from the InVEST platform for mapping ecosystem services[6]. This model uses geotagged photos which were uploaded to the photo sharing online service flickr[7] as a proxy for tourism activity in a locality. The model generates an index for each locality (either a grid cell or a polygon) of photo-user-days, i.e., the number of unique photographers visiting a locality in a single day. We generated this index using a hexagonal grid that was 10 km wide and spanned the country. The index was calculated over the entire timespan of the photo datasets, from 2005 to 2014.

We carried out an exploration of the relationship between the photo index of tourism and other variables. First, for each hexagon we tabulated the density of primary and secondary roads, the area of each hexagon in protected region status, the population count measured from the Global Human Settlement Layer dataset[8], and the presence or absence of large water bodies, defined as having an area greater than 1 square kilometer. We applied geographically weighted regression in R using the four variables road density, protected area status, population count, and presence of large water bodies as predictors of the photo index value. When we compared a map of the values predicted by the regression to a map of the original photo index value, the spatial fit was poor. This led us to abandon this analysis and accordingly did not try to interpret the maps of the coefficients of the predictor variables for the geographically weighted regression.

We also compiled visitor information specifically for national parks in Zimbabwe using the Tourism Trends annual reports published by the Zimbabwe Tourism Authority's Domestic Tourism and Strategic Research Division. We compiled data for the reports from 2010-2018. We recognize, however, that these two types of tourism data do not present a holistic view of tourism and recreation. It would, for example, be useful to determine the relative proportion of income from low-density, more expensive safari hunting compared to less expensive photographic tourism, which likely has a higher impact as visitors are concentrated in specific areas.

BIODIVERSITY, INCLUDING RARE PLANTS

We compiled spatial data on species richness and endemism for different vertebrate taxonomic groups (birds, large mammals, reptiles and amphibians) for the broader miombo ecoregion (covering the majority of six southern Africa countries and small portions of another three countries) and extracted the polygons within Zimbabwe (Timberlake et al. 2001). However, the source data *only* addressed miombo woodland. Consequently, the biodiversity of the eastern Afromontane forests, which is exceptionally high in some taxonomic groups at a continental scale, is not reflected.

We assembled additional biodiversity information including Important Bird Areas (Birdlife International 2020) and unique ecological and evolutionary phenomena (rare vegetation types and important mammal migration areas) (Timberlake 2001). The 10 biodiversity elements were summed in order to rank areas (values from 1-10), based on the number of different biodiversity elements present. Although this approach is limited, it incorporates the biodiversity data available at the national scale and could be greatly improved through subsequent regional scale analyses. In addition, future relationships with partner organizations might yield additional data and ideas for more species-specific analyses.

Data on threatened plant species were digitized from a study by Mapaura (2002) which describes the distribution of endemic and near-endemic species and their status by geographic area in Zimbabwe.

NON-TIMBER FOREST PRODUCTS

There is a large number of papers (albeit mostly from the 1990s) that describe the importance of miombo and mopane woodlands for providing Non-Timber Forest Products (NTFPs) such as wild fruits (e.g., Mazhanje [*Uapca kirkiana*], matamba [*Strychnos*], matohwe); honey; mopane worms; thatch grass; and, medicines. Some of these products, like Mazhanje, are widely available during their peak seasons and are harvested in large volumes to sell in urban areas. One study of NTFPs, at the local scale was performed by Birdlife Zimbabwe for the Driefontein Grasslands, which quantified

[6] InVEST https://naturalcapitalproject.stanford.edu/software/invest

[7] flickr https://www.flickr.com/

[8] Global Human Settlement Layer https://ec.europa.eu/jrc/en/global-human-settlement-layer

harvested and cultivated goods and their associated economic value (World Birdwatch 2014). Although there are many NTFPs recognized as important products of Zimbabwe's woodlands (Campbell 1996), acquiring spatial data on the distribution on any one NTFP, particularly at the national scale, was challenging.

As an illustrative example of NTFP spatial data for one species, we were fortunate to be provided with a study undertaken on the baobab tree (*Adansonia digitata*) from Gus le Breton (PhytoTrade Africa). We used this to show how spatial data on an NTFP can be woven into a broader ecosystem services analysis. The study by Douie and Whitaker (2014) describes the distribution of baobab trees in resettled and communal lands in Zimbabwe and explores how rural producers of baobab products can be linked to local, regional, and international markets. In particular, analysis is undertaken of the use of its fruit, considered a super-fruit, providing oils for cosmetics and oleo-chemicals. A component of this study, developed using 2,907 points collected in fieldwork and using climatic and elevation data, was the development of a probability map of baobab occurrence (trees/km^2) using Maxent spatial modeling software. Based on this model, the study estimates that ~8 million baobab trees occur in Zimbabwe. Information was also provided detailing baobab yield, which shows the volume and value of marketable products from baobab pulp and seed (e.g., fine and coarse powder, fiber, oil, and press cake).

5.3 OTHER FACTORS AFFECTING ECOSYSTEM SERVICES

POPULATION CHANGE

Population data are provided by the Global Human Settlement Layer[9], developed by the European Union's Joint Research Council (JRC). This spatial raster dataset depicts the distribution and density of population by grid for four target years: 1975, 1990, 2000, and 2015. The JRC created it using residential population estimates for each target year (CIESIN, GPWv4.10) which were disaggregated from census units and allocated to grid cells (1 km resolution) according to the modeled distribution and density of built-up areas corresponding to each target year. We calculated the change in population between each of the target years, and spatially smoothed these data over a 50 km radius to better highlight patterns of change.

MINING – COMMERCIAL AND ARTISANAL

Spatial data relating to mining activities were compiled from four sources with the help of collaborators in Zimbabwe. First, coordinates of 109 mine sites were provided by the Zimbabwe Environmental Law Association (ZELA) and the International Peace and Information Service (IPIS, based in Belgium) who compiled mining data from various organizations, including Zimbabwe's Ministry of Mines. Information associated with this dataset included their operational status and type of mine. Second, a list of mine names, district, type of mine and operational status was provided by the Institute of Mining Research. Where possible, we assigned this list of mines to spatial locations based on online searches of the mine name and using the online database hosted by the Hudson Institute of Mineralogy[10]; in total, this was possible for 51 mines. Third, the locations of 22 artisanal mine sites were provided by the Zimbabwe Miners Federation, although no information were provided on the type of mine or its operational status. Finally, a description and grid references of 11 mine prospecting sites (exclusive prospecting orders, EPOs) were provided by an anonymous source. Investors apply to the Ministry of Mining Affairs to create an EPO on a rolling basis, so these likely represent a snapshot of all the possible EPOs. The on-the-ground investigations into an EPO can last for three years and the status of these 11 is unknown.

Photo: Blessing Hungwe

Above, a Zimbabwean gold rush. Everyone grabs a shovel, regardless of past mining experience.

[9]Global Human Settlement Layer, 2019: https://ghsl.jrc.ec.europa.eu/

[10]Hudson Institute of Mineralogy online database: https://www.mindat.org/

TIMBER HARVEST

Spatial data on the location of timber harvesting areas were provided by Zimbabwe's Forestry Commission and data on the amount of timber were compiled from annual reports. The reports were available from 2008 to 2018 (with the exception of 2015). From these reports we compiled the distribution of commercial forests by province (ha), total production, total employment, and sales (local and export).

BARE GROUND

To provide general information on areas of low productivity and erosion, we provide a map of bare ground calculated as the percent of a pixel (30 m) which is bare developed from the 2019 Copernicus Land Cover dataset[11]. In the future, it would be insightful to explore other image sources of bare ground at a higher spatial resolution, for example in a regional scale analysis.

Bare ground is a potentially useful indication of areas of erosion or degradation.

5.4 ASSESSMENT METHODOLOGY TO QUANTIFY TREE LOSS, FIRE AND ECOSYSTEM SERVICES

Once we had compiled data on tree cover loss, fire, and ecosystem services at the national scale, our objective was to assess how these data varied regionally and by patterns of land use (Figure 1). To assess regional patterns, we used the 10 provinces and the 59 districts nested within the provinces (Figure 3). To assess tree loss, fire, and ecosystem services by land use type, we used a spatial dataset on land tenure from the Ministry of Land, Agriculture, Water, Climate and Rural Resettlement, which depicts a variety of agricultural areas (A1 small farms and A2 large farms) and non-agricultural areas (e.g., national parks, recreational parks, safari areas) and communal lands (Figure 3). Note that no metadata or details were available to assess the accuracy of these land-use types, but these were the only data we were able to acquire. Privately owned game reserves (e.g., Bubye Valley and Save Valley Conservancies) are considered "large scale commercial agriculture" areas and have proven over many decades to conserve and provide diverse ecosystem services such as biodiversity but may not be fully represented in this land tenure map. All data analyses were conducted in ArcGIS and GRASS 7 software and graphics and plots were generated in R software.

Hwange, Zimbabwe
Photo: Nqobile Vundla

[11]Copernicus Land Cover dataset, 2019: https://lcviewer.vito.be/2019

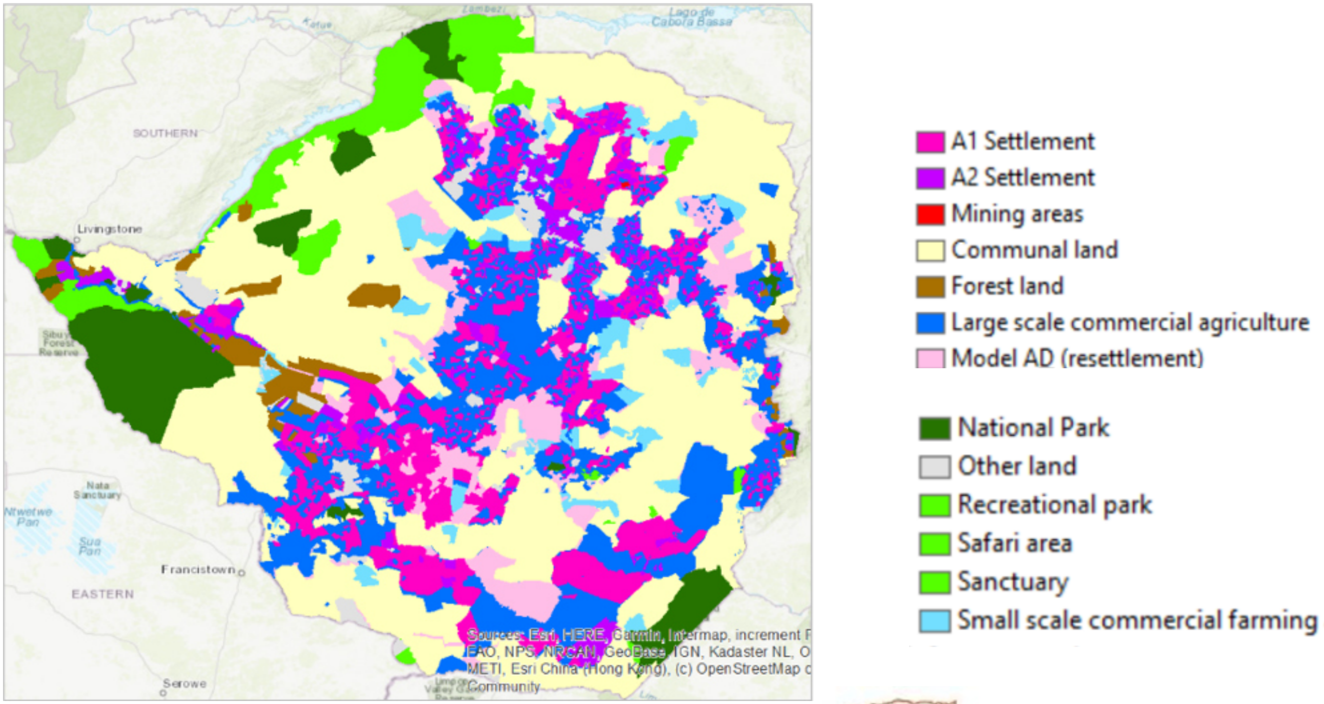


Figure 3. Map of land tenure type (left) showing areas of resettlement associated with the Fast Track Land Reform Program and the location of 10 provinces (bottom right) in Zimbabwe.

5.5 ECONOMIC VALUES

One objective of this assessment was to investigate the availability of data on the economic value of ecosystem services in Zimbabwe. Gathering this information was remarkably challenging, however, and partial information has only been gathered on a few topics, including carbon, non-timber forest products (baobab trees and fruit), and tourism.

6.0 RESULTS

6.1 IMPACTS OF LAND REFORM AND LAND USE CHANGE SINCE 2000

TREE COVER

At the national scale between 2000-2018, areas of high tree loss (≥ 3.5%) included the Eastern Highlands and a large portion of the Midlands, Matabeleland North, and Mashonaland West Provinces (Figure 4). In contrast, areas along the southwestern and northwestern margins experienced virtually no tree loss (0-0.18%); generally, these areas overlap with agro-ecological zone V, which is characterized by low, erratic rainfall, and unproductive for agriculture.

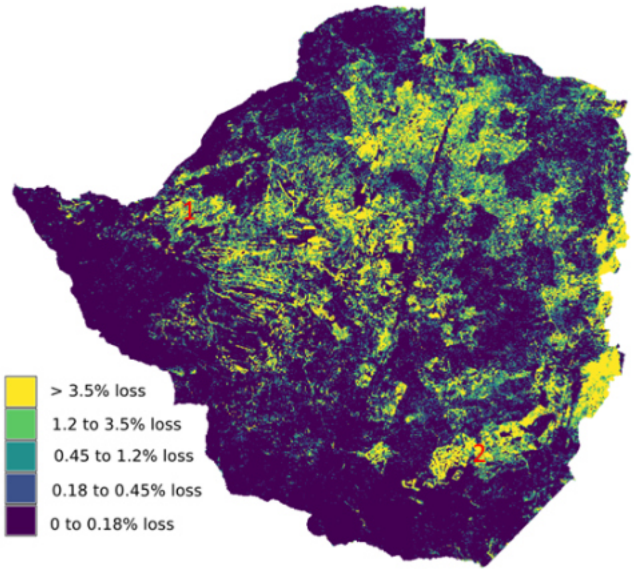


Figure 4. Loss in tree cover from 2000-2018, using 2000 as a baseline calculated from global forest maps (Hansen et al. 2013).

Patterns of tree loss varied dramatically by province (Figure 5): The municipal provinces of Harare and Bulawayo showed the highest loss of trees between 2000-2004, at approximately 3.75%, along with Masvingo Province in the southeast. Masvingo shows the most dramatic increase in rates of tree loss from 2000-2004 (3.75%) to 2004-2008 (6.25%), plateauing between 2008-2012, and then declining in tree loss rate from 2012-2016 (1.25%). In fact, some districts within Masvingo Province, such as the Mwenzi, experienced a 20% rate of tree loss in 2010. The province of Manicaland, that encompasses the Eastern Highlands and the majority of the country's commercial timber plantations, shows a steady and constant increase in the rate of tree loss over time, peaking at 5% in 2016. Finally, some provinces, such as Mashonaland East, Matabeleland North, and Matabeleland South, have a markedly low rate of tree loss between 2000-2008 (around 2.5% per year), followed by a reduction (Figure 5).

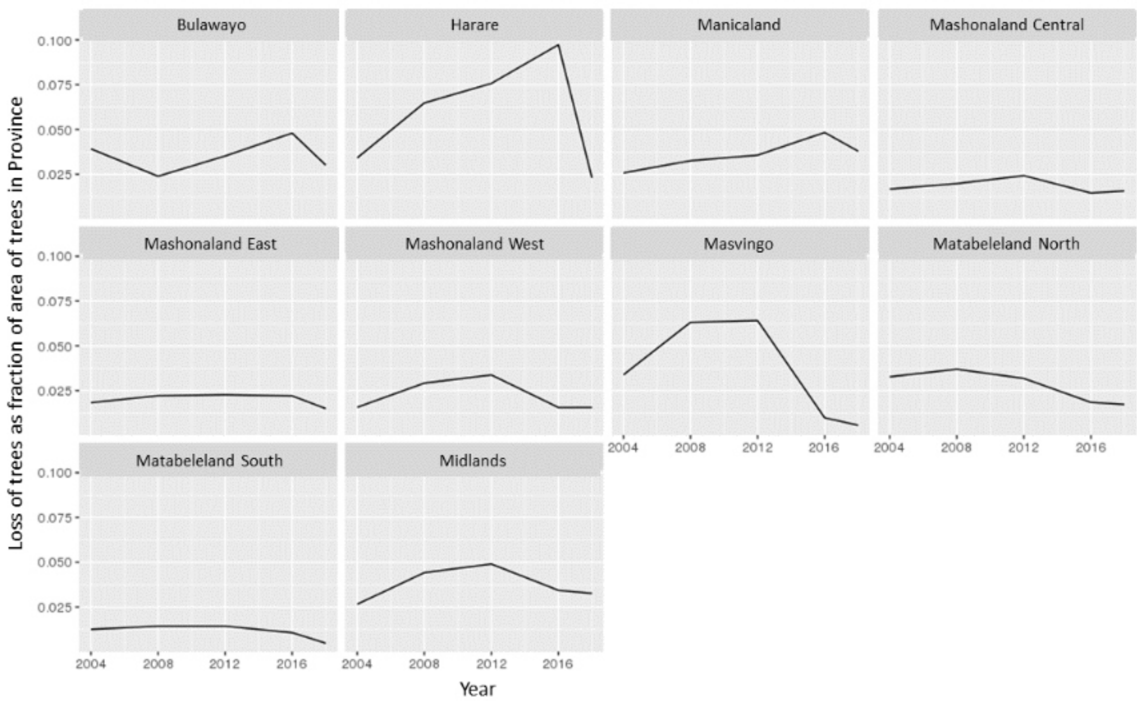


Figure 5. Tree loss rates by province over four time periods: 2000-2004, 2004-2008, 2008-2012 and 2012-2016 (data are also shown from 2016-2018 but since incomplete not as reliable).

By land tenure, distinct differences in the pattern of tree loss are visible between agricultural land cover types, small (A1) and large-scale commercial farming (A2), and non-agricultural cover types (national park, recreational park, safari areas), as would be expected. The A1 model farms showed a sharp increase in the rate of loss from 2000 to 2008 to 6%, after which rates of tree loss plateaued 2008-2012, and then declined between 2012-2016 (Figure 6). The rate of tree loss on A2 farms, large scale commercial and small scale commercial, all increased steadily from 2000-2012, peaking at 3.5%, 4.5%, and 2% tree loss respectively, before decreasing after 2012. Although these rates appear relatively low, the loss of trees at each timestep is cumulative, so there is a substantial increase over time. For the non-agricultural land tenure types, such as national parks and safari areas, the rates of loss remained steady or decreasing across the two decades, remaining under one percent. However, it must be noted that in some of these areas—such as Gonarezhou, Hwange, and Chizarira National Parks, and the Zambezi escarpment in the lower Zambezi Valley areas of Mana Pools National Park and Chewore Safari Area—high densities of elephants have caused major deforestation effects at the local scale. In some areas this deforestation occurred prior to 2000 and thus is not reflected in the data presented on tree loss in national parks and safari areas. In some national parks, such as Gonarezhou and Hwange, this local deforestation continues today given high densities of elephants, which likely could be detected using higher resolution imagery.

A1 model farms = small farm plots, averaging 5 ha in size

A2 model farms = larger, self-contained farm plots, averaging 318 ha in size

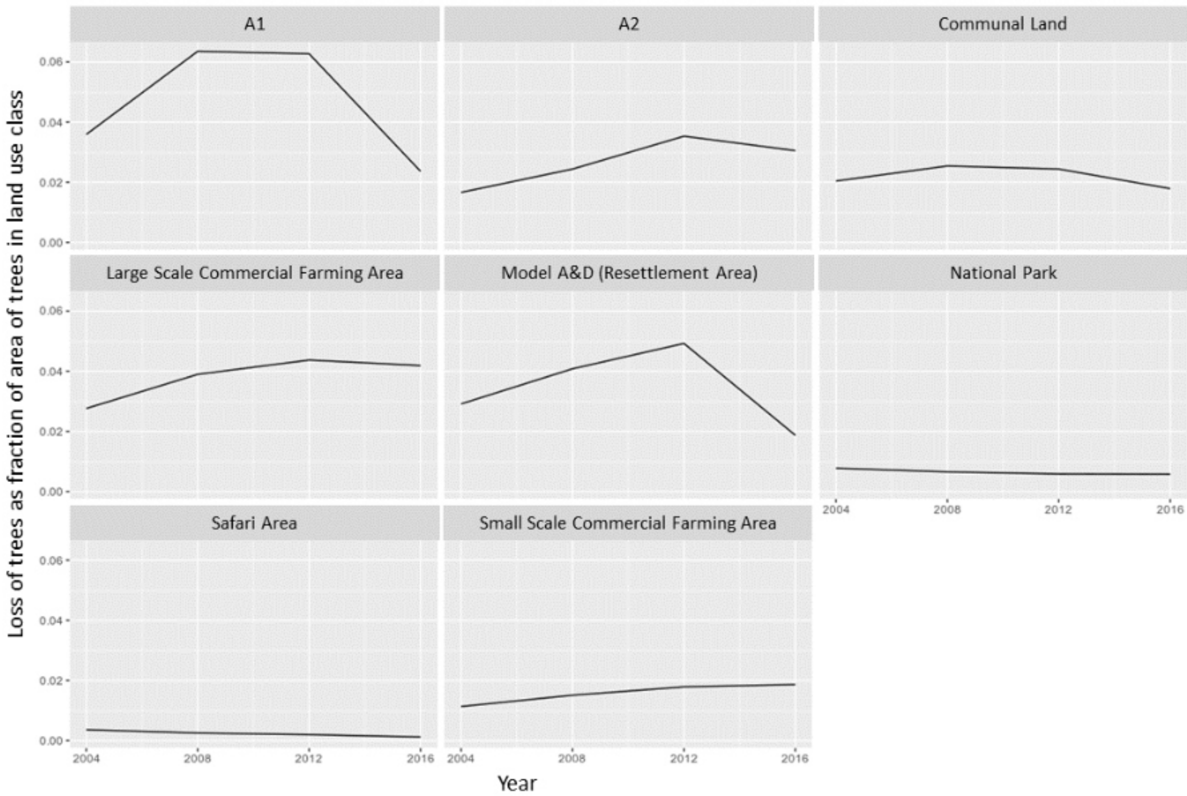


Figure 6. Tree loss rate by different land use types over four time periods 2000-2014, 2004-2008, 2008-2012 and 2012-2016 (data are also shown from 2016-2018 but since incomplete not as reliable).

In 2010, 12% of the country was burning

Mashonaland West had the highest burn rate, with up to 30% of the province burning in 2010

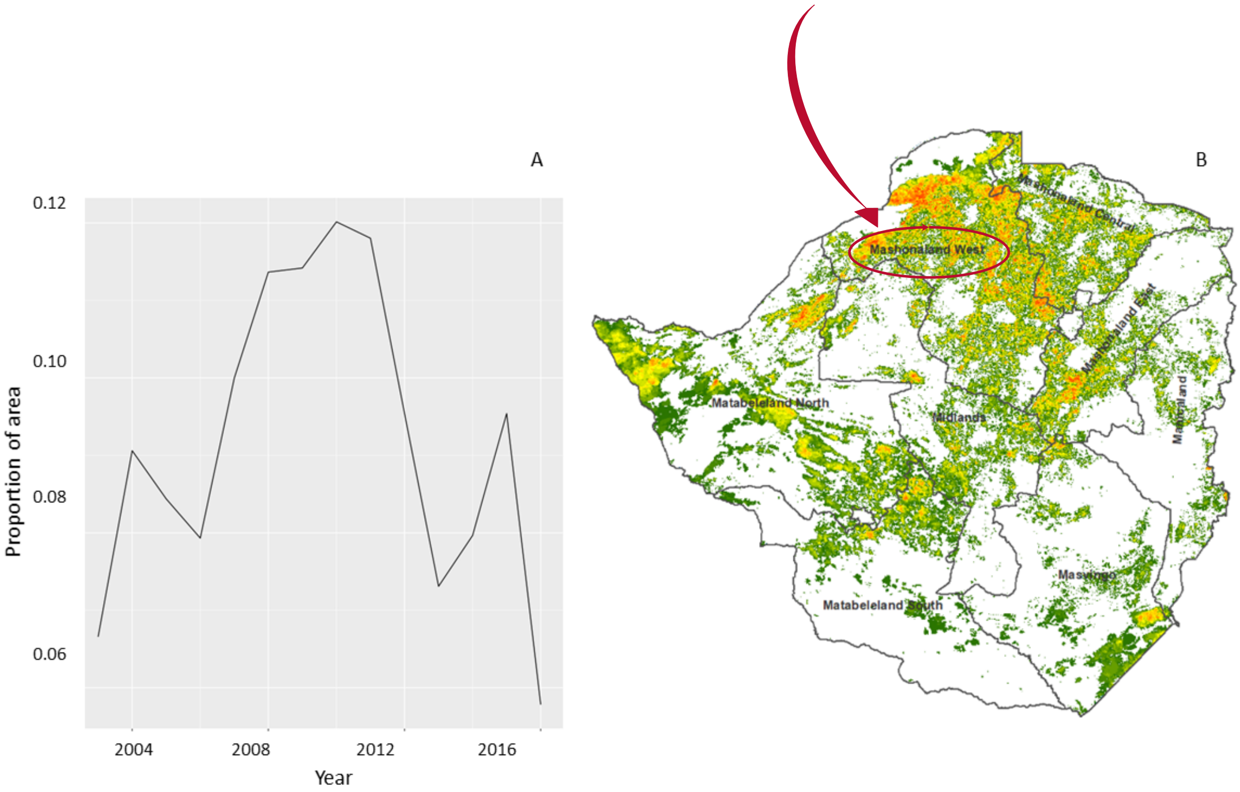


Figure 7. Recent fire history data for Zimbabwe derived from the Global Fire Emissions Database (500 m pixel resolution): (A) Graph of the proportion of area in Zimbabwe that burned over time; and, (B) Map of the total count of fires from 2003-2016: red areas have more fires and green areas the fewest fires.

FIRE

The proportion of area burned in Zimbabwe rose relatively steadily from 6.5% in 2003 to a maximum areal extent in 2010, with 12% of the country burning (Figure 7A). The total area that burned in Zimbabwe generally decreased after 2010 to a low of 5.5% in 2016, except for 2013-2015, which experienced a 2% increase.

Provinces with the highest areas burned included Mashonaland West, with up to 30% of the province burned in 2010, particular hotspots included the Charara and Hurungwe Safari Areas adjacent to Lake Kariba Recreational Park (Figure 7B); Mashonaland Central has had relatively high levels of burning since 2010, peaking at 20%, although without a concentration of fires in any one area (i.e., fewer red areas in Figure 7B). Finally, Matabeleland North had up to 15% of the province burned in 2010, including the Matetsi Safari Area and Ngamo and Gwayi State Forests adjacent to Hwange National Park and Chizarira National Park. Other provinces such as Masvingo, had a relatively low amounts of burning (< 5% from 2005-2016, Figure 8) but there were specific hotspots, including Gonarezhou National Park (Figure 7B).

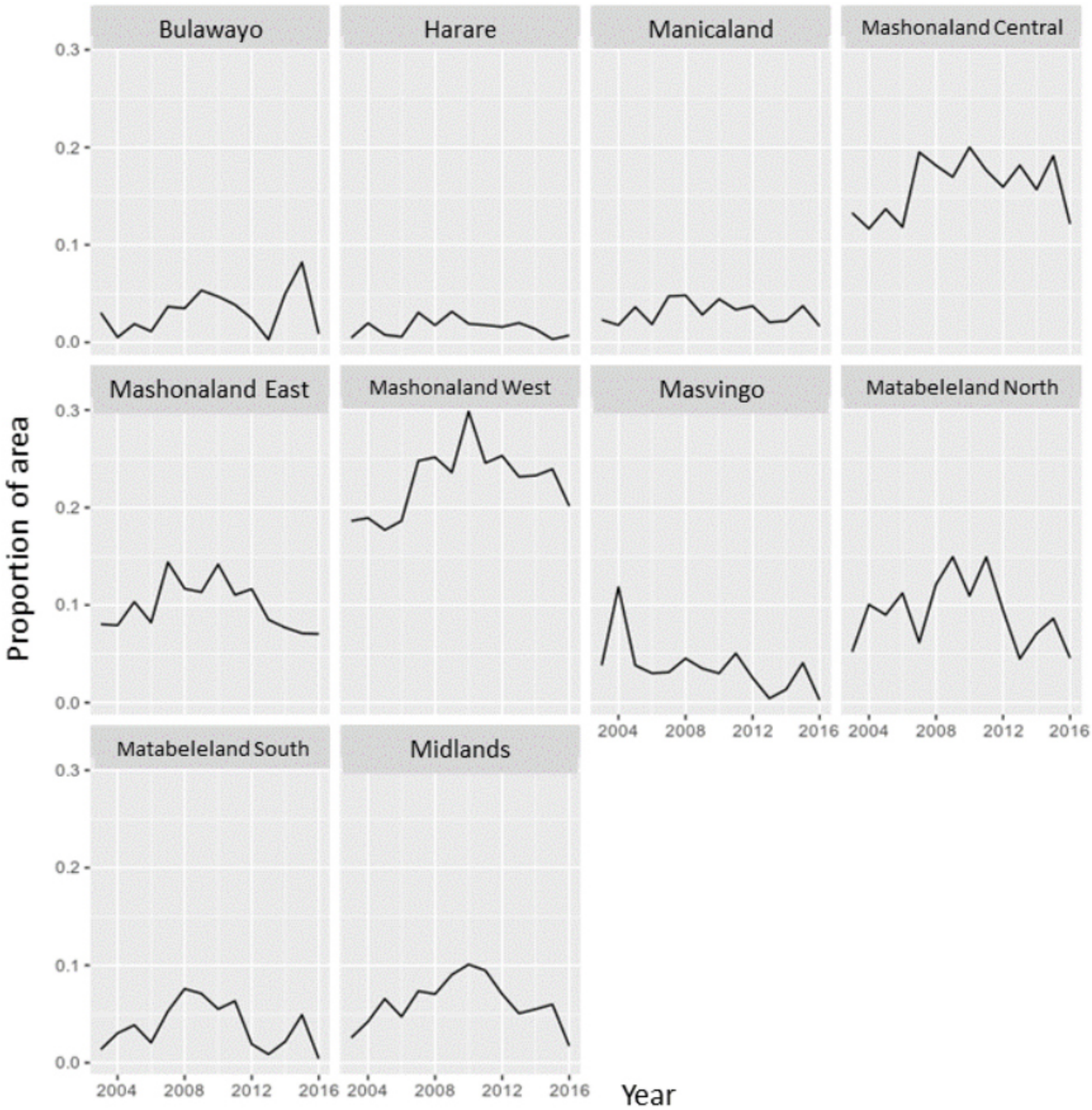


Figure 8. Proportion of area burned by province from 2003-2016 (Global Fire Emissions Database).

By land tenure, agricultural land classes had the highest burned areas, particularly in the A2 model farms (peaking at almost 30% of all A2 areas burning in 2010, Figure 9) and a high of 19% in the A1 model farm areas. Large and small scale commercial farming areas also showed a rise in the area burned, to a maximum in 2015 of 15% of their area. The non-agricultural land tenure classes comprising national parks and safari areas both showed erratic patterns in the proportion burned over time. In contrast, the proportion of communal lands burned was relatively steady, remaining below 2% (Figure 9).

A2 model farms had the highest proportion of burned areas from 2000-2018, peaking in 2010 with almost 30% of all A2 areas burning.

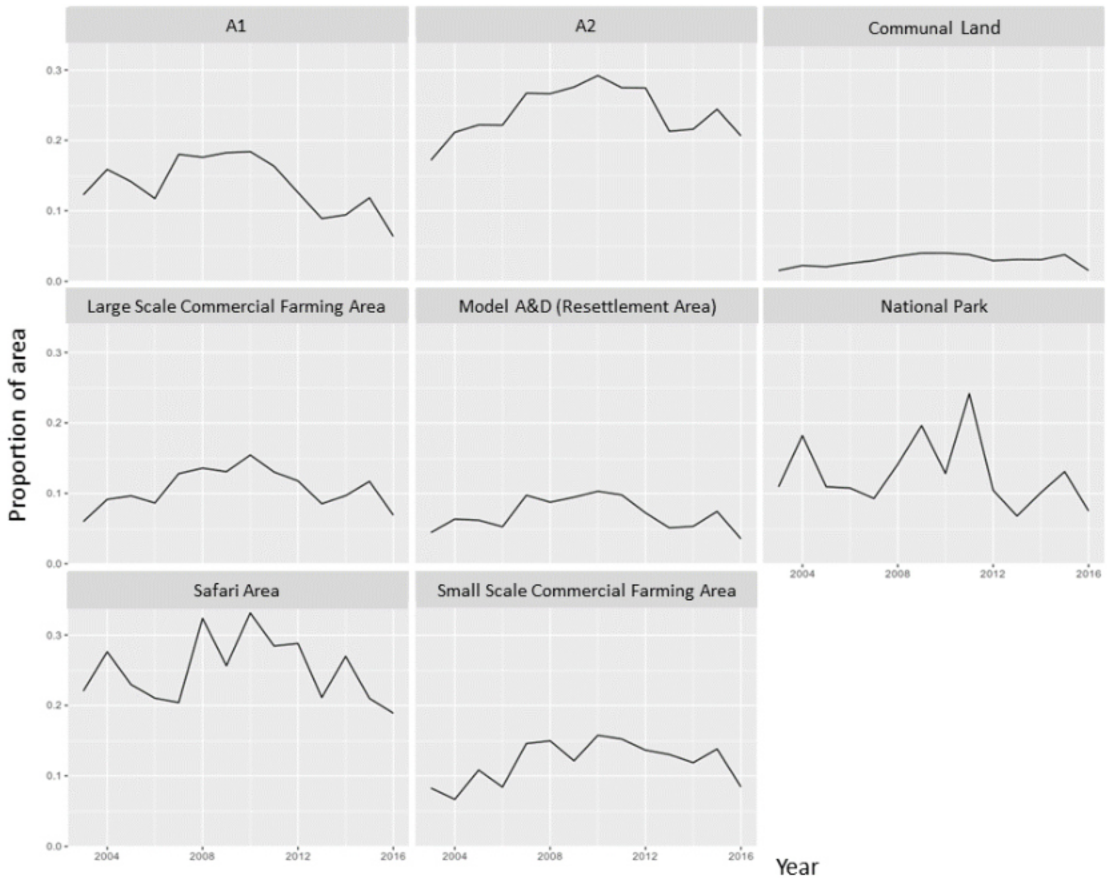


Figure 9. Proportion of area burned by land tenure from 2003-2016 (source: Global Fire Emissions Database).

6.2 PATTERNS OF ECOSYSTEM SERVICES AT NATIONAL SCALE

BIOMASS – CHARCOAL AND FUELWOOD

The radar imagery-derived estimates from McNicol et al. (2018) show the highest levels of biomass in the Eastern Highlands (127 tonnes/ha) and along the eastern border of the country. Areas with the lowest levels of biomass include west of Lake Kariba, along the Zambezi River in the Mana Pools National Park and Chewore Safari Area, and in the Gwero area of central Zimbabwe (Figure 10).

The Eastern Highlands, along the eastern border of the country, have the highest levels of biomass.

In addition to looking at patterns of biomass at the national scale we can also look specifically at biomass on communal lands (Figure 11). Given the role of communal lands for providing ecosystem services such as wood, charcoal, construction materials, meat, and medicines, an understanding of these patterns is important to indicate which communal lands are able to provide such services compared to others that might struggle to do so, particular under increasing human use and future climates. Communal lands with high mean biomass (~33 tonnes/ha) include the areas north of

Hwange National Park and the northern tip of the Eastern Highlands, while communal areas with lower mean biomass (< 10 tonnes/ha) are located in the southwest of Zimbabwe on the border with South Africa.

> Communal lands north of Hwange National Park & the northern tip of the Eastern Highlands have a high mean biomass

With an estimate of aboveground biomass established, we can also apply conversion factors to indicate the provision of specific ecosystem services, such as charcoal and fuelwood. For example, we can apply a conversion factor of 47.5% to convert biomass to an estimate of carbon storage. Studies have also identified a conversion rate (23%, FAO reference) to calculate the amount of charcoal from the aboveground biomass: based on the Nicol et al. (2018) data for 2007, communal lands in Zimbabwe harbored a maximum value of 29 tonnes/ha of charcoal. Similarly, a conversion factor of 12.7% (Lewis et al. 2009) can be applied to convert biomass to fuelwood, showing Zimbabwe's communal lands holding 16 tonnes/ha. Understanding the amount of charcoal and firewood available in Zimbabwe's communal forests could highlight areas where strategic planting of trees, for example, could be implemented to increase biomass and therefore services to rural populations.

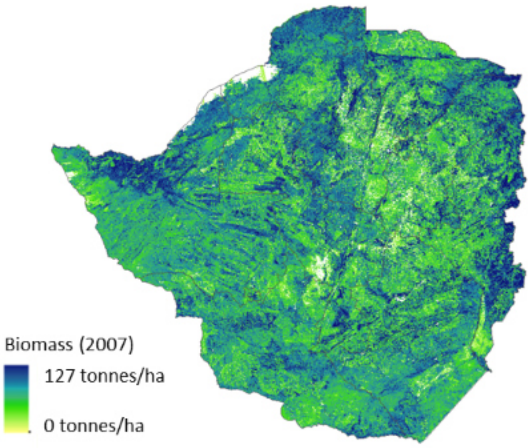


Figure 10. Biomass estimates of aboveground biomass (source McNicol et al. 2018).

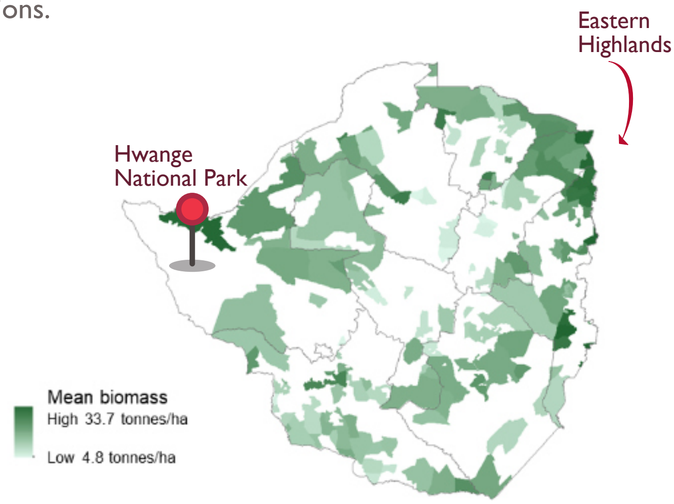


Figure 11. Calculation of mean biomass on communal lands in Zimbabwe.

WATER

Based on the mean annual precipitation for 1999-2013, we selected 2002 as the driest year and 2013 as the wettest year to compare to the average across the entire period for the hydrological outputs from SWAT+ (Figure 12).

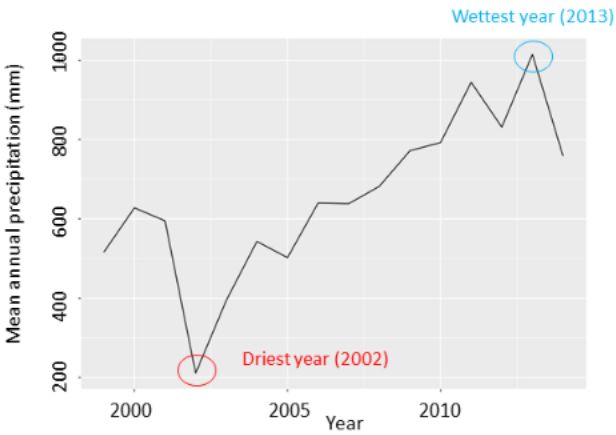


Figure 12. Precipitation data (mm) for 1999-2013 showing driest and wettest years that were used in subsequent analyses.

The average water balance—calculated as precipitation minus evapotranspiration—of the 210 landscape units in and around Zimbabwe ranges from less than 200 mm/yr in units that are in the southwest quadrat of the country (Figure 13A) to values of 800-1400 mm/yr in landscape units located along the northern edge of the country. In the drought year of 2002, the vast majority of landscape units had a negative water balance (0-200 mm/yr) . Exceptions to this pattern, were landscape units along the northwest border of the country and five units in the southeast of the country which has a positive water balance, which is surprising given the general aridity of this region (Figure 13B). Finally, in a very wet year (2013) we found many of the landscape units had an average water balance 0-200 mm/yr have now increased to 200 -400 mm/yr. Landscape units experiencing more than 1000 mm/yr also emerge along the northwest border and in the Eastern Highlands (Figure 13C). Other studies have found similar patterns. For example, Chikodzi (2013) used GRACE satellite data and found groundwater levels in most parts of Zimbabwe's catchments are in a state of decline.

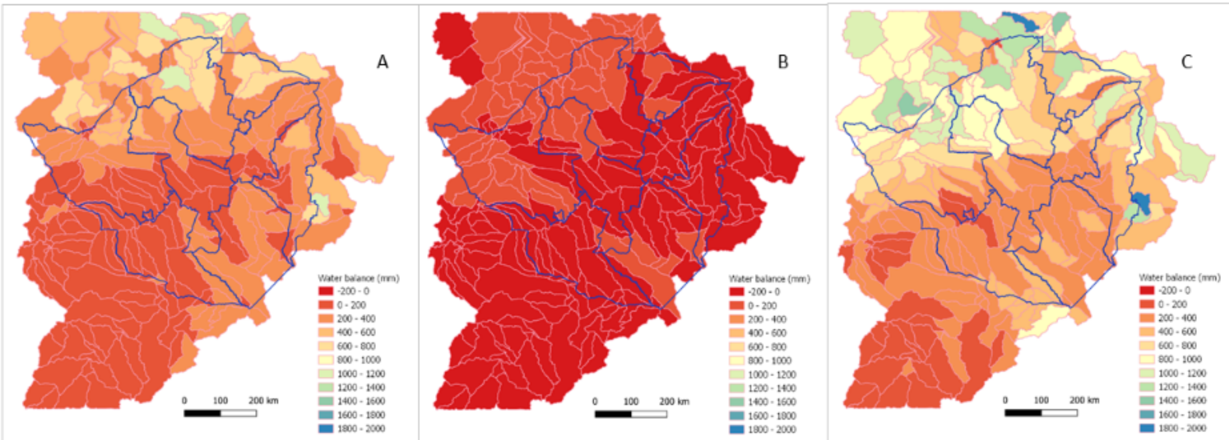


Figure 13. Water balance (mm) of 210 landscape units: (A) average 1999-2013; (B) driest year between 1999-2013 (2002); and (C) the wettest year between 1999-2013 (2013).

Another output from the SWAT+ model is sediment yield, the inverse of which—sediment retention—can be considered another ecosystem service provided by natural vegetation (e.g., sediment retention and vegetative cover generally reduce siltation into reservoirs such as Lake Kariba, which can reduce hydropower generation). Landscape units of highest sediment yield under average precipitation (1999-2013) are focused in Mashonaland Central Province (32-106 tonnes/ha) and also at the southern end of the Eastern Highlands in Manicaland (Figure 14A). Under drought conditions, this pattern simplifies and all landscape units in Zimbabwe have 0-2.1 tonnes/ha with the exception of three units (two of which are higher yielding units in Manicaland) (Figure 14B). Under exceptionally wet conditions the pattern is largely similar to under average conditions, as might be expected, with the addition of more landscape units into higher categories of sediment yield (Figure 14C).

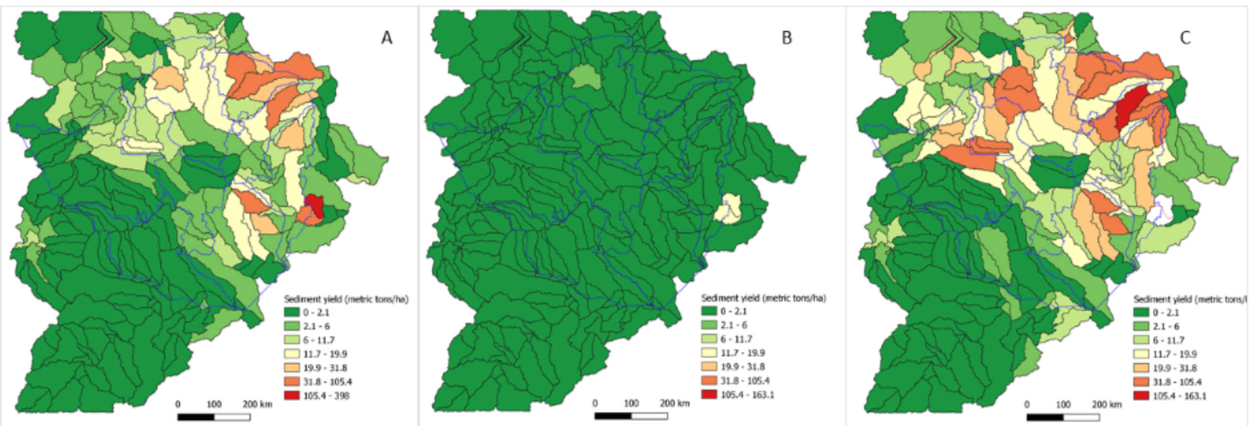
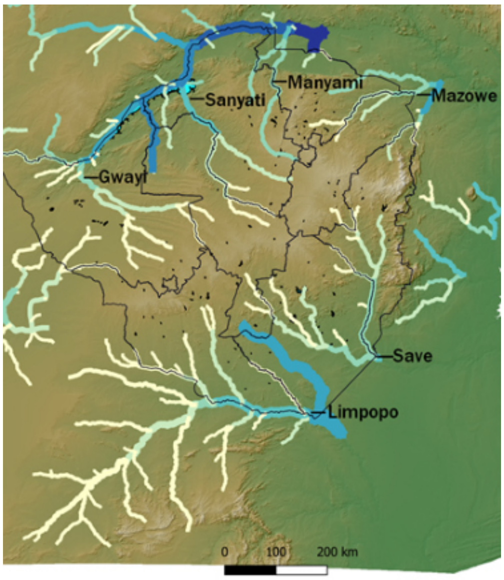


Figure 14. Sediment yield (tonnes/ha) of 210 landscape units: (A) average 1999-2013; (B) driest year between 1999-2013 (2002); and (C) the wettest year between 1999-2013 (2013).

In relation to within-year patterns of streamflow in Zimbabwe, there are three precipitation-related seasons generally recognized, particularly in relation to crops: a rainy season from November through March, a cool winter in April through August, and a hot, dry period in September through to the middle of November (FAO report). Agricultural activities are aligned with these seasonal patterns: most crops are planted in November/December at the beginning of the rains and harvested between April and June (although some crops such as winter wheat, barley and horticultural products are grown in the dry season under irrigation).



Temporal variations in annual precipitation can be viewed in the streamflow of major rivers (Figure 15). Along the southern and southeast edges of Zimbabwe, the Limpopo and Save Rivers both have an average of >10,000 m3/yr at peak streamflow estimated from the SWAT+ model in January (month 1), which gradually declines to about 1000 m3/yr in September (month 9, Figure 15). In the exceptionally dry year (2002), we can see the severe reduction in streamflow to practically zero in September, particularly in the Manyami, Mazowe, and Sanyati rivers in northern Zimbabwe.

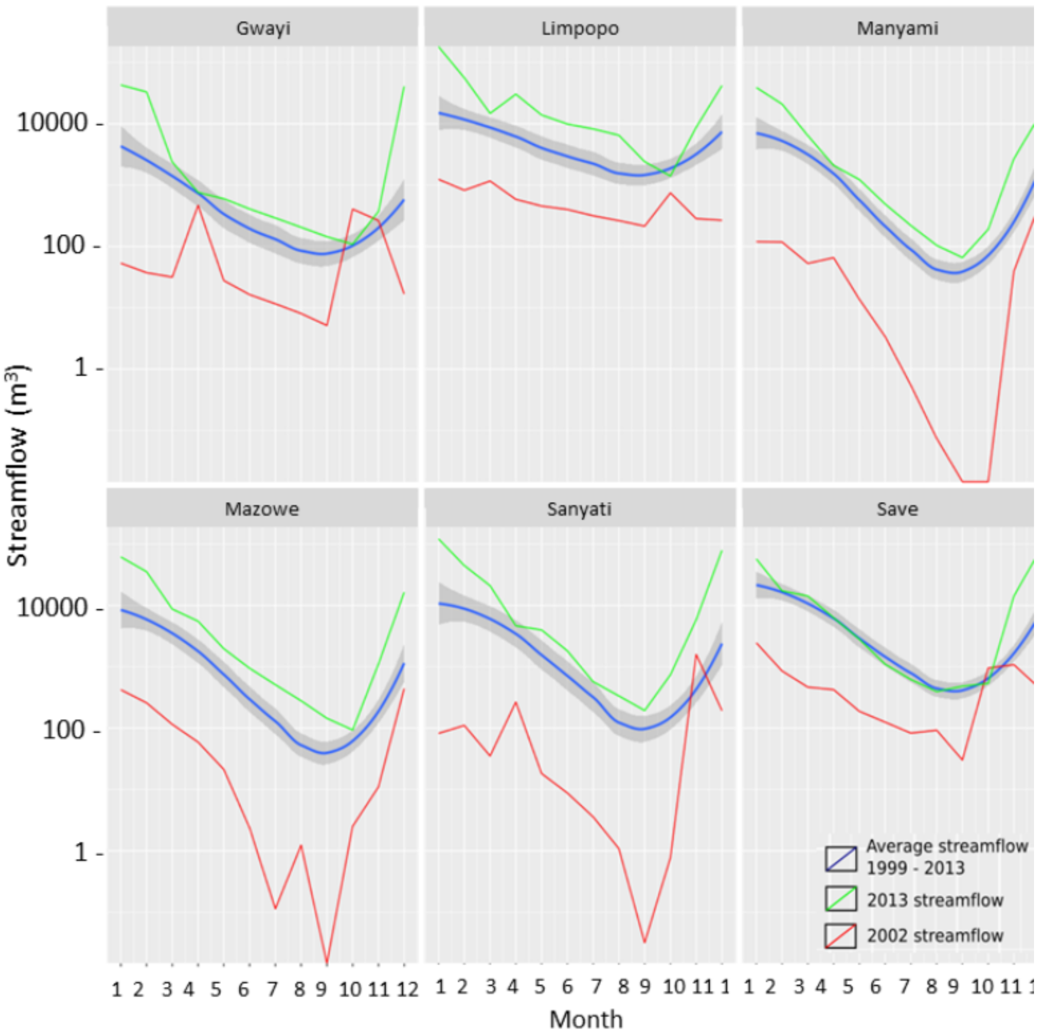


Figure 15. Annual streamflow (m^3) for six major rivers in Zimbabwe from the average 1999-2013; driest year between 1999-2013 (2002); and the wettest year between 1999-2013 (2013). Inset map shows the location of the rivers.

TOURISM AND RECREATION

The output of the recreation model is an index that correlates to the number of photographs taken in any particular 10 km cell in the country (Figure 16). To highlight tourism visits to natural areas, rather than urban-related tourism, we assigned any cells with >80,000 photo-user days as urban (red, Figure 16). Urban-related tourism cells are concentrated in Harare and Bulawayo as might be expected, as well as Gweru and some additional isolated locations throughout the country. Looking at the non-urban recreation patterns, higher number of photo-user days are concentrated in the Victoria Falls area (Livingstone in Figure 16), Hwange National Park, throughout the length of Lake Kariba on the northern border of the country, south of Bulawayo in the Matopos National Park, and scattered throughout the Eastern Highlands. Given these patterns with protected areas it is somewhat surprising that we did not find a relationship with photo-user days and protected areas or primary and secondary roads.

> Primary tourism sites are Victoria Falls, Hwange National Park, Lake Kariba, Matopos National Park and the Eastern Highlands

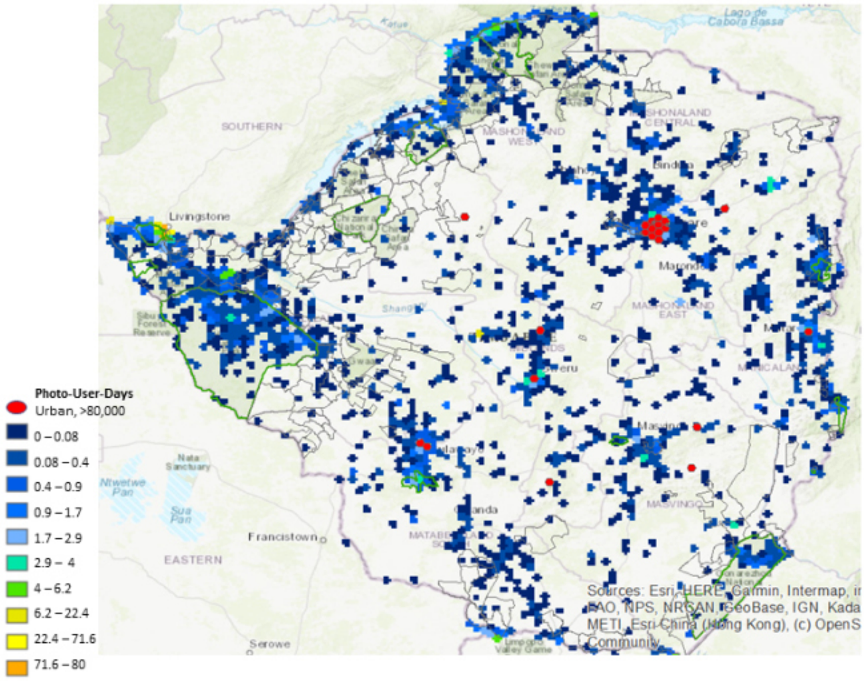


Figure 16. Output of the InVEST recreation model showing and index of the number of photo-user days per 10 km hexagonal cell based on Flickr uploaded photos 2005-2014.

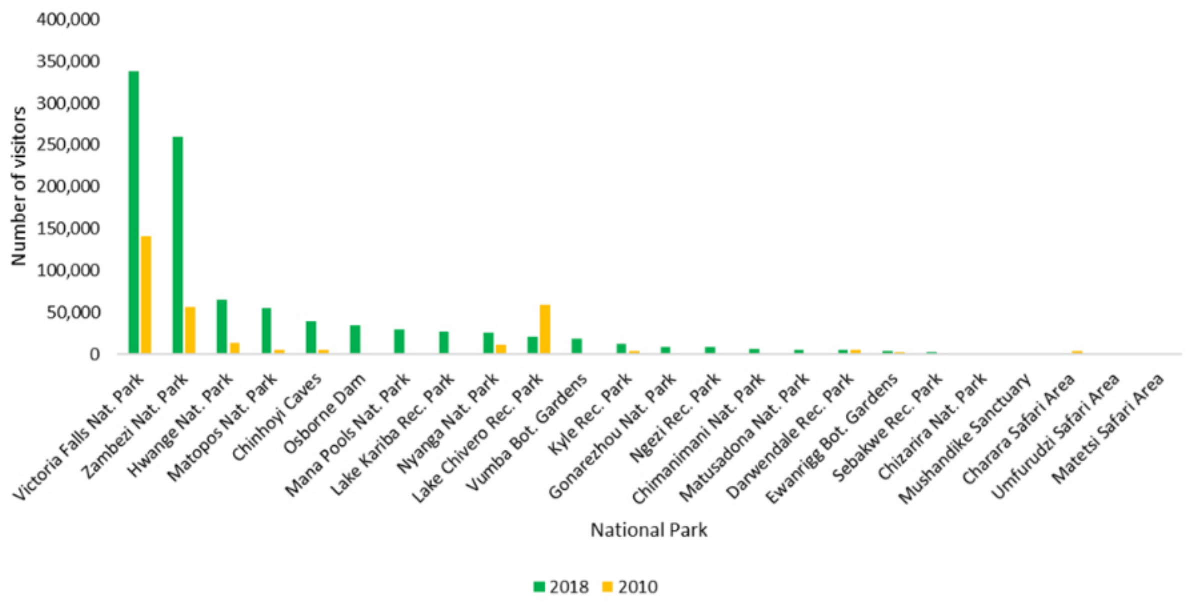


Figure 17. Visitor arrivals by national park in 2018 and 2010 (source Tourism Trends reports from 2010 and 2018 published by the Zimbabwe Tourism Authority).

To assess patterns of tourism and recreation more specifically within designated protected areas, we also compiled data on visitor arrivals by national park. These data are reported in the annual Tourism Trends reports published by the Zimbabwe Tourism Authority's Domestic Tourism and Strategic Research Division and we compiled these for 2010-2018. In 2018, Zimbabwe received 971,397 visitors to national parks. Visitation patterns were dominated by the Rainforest (Victoria Falls) National Park and nearby Zambezi National Park (with 35% and 27% of total visitors, respectively). About three-quarters of these visits were from foreign versus domestic tourists, compared to more domestic tourism in the other national parks. The second tier of most visited national parks included Hwange (7%), Matopos (6%), and then Chinhoyi Caves, Osborne Dam, Mana Pools and Lake Kariba with (3-4%) visitors (Figure 17).

BIODIVERSITY, INCLUDING RARE PLANTS

In summarizing the biodiversity results, it is important to note that the biodiversity data are incomplete as many of the data layers are only for the miombo ecoregion so caution should be taken in interpreting the maps. Consequently, the biodiversity of non-miombo areas, such as the high diversity of the Afromontane forest of the Eastern Highlands, is not reflected. A further omission is that large private conservancies, such as Save Valley, Malilangwe, Nuanetsi and Bubye Valley, have experienced increased numbers of rhinos, elephants, cheetahs and wild dogs over recent years and these data, again, will not be reflected in our analysis.

We extracted the biodiversity data provided from the Miombo Ecoregion Areas of Biological Interest Report (Timberlake 2001) for Zimbabwe, for species richness of birds, large mammals, reptiles and amphibians; species endemism for plants, large mammals, reptiles and amphibians; rare vegetation; and, important mammal migration areas (Figure 18). While these layers do not represent the complete suite of layers available in the assessment, these were the readily accessible ones in the database. We also overlaid these polygons with Birdlife International's Important Bird Areas.

As might be expected, the biodiversity data showed concentrations across Zimbabwe in the national parks, which are likely to have been comparatively well surveyed compared to surrounding areas. Key national parks include Hwange and Gonarezhou, and the northern tip of the country along the Zambezi River to the northeast of Lake Kariba and encompassing Mana Pools National Park (Figure 19).

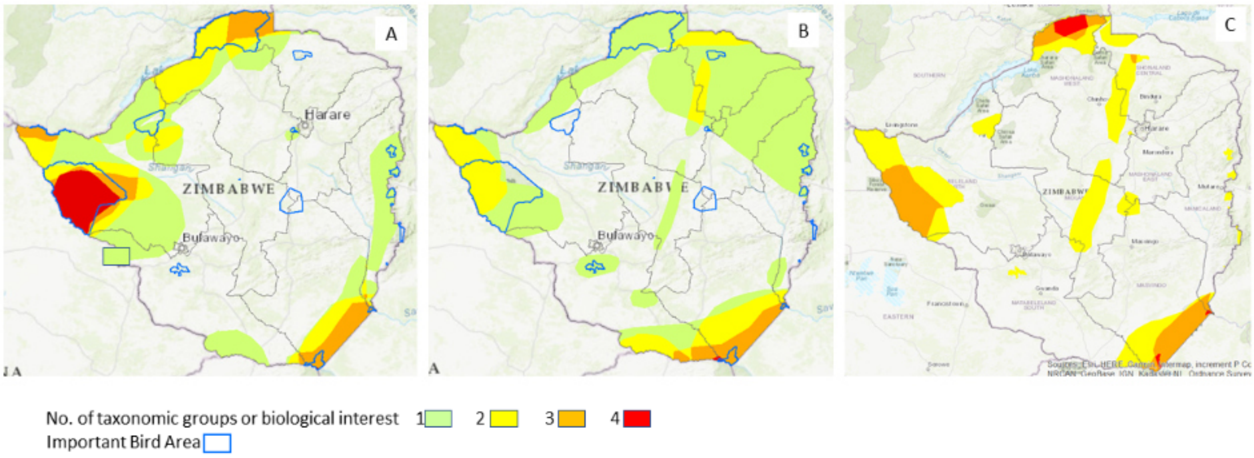


Figure 18. Maps of (A) species richness, (B) species endemism and (C) rare vegetation, Important Bird Areas, and important mammal migration areas for the miombo ecoregion areas in Zimbabwe (source Timberlake et al. 2001). Note that these data are only for the miombo ecoregion, so data for other biodiverse areas such as the Eastern Highlands are not included.

If all 10 biodiversity layers are compiled into one map and overlain with protected areas IUCN categories I-IV, there are a handful of important areas that are currently unprotected. These include area to the southwest of Gonarezhou National Park, the northern end of the Great Dyke, and the area to the east of the Mana Pools (Figure 19). Since these data do not include the Eastern Highlands, we cannot evaluate the role of national parks such as Nyanga and Chimanimani for capturing patterns of biodiversity at the national scale. However, previous efforts from the 1980s by a group of ecologists at the then Department of National Parks and Wildlife Management (and led by the Chief Ecologist, David Cumming), established priorities for Zimbabwe's protected areas using multi-dimensional criteria. Criteria included biological, conservation, socio-economic, landscape and amenity, and led to the identification of both Nyanga and Chimanimani National Park as high priority areas.

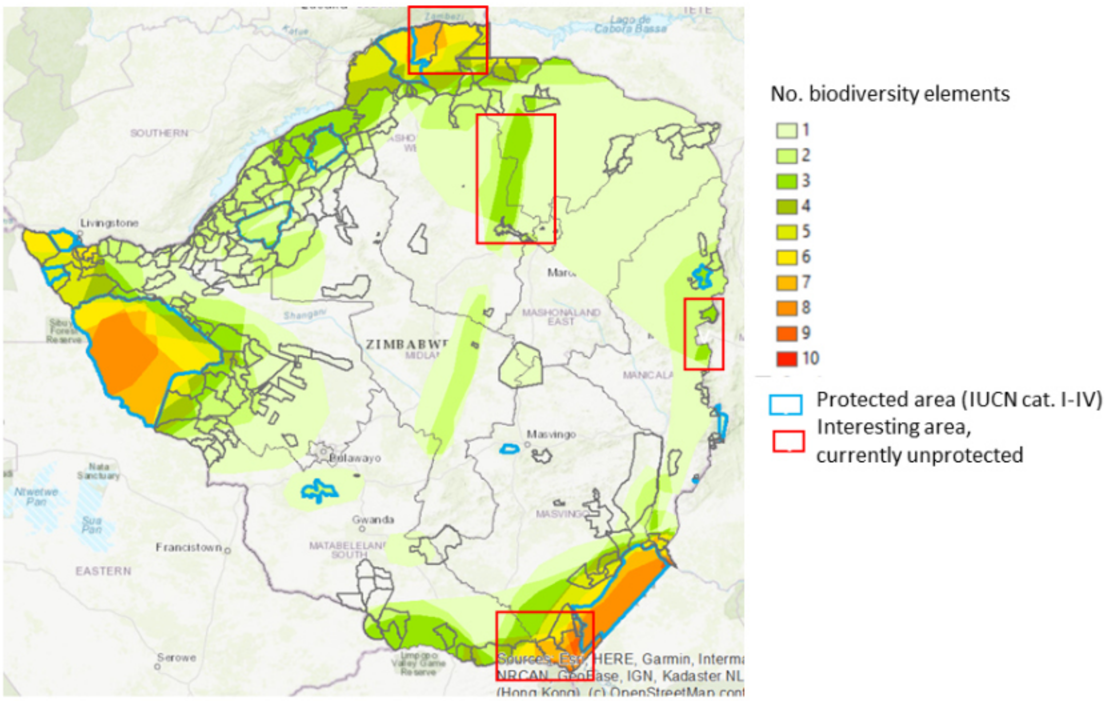


Figure 19. Overlay of the 10 biodiversity elements and protected areas, and significant biodiversity areas which are currently unprotected (identified by report authors). Note that these data are only for the miombo ecoregion, so data for other biodiverse areas such as the Eastern Highlands are not included

We again emphasize that the biodiversity data only reflects miombo woodlands and fails to capture the richness of the Eastern Afromontane forests. These forests are rich in plants, support restricted range birds and other special forest birds, threatened amphibians and small mammals. These attributes have resulted in the recent establishment of five Key Biodiversity Areas (KBAs) in this region.

We also digitized data on the number of threatened plants using geographic areas and data published by Mapaura and Timberlake (2002). Areas with exceptional numbers of threatened plants are in the Chimanimani region of the Eastern Highlands, which hosts 94 species identified with Critical, Endangered, or Vulnerable status. Other important areas within Zimbabwe for threatened plants include the Limpopo-Save Lowveld in the southeastern corner of the country (48 species) and the Limpopo escarpments (25 species) where hills catch moist air (Figure 20).

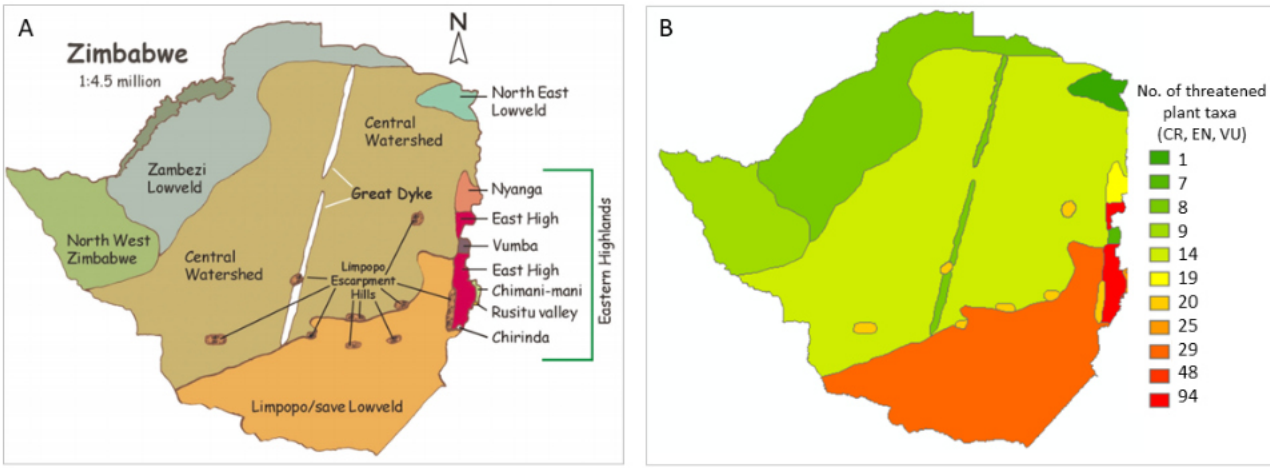


Figure 20. Maps showing (A) geographic areas used for red data list (map reproduced from Mapaura and Timberlake 2002) and (B) number of threatened taxa (Critical, Endangered, Vulnerable) by geographic area.

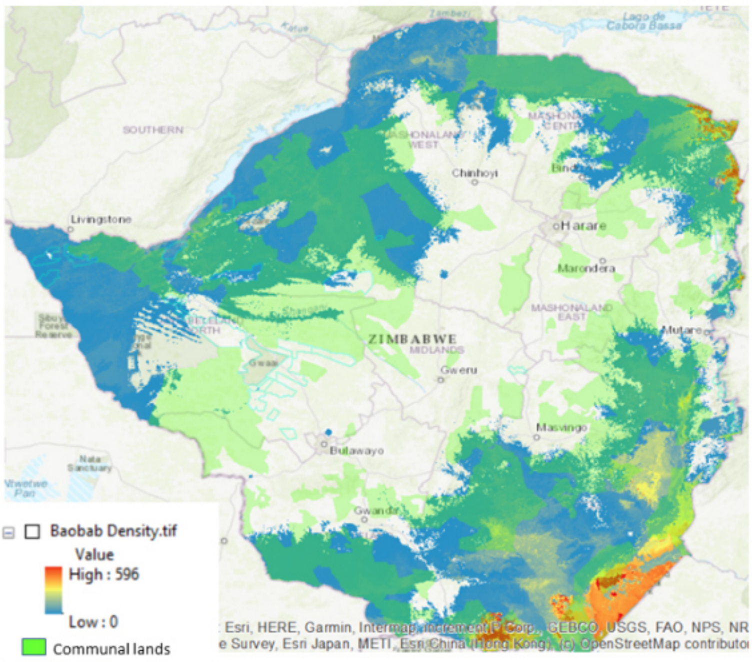


Figure 21. Map of predicted baobab density (tree/km^2), Douie and Whitaker (2014).

NON-TIMBER FOREST PRODUCTS

Using almost 3,000 locations of baobab locations, combined with climatic and elevation data, a map of predicted baobab density was generated by Douie and Whitaker (2014). Predicted locations of low densities of baobab trees occur around the periphery of Zimbabwe, with low suitability in the central area (Figure 21). Particular hotspots, with densities reaching over 500 trees per km^2, included the northeastern region of Mashonaland East province and the southeast of Masvingo province, within and to the west of Gonarezhou National Park.

The distribution of communal lands (green) is also shown, to indicate how baobab density varies between these areas (Figure 21). Of the area predicted by the species distribution model to harbor suitable environmental and climatic conditions for the baobab tree, 25% is estimated to be within communal lands. In particular, communal lands along the northeastern and southern-southeastern border of Zimbabwe have relatively high densities of baobab.

However, it must be noted that the baobab is just an example of one NTFP and not a surrogate for all NTFPs. Indeed, it is somewhat unique since it is scattered in its distribution, not linked to any particular vegetation type, and studies suggest that it has been spread by human activities over the centuries. Nonetheless in our assessment we use it to demonstrate how NTFP data can be combined into a national analysis with other ecosystem services.

6.3 OTHER FACTORS AFFECTING ECOSYSTEM SERVICES

POPULATION CHANGE

The early (1975-1990) and late (2000-2015) time periods showed the greatest change in human settlement, with more widespread increases in population compared to the middle (1990-2000) time period (areas of red in Figure 22). In the early time period from 1975-1990, the provincial capitals showed high levels of increase, notably: Harare (A in Figure 22) and its surrounding areas in Mashonaland East; Chinhoyi (B); Bulawayo (C); and, Mutare (D) and surrounding areas in Manicaland. Other provincial capitals also increased in population, such as Gweru (E) in the Midlands and Gwanda (F) in Matabeleland South Provinces.

> One of the greatest changes in human settlement occurred from 2000 - 2015
>
> Population increases around Harare and Chinhoyi were particularly intense

In the middle time period (1990-2000) while the populations in the provincial capitals such as Harare (and neighboring Chitungwiza), Chinhoyi, and Bulawayo continued to grow, there were much lower levels of population change in previously active provinces such as Matabeleland North and Matabeleland South. However, new centers of population increase in this period occurred in the southern tip of Masvingo province (G). In some cases, the direction of population change switched between the early and middle epochs. For example, between 1975-1990, an area to the northeast of Chinhoyi (H) on Mashonaland West's border with Mashonaland Central an area to the east of Bulawayo (I), and Chiredzi (J) in Masvingo province experienced a population increase in the earlier time period, which switched to a population decrease between 1990-2000.

In the late time period between 2000-2015, cities and towns which had shown a population increase continued to do so, but at a more intense rate and affecting a wider surrounding area (Figure 22). Population increases around Harare and Chinhoyi are particularly intense, while new areas of population increase emerged: towns along the northwestern border of the Midlands province (K) and along the northern edge of Matabeleland North (L) to the east of Victoria Falls are all new areas of increase during this interval. Towns showing a decrease in population in this time period are almost exclusively limited to ones in the Midlands province. The extent to which population changes associated with the Fast Track Land Reform resettlement patterns are reflected in these data is likely limited, since this is a global dataset that integrates built-up areas mapped from 30 m imagery; consequently, smaller farming settlements and communities are unlikely to be detected.

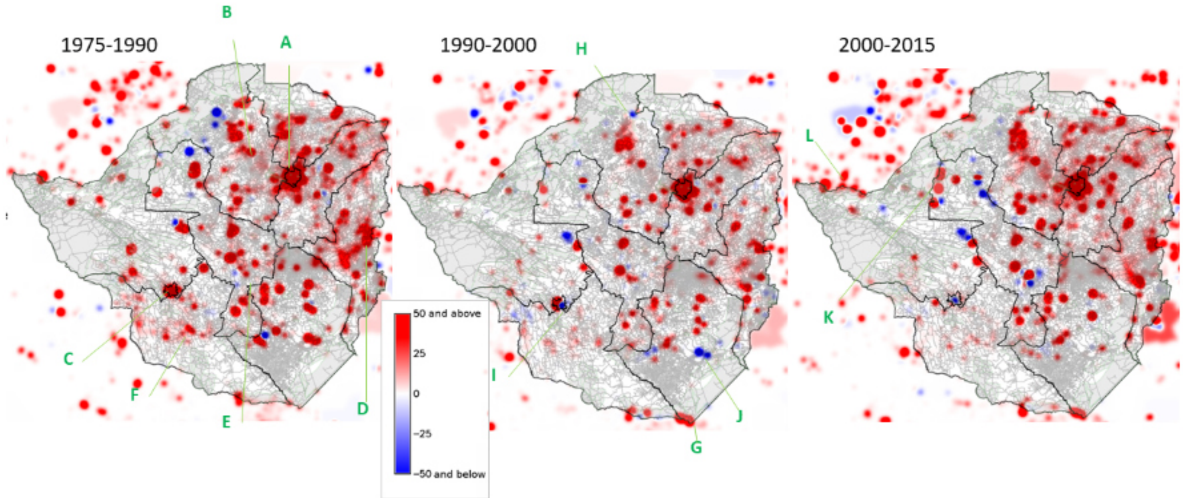


Figure 22. Population change data for 1975-1990; 1990-2000; and 2000-2015 (Global Human Settlement layer, 2019); green letters indicate settlements referred to in the text.

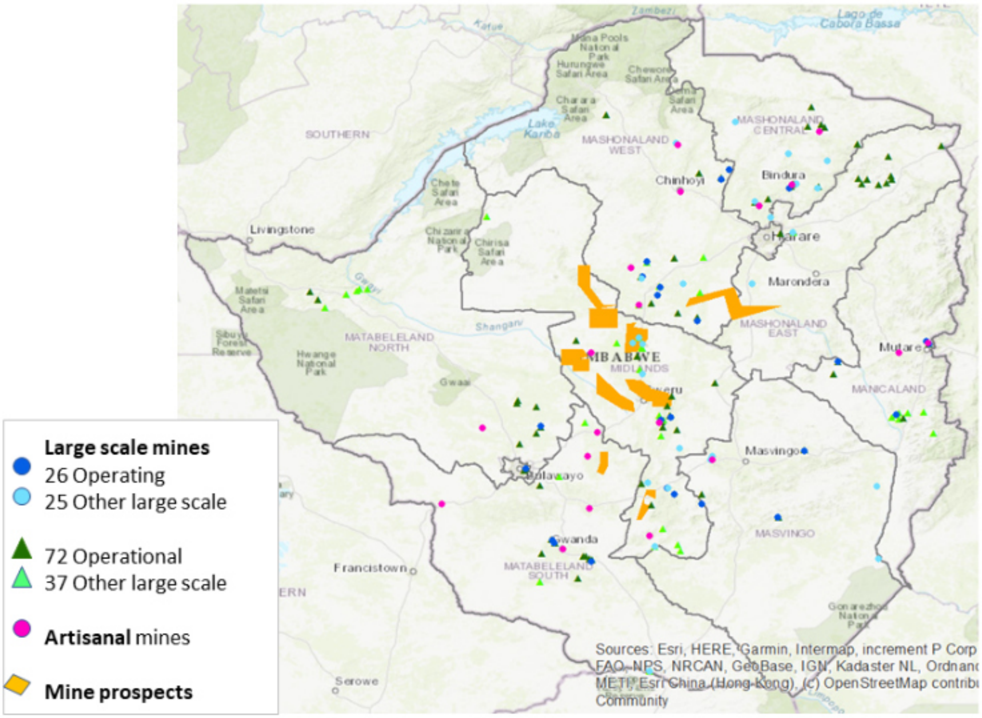


Figure 23. Compilation of available mining data, showing both commercial and artisanal activity.

MINING – COMMERCIAL AND ARTISANAL

We compiled the four sources of mining data and overlaid them into one map (Figure 23). The data show some concentrations of mining areas, for example in central Matabeleland South, northern Mashonaland East, and southern Mashonaland West. However, our data set is a dramatic underestimate of the full extent of commercial and artisanal mining activities in Zimbabwe, and thus additional inference and interpretation is limited. This is particularly concerning given the negative impacts of mining on rivers and streams, and the encroachment into protected areas.

A group of Zimbabwean women pan for gold.

The data are especially limited for artisanal gold mining, which has expanded exponentially with the rising price of minerals and has become very widespread owing to the decline of formal employment opportunities. In Zimbabwe, the mining sector represents a majority of the country's exports and has long been associated with illicit financial flows and limited transparency. A more detailed and accurate compilation of these data would be enormously helpful to understand potential land use conflicts, as well as mitigation and restoration opportunities. If properly managed, the mining sector can serve as a development tool to for widespread socioeconomic investments. However, mining can also cause severe impacts on public health and ecosystem services, through mercury pollution, contaminated water and soil, and habitat and biodiversity loss.

In 2018, plantation forests for harvesting timber were only located in two provinces: Manicaland and the Midlands

TIMBER HARVEST

Plantation forests for harvesting timber for both local and export sales are currently (2018) located in just two provinces: Manicaland (64,821 ha or 94%) in the Eastern Highlands and the Midlands (4,027 ha or 6%). This is in contrast to 10 years prior when there were plantations in Mashonaland East, West, and Central although, even then, these still only accounted for 6% of the total plantation area of the country (Table 1). The commercial plantations in the Eastern Highlands consist of pine, wattle, and some *Eucalyptus*, located in between the indigenous high biodiversity forests.

Interestingly, the total timber production in 2018 (302,500 m3) is similar to 2008 (Table 1), however, in the interim period, production fluctuated between a low of 208,695 m3 in 2010 to a high of 427,407 m3 in 2017. Although production is similar, the 2018 export sales are only one-fifth of the 2010 sales. Similarly, the number of people employed in both permanent and fixed period contracts related to cutting, sawmills, and processing plants is about one-third of the total employment a decade earlier. Over the last three years of available data, employment has remained relatively steady at an average of 4,245 people (Table 1).

Year	Plantation Area by Province (ha)					
	Manicaland	Mashonaland West	Mashonaland Central	Mashonaland East	Midlands	Total
2008	90,805	1,760	340	2,676	2,737	98,318
2009	81,301	1,759	300	2,255	4, 247	89,862
2010	80936	1,042	0	1,065	3,897	86,940
2011	85,890	0	0	0	3,865	89,755
2012	77,718	0	0	0	3,865	81,583
2013	191,612	0	0	0	8,170	199,782
2014	193,534	0	0	0	8,170	201,704
2015	-	-	-	-	-	-
2016	65,168	0	0	0	4,724	69,892
2017	64,780	0	0	0	4,016	69,096
2018	64,821	0	0	0	4,027	68,848

Table 1A. Summary data from the Zimbabwe Forestry Commission's annual reports on Timber Industry Statistics (2008-2018, data unavailable for 2015).

Year	Production & Sales					Total Employment
	Total Production (m3)	Sales (local & export)	Local Sales US$	Export Volume	Export Sales US$	
2008	303,476	246,988	-	140,524	40,014,741	14,493
2009	243,365	235,446	-	96,505	30,147,436	10,209
2010	208,695	244,403	31,877,872	-	30,515,700	7,242
2011	265,753	185,455	23,909,078	-	11,297,356	8,012
2012	279,522	267,888	36,048,910		21,407,922	8,169
2013	-	-	-	-	-	5,018
2014	-	-	-	-	-	3,833
2015	-	-	-	-	-	-
2016	211,743	52,705	26,444,777	-	21,143,234	3,940
2017	427,407	423,731	41,989,397	-	11,378,402	4,429
2018	302,500	162,434	48,508,497	-	8,632,784	4,365

Table 1B. Summary data from the Zimbabwe Forestry Commission's annual reports on Timber Industry Statistics (2008-2018, data unavailable for 2015).

BARE GROUND

Image-based mapping of bare ground is a potentially useful indication of areas of erosion or degradation. We reviewed the readily available data on bare ground from the 2019 Copernicus Land Cover dataset[12], available at 30 m spatial resolution (Figure 24). Although at this spatial scale only broad patterns of bare ground can be indicated, the southern border of Zimbabwe with South Africa in Matabeleland South province had the highest rates of bare ground (more than 16% of any 30 m pixel). Other provinces with relatively high and widespread bare ground compared to other provinces include the Midlands, Masvingo and Manicaland. Such an analysis with finer resolution imagery would be useful to repeat in the future.

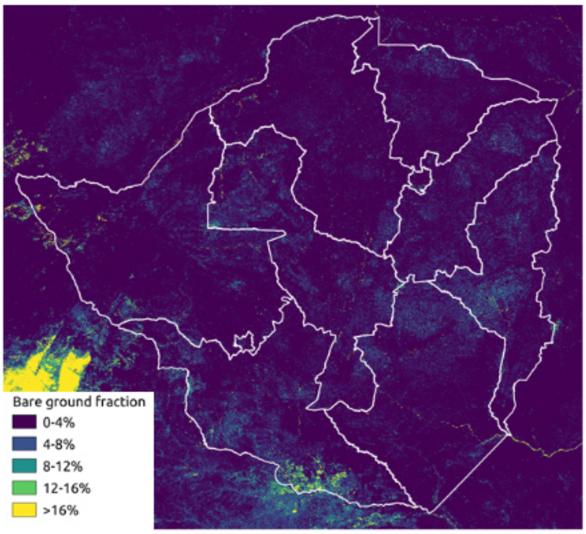


Figure 24. Fraction of bare ground mapped in 2019, Copernicus Land Cover dataset.

[12]2019 Copernicus Land Cover dataset https://lcvewer.vito.be/2019

6.4 ECONOMIC VALUES

One objective of this assessment was to gather information on the economic values associated with ecosystem services. Given the paucity of data, however, this objective remained an elusive goal for all but a few of the ecosystem services.

CARBON STORAGE

One technique widely used in the USA for the economic valuation of carbon storage is to use the Social Cost of Carbon. This applies a calculation of the residence time of carbon dioxide in the atmosphere, along with the wide-ranging impacts of climate change. The impact of an incremental increase in carbon emissions in a given year is estimated, and then the costs associated with fixing it (e.g., impacts on agricultural production or health care). The current estimate of the Social Cost of Carbon in the USA is $51 per metric ton (at the 3% discount rate, US Interagency Working Group on Social Cost of Greenhouse Gases, 2021).

As an example, in the map presented of mean biomass in communal lands (Figure 11) the Social Cost of Carbon associated with the tonne/ha of biomass on communal lands can be calculated by converting biomass to carbon, calculating the CO2 equivalent, and multiplying by $51 (price in the USA from February 2021); giving an upper amount of $2,965 per ha and lower amount of $422 per ha. While there might be more appropriate economic values to apply, this example illustrates how the quantity of biomass can be translated into an economic value.

NON-TIMBER FOREST PRODUCTS – BAOBAB

As an example of the monetized value of NTFPs, in the study of baobab resources in Zimbabwe, Gus le Breton and PhytoTrade Africa used a calculation to estimate the value of baobab pulp. With an assumption that 70% of baobab trees are fruiting and producing an average of 50 fruit per tree with an average size of 150 g per fruit and applying a value of $50 per metric ton for the fruit pulp, and using the predicted baobab distribution map, the value of baobab fruit can be calculated. Throughout most of the country this is relatively low (Figure 25) however, in the high density areas, then values of baobab fruit can peak at $78/km^2.

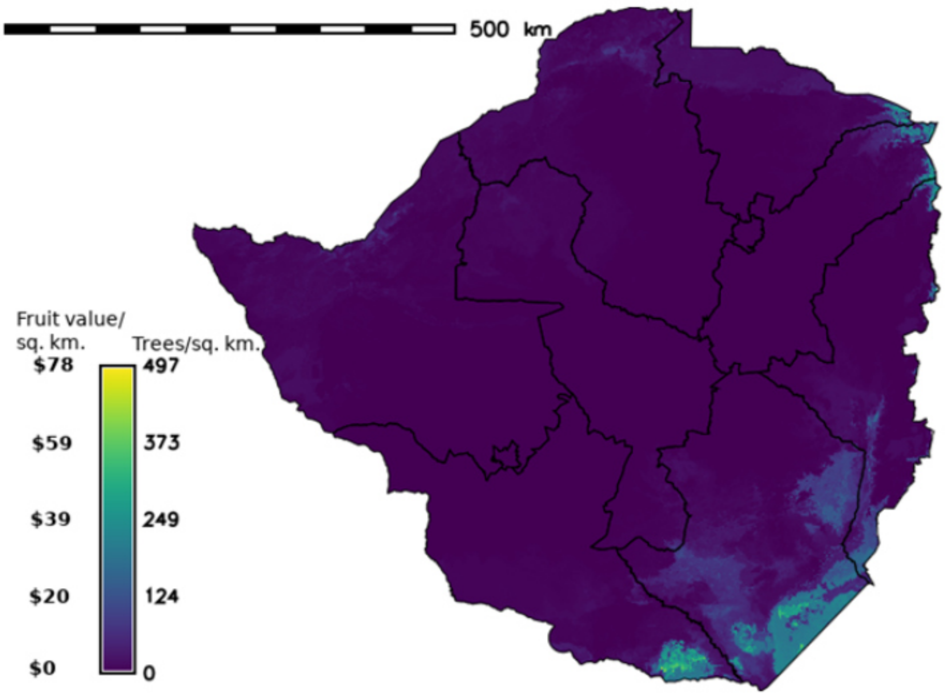


Figure 25. Estimate of value of baobab resources based on baobab density map (Figure 21) and estimates of number and weight of fruit per tree.

TOURISM AND RECREATION

To indicate patterns of tourism-related revenue, we used data derived from the Tourism Trends reports published by the Zimbabwe Tourism Authority's Domestic Tourism and Strategic Research Division and Exit Survey data published by Zimbabwe's National Statistics Agency (2015). We compiled data on hotel room capacity for different districts in Zimbabwe and recorded the percent of rooms filled by foreign clientele. These data were integrated with expenses reported by foreign visitors in the Exit Survey (2015) which were assigned proportionally based on the number of hotel rooms filled (Figure 26). Note, however, that this will not account for differences in prices of hotel rooms in different parts of the country. In the long-term, data from ZimParks can hopefully provide a better indication of monetary values associated with tourism.

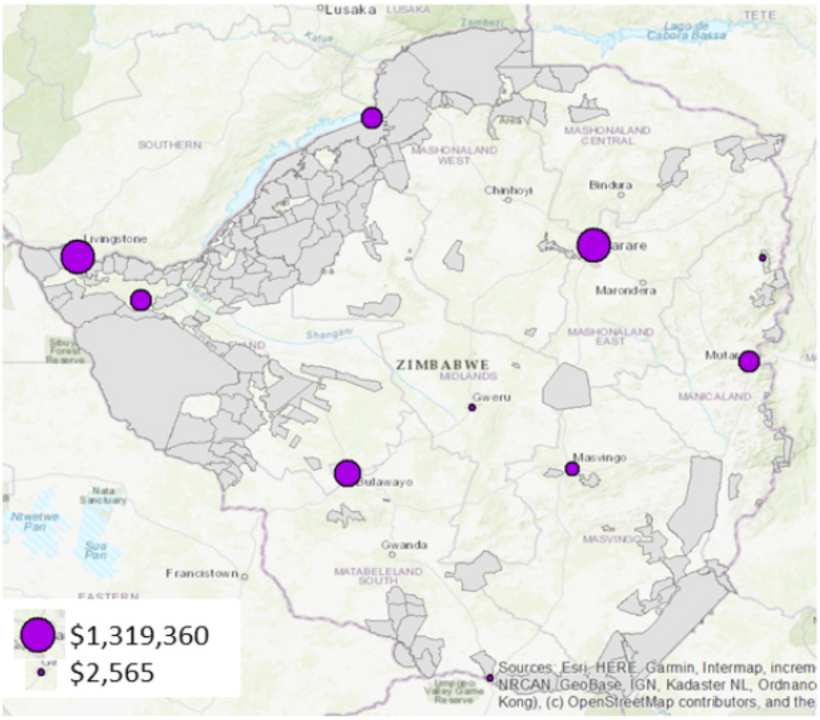


Figure 26. Expenditures on hotel accommodation (source: compiled from Tourism Trends report and Exit Survey, 2015.

6.5 INTEGRATION OF ECOSYSTEM SERVICES DATA LAYERS

To explore patterns across multiple ecosystem services in Zimbabwe we undertook two analyses. First, we integrated data from six different services, which involved first scaling the data values for each of the services into 10% classes so they could be compared (Figure 27).

Table 2. Correlation between six ecosystem services in Zimbabwe.

	Biodiversity	Biomass	Recreation	Tree cover	Water balance	Baobab
Biodiversity	1.00	0.01	0.08	0.06	-0.13	0.34
Biomass	0.01	1.00	0.05	0.49	0.13	0.05
Recreation	0.08	0.05	1.00	0.03	0.02	-0.03
Tree cover	0.06	0.49	0.03	1.00	0.33	0.00
Water balance	-0.13	0.13	0.02	0.33	1.00	-0.16
Baobab	0.34	0.05	-0.03	0.00	-0.16	1.00

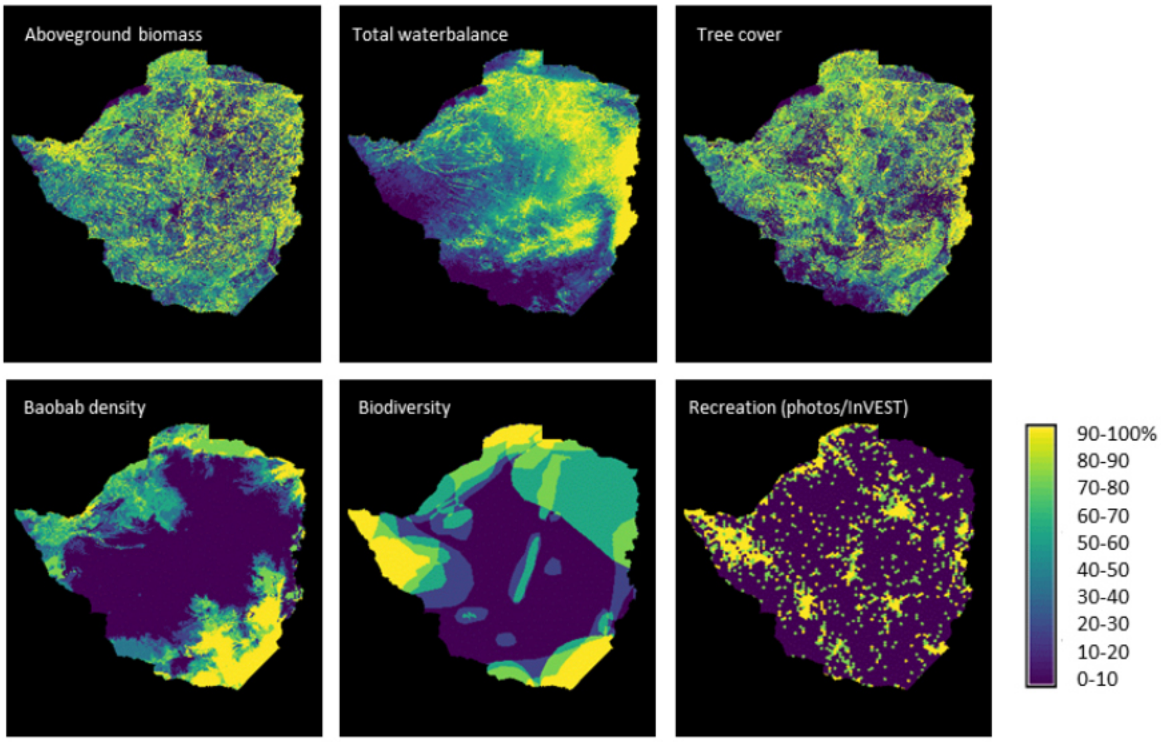
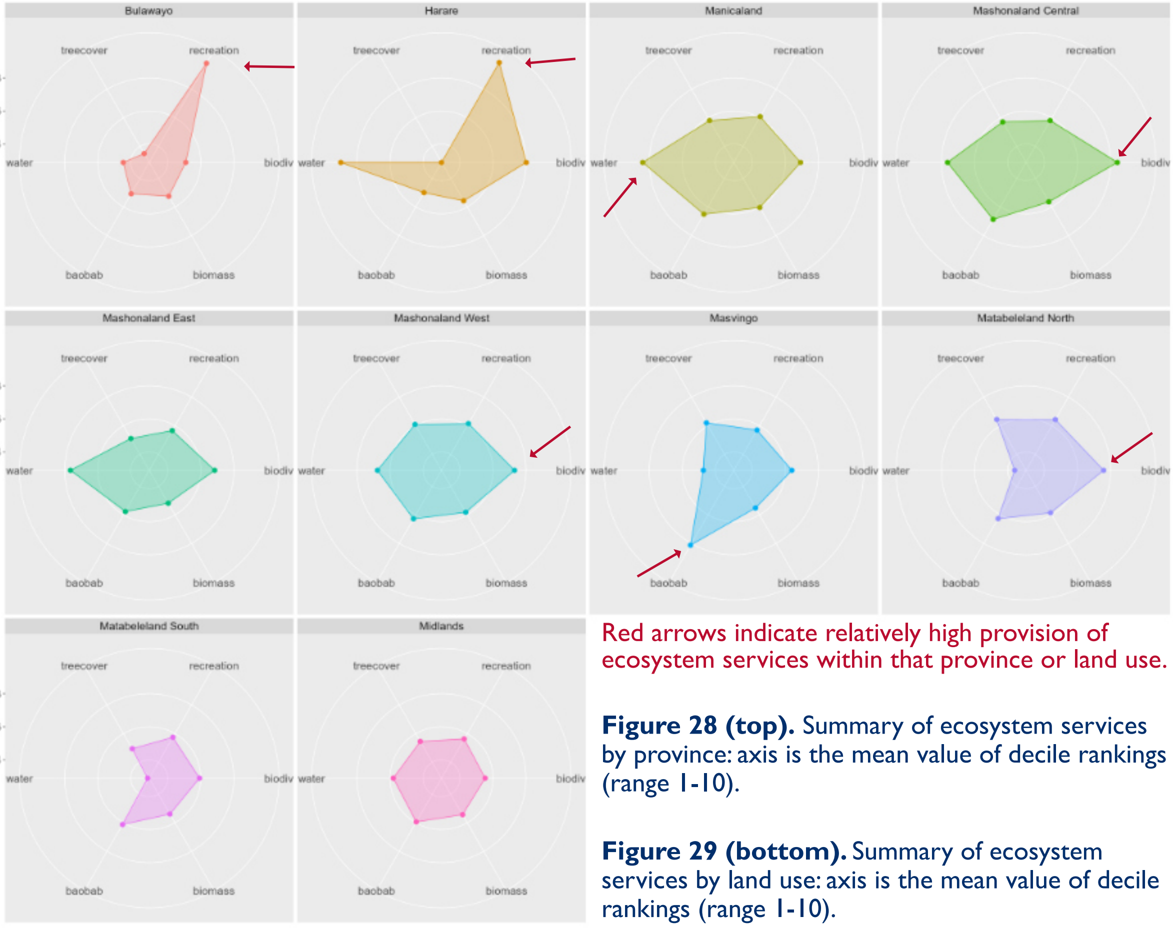


Figure 27. Standardization of values for six ecosystem services by decile rankings. Note that biodiversity data are only for the miombo ecoregion, so data for other biodiverse areas such as the Eastern Highlands are not included.

A correlation analysis was then performed on the scaled data of the different services. However, only moderate to weak relationships between the services were identified. For example, the analysis showed the strongest positive relationship between biomass and tree cover (0.49) which would be expected, followed by baobab density and biodiversity (0.34), and tree cover and water balance (0.33) (Table 2). So, even though no strong patterns were displayed at the national scale, this is likely to do with the limitations of the input data. For example, a positive relationship between biodiversity and tree cover or biomass might be expected, but since our biodiversity data focused on miombo woodland and not montane vegetation types then only a minimal relationship was found (< 0.1). Alternatively, a relationship between biodiversity and tourism might have been expected given that many of the country's national parks appeared as important for biodiversity.

A correlation analysis showed the strongest positive relationship between **biomass & tree cover**, followed by **baobab density & biodiversity**, and **tree cover & water balance**

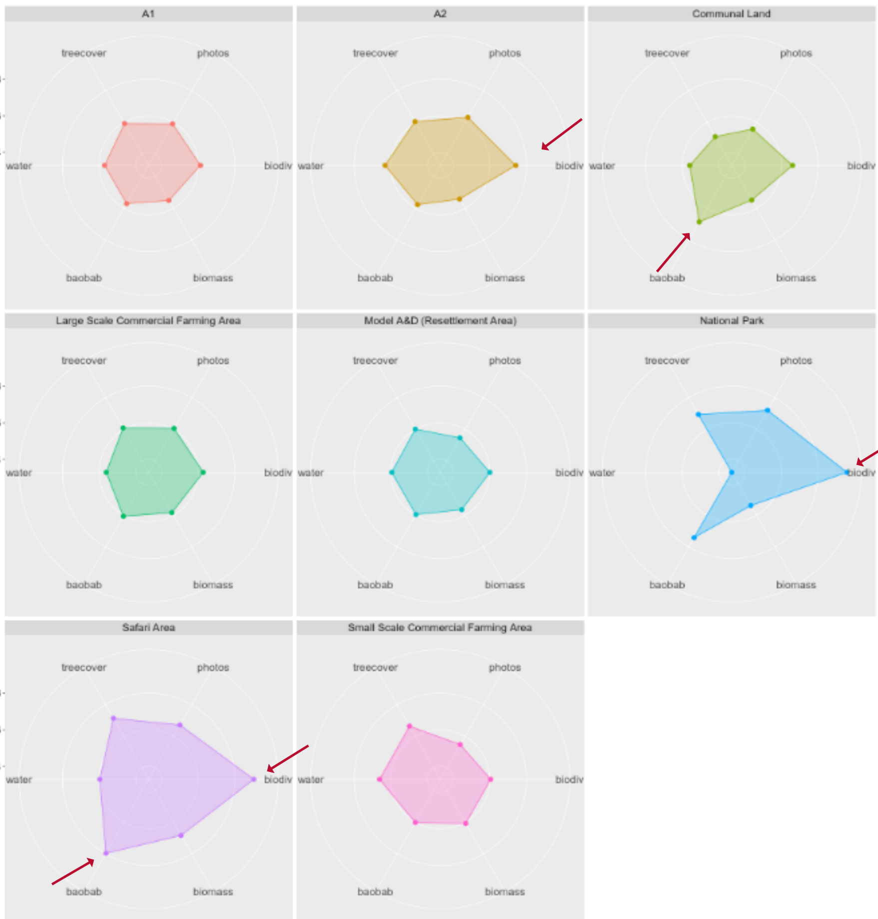
The second analyses we undertook was to assess patterns in the provision of ecosystem services by administrative province and land use type. Reviewing the six ecosystem services by each of the 10 provinces revealed certain patterns (Figure 28). Some provinces were remarkably balanced across the six services such as the Midlands province, while other provinces showed one or two dominant services, e,g., tourism and recreation services in Bulawayo or high density of baobabs in Masvingo (Figure 28). By ecosystem service, as seen previously in the recreation outputs developed using the InVEST tourism module (Figure 16), the major cities of Harare and Bulawayo are prominent in terms of tourism and the number of photo-days recorded. In terms of biodiversity services, three provinces show relatively high values including Mashonaland Central, Mashonaland West, and Matabeleland North, while water balance was relatively strong in Manicaland province, reflecting the influence of the high elevation forests of the Eastern Highlands.



Red arrows indicate relatively high provision of ecosystem services within that province or land use.

Figure 28 (top). Summary of ecosystem services by province: axis is the mean value of decile rankings (range 1-10).

Figure 29 (bottom). Summary of ecosystem services by land use: axis is the mean value of decile rankings (range 1-10).



We repeated the same analysis by major land use type (Figure 29). Again, some land use types showed remarkably even provision of services, such as the A1 resettlement areas, Model A&D resettlement areas, and small- and large-scale commercial farming areas. As might be expected, biodiversity was higher in national parks and safari areas and, interestingly, in A2 resettlement areas. Another distinctive feature, as noted in the maps of baobab density (Figure 21), was the relatively dominance of baobab (i.e., provision of non-timber forest product services) in communal lands.

7.0 RECOMMENDATIONS

Data compilation for the assessment proved immensely challenging. Many data sources were pursued, followed by extensive outreach via email and phone, but COVID-19 travel restrictions prohibited in-person meetings, and many promising data sources proved to be sensitive or elusive. Nevertheless, this assessment provides a comprehensive dataset documenting changes in tree cover, fire patterns, and population settlement over the past two decades, and the first national-scale snapshot of ecosystem services in Zimbabwe that goes beyond provisioning or regulating services.

Based on the experiences from the assessment, USFS makes the following recommendations for future ecosystem service analyses focusing on Zimbabwe:

7.1 DATA ANALYSES

Based on data limitations at the national scale, we recommend that future ecosystem service analyses in Zimbabwe are conducted at regional and local spatial scales.

Forest and Woodland Cover

- Establish a link between forest and woodland loss and the loss of associated ecosystem services. In particular, if the economic value of these services could be calculated on a per hectare basis, then the full value of forests and woodlands could be viewed against other types of land use such as agriculture. In turn, this would provide valuable information for policy decisions relating to land use and influencing priorities at the national scale.

- Compile data on agricultural production and the contribution that healthy forests and woodlands can make to cultivation. For example, cultivation in close proximity can benefit from moisture and water provided by forests, increased pollination, and soil fertility. Being able to understand these connections and, even better, to quantify these economic values from forests would further highlight NTFPS provided by Zimbabwe's forests and woodlands.

- Conduct further analysis of bare ground with finer resolution imagery and at multiple time steps.

Fire

- Further analysis of patterns of fire could be conducted at regional and local scales. This could address the positive correlation between fire and rainfall in the previous season, which results in greater grass biomass, and also the negative correlation of fire with overgrazing in communal lands. In some areas, such as southern Zimbabwe, there is simply no grass to burn in the dry season.

Biomass

- Data on biomass and carbon storage at the local scale could be determined for selected areas by estimating forest and woodland densities and using standard formulas to calculate carbon stock. Analyses could also draw on collections of empirical biomass estimates for southern Africa SEOSAW.[13] Improving carbon storage estimates for miombo and mopane woodlands would be beneficial to understand their contribution to carbon budgets compared to more forested ecosystems.

Hydrology

- Model hydrology at a finer spatial resolution with a regional focus. Modeling within one of the seven recognized regional water catchments in Zimbabwe should facilitate data acquisition for inclusion into hydrological models.

[13] https://seosaw.github.io/

Tourism

- Improve data on tourism and recreation, for example, through collaborative links with ZimParks and the Zimbabwe Tourism Authority. Acquiring data on the estimated travel costs of tourism or the annual revenue generated from nature-based tourism would improve the collective understanding of cultural services provided by natural areas, information that could be integrated into national level decision-making.

Biodiversity

- Compile species distribution data for the Eastern Highlands, again possibly through links with ZimParks, e.g., recent studies have highlighted the plant diversity and richness of four montane areas (Nyanga, Bvumba, Chimanimani, and Chirinda, Timberlake 2017). Compiling comparative biodiversity data across a range of taxonomic groups for the entire country would allow a systematic analysis of biodiversity priorities to be conducted, which could inform national level decision making

- Conduct spatial analyses and modeling for key species. For example, identifying intact blocks of habitat at the regional scale that might provide movement corridors for species between protected areas, thereby highlighting priority areas for interventions such as human-wildlife conflict mitigation.

Non-Timber Forest Products

- Compile additional spatial data on other Non-Timber Forest Products (e.g., fuel, materials for construction, medicines, honey) through emerging ecosystem service tools such as TESSA (Peh et al. 2017). This tool could be applied at the community scale using a participatory approach in the South Eastern Lowveld to capture information on harvested wild goods, cultivated goods, and how much fuel is extracted per year, as has already been conducted for the Driefontein Grasslands (World Birdwatch 2014). Such an analysis would provide recent data on NTFPs and an indication of the economic value of these ecosystem services to rural communities.

Climate Change

- Integrate data on future climates. Outputs from a range of global climate models could be integrated into models of ecosystem services, e.g., hydrological models, or used to project the distribution of tree cover, e.g., of communal lands. Such projections would indicate the vulnerability of natural resources and the ecosystem services they provide which could contribute to natural resource planning.

7.2 NEXT STEPS

All organization and individuals consulted during this project will receive copies of the report and accompanying infographic, as well as the associated data upon request. USFS will also follow-up with Zimbabwean colleagues, as well as USAID and US Department of State, to offer project briefings, determine potential partnership opportunities, and identify needs for technical assistance with the application of these analyses. Program opportunities related to the following themes will be pursued: watershed and rangeland management, forest restoration, non-timber forest products, biodiversity and tourism, and mining.

USFS is also exploring follow-on activities from the assessment and will conduct a finer scale regional assessment of ecosystem services in the Southeast Lowveld region, partnering with our existing networks. Using this national assessment as a foundation, the USFS's International Programs plans to undertake a regional study of the South Eastern Lowveld, one of the priority regions for biodiversity that is also at high risk for drought, as well as climatic and economic shocks. Working at this spatial scale will allow the modeling of ecosystem services at a finer spatial scale, thereby increasing their accuracy through incorporating empirical data. It will also allow work at the community scale to better understand the use of non-timber forest products from community forests and in particular, to explore the economic values of selected ecosystem services to highlight the benefits natural landscapes provide. This type of regional assessment would support on-the-ground programming by partners who have worked over the last few years to explore the development of a new protected area in the Southeast Lowveld, as well as community-focused programming related to the themes above.

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APPENDIX

Ecology meeting participants
16 November 2020

1. Simbarashe Chiseva
2. David Cumming,
3. Togarasei Fakarayi
4. Anderson Muchawona
5. Jonathan Timberlake
6. Raoul du Toit
7. Beth Hahn
8. Emma Underwood

Mining meeting participants
5 November 2020

1. Shamiso Mtisi
2. Joshua Machinga
3. Emmanuel Chinembiri
4. Paul Matshona
5. Lyman Mlambo
6. Blessing Hungwe
7. Beth Hahn
8. Emma Underwood

Below, Victoria Falls National Park, a hotspot for ecosystem services related to tourism and water, Matabeleland North Province.

Photo: U.S. Forest Service