The Economic Value of the Cubango-Okavango River Basin

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Prepared by Conservation Strategy Fund
in partnership with Wild Bird Trust

A young Nile Crocodile in the Okavango | Photo taken by Ondrej Prosicky in Moremi, Botswana

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EXECUTIVE SUMMARY

Strategic Significance

Spanning Angola, Namibia, and Botswana, the Cubango-Okavango River Basin (CORB) is a rare example of a free-flowing large river ecosystem. Its predictable yet variable flood pulse is vital for sustaining life within the basin, regularly turning an otherwise dry landscape into an oasis of life and animal activity.

The CORB's river system originates in Angola's semi-humid highlands, fed by two main tributaries: the Cubango in the west and the Cuito in the East. These tributaries are further nourished by numerous smaller rivers before the water flows into the Okavango Delta. The CORB is the main water source for one million people across the three countries in which it spans - Botswana, Namibia, and Angola - and provides vital habitats for some of the world most threatened bird and large mammal species.

From tourism and climate regulation to the ecological benefits of woodlands and aquatic ecosystems, the CORB provides ecosystem services that are vital to sustaining human well-being and maintaining environmental resilience. Valuing the multiple ecosystem services provided to society by this catchment is necessary to secure ample funding for the sustainable management and further protection of the CORB.

This study by Conservation Strategy Fund (CSF), in partnership with the Wild Bird Trust (WBT), assesses the economic value of eight (8) of the ecosystem services delivered by the Cubango-Okavango River Basin. The ecosystem services include crop and livestock provisioning, wood provisioning, wild animals, fisheries, water supply, climate regulation, and recreation. Through rigorous analysis and integration of diverse data sources, we contribute to the literature on the economic imperative for conservation and sustainable management practices in the Cubango-Okavango River Basin.

With this updated data, decision-makers can more accurately integrate the CORB's value to society in policy and investment decisions and will be better able to assess the costs of its loss and the benefits of its protection.

Scope of Study

Our study serves to update the findings of Turpie et al., (2006), which quantified the economic value of various ecosystem services within the Okavango Delta Ramsar site in Botswana, including the Okavango Delta World Heritage Site and its buffer zone, at P1.03 billion in 2005 (US$ 227 million in 2022). CSF's research extends this valuation area to encompass the Cubango-Okavango River Basin within Angola and Namibia, referred to in this report as CORB. This study provides information on the economic value of ecosystem services delivered by the ecosystems of the Cubango-Okavango Basin, with the intention of making an "economic case for conservation" that justifies the investment of funds in the protection of the ecosystem. Furthermore, this study can help to better develop more effective compensation mechanisms for human-wildlife conflicts.

To conduct the analysis, we do not consider the full extent of the Cubango-Okavango River Basin, but rather the Cubango-Okavango River Basin extend in Angola (150,405 km^2) and Namibia (21,787 km^2) and the Botswana study area comprises the Okavango Delta Ramsar site (55,620 km^2) as outlined in Figure 2. Originating in Angola's highlands, the basin's hydrological network extends across diverse habitat types and is characterised by seasonal flood pulses and hydrological variability. At the heart of its ecological functioning lies the intricate relationship between basin communities and their natural surroundings. Predominantly dependent on subsistence agriculture and pastoralism, these communities often confront challenges posed by climatic variability and resource constraints.

Floodplains of the Okavango River Delta in Botswana | Photo by Simon Greig

Results

CSF estimates the CORB's total economic value (TEV) at approximately 1.1 billion per year in 2022 US$. Botswana and Angola emerge as pivotal contributors to the CORB's economic value, accounting together for more than 90% of the total economic value provided by these ecosystem services. Namibia contributes a comparatively lower economic value relative to is smaller area as seen below in Table 1.

Table 1: Economic Value of Ecosystem Services Provided by CORB to Angola, Botswana, and Namibia (2022 US$)

Country	Size (ha)	Annual value ($)	Value ($) per capita
Angola CORB	15 million	802 million	1,075
Botswana Ramsar Site	5.5 million	268 million	1,363
Namibia CORB	2.2 million	75 million	219
All countries	22.8 million	1.15 billion	

In addition to the annual values, which refer to the flow of the ecosystem services, our study also reveals CORB's significant contribution to carbon storage which, if released due to habitat destruction, would result in significant climate change damage costs. Angola, Botswana, and Namibia each contribute substantial value by way of carbon storage, underscoring the economic importance of understanding and managing carbon resources for environmental and economic sustainability. In total, the economic value of carbon stock of the CORB is attributed to the tonnage of carbon stored in its ecosystems. Here, the carbon stocks are 686 million tonnes in the Soil Organic Carbon (0 - 50cm layer) and 569 million tonnes in the above and belowground biomass. It's crucial to note that there's no current pathway to monetize carbon values across the CORB. While carbon's proportional value to the overall Ecosystem Service Valuation is relatively high, other Ecosystem Services pose a more immediate financial risk if compromised and careful consideration should be given to those.

Overall, these findings provide crucial insights into the economic significance of the Basin's ecosystem services, reinforcing the urgency for concerted efforts to conserve and sustainably manage this vital natural resource for the benefit of present and future generations.

Key Insights

Short-Term

Addressing Data Gaps: There is a need to address numerous data gaps which would allow a much more accurate and granular assessment of the ecosystem services provided by the CORB. By closing such data gaps, the methodology can be adapted to assess these values more specifically. One such example is the tourism data of the study area in Botswana. Tourism has been shown to be a major contributor to the value provided, however, there is limited data on the tourism arrivals, and we recommend that the sector undertakes a more coordinated and collaborative approach to recording tourism arrivals and time spent in the Delta itself.

Improved Management of Natural Resources: Prioritise efforts to reduce the reliance on wild animals and fuelwood for sustenance among Basin communities. This could involve initiatives to improve alternative livelihoods and promote sustainable resource management practices like fisheries reserves, reforestation projects and improved methods of charcoal production. For countries involved in the management and use of the Cubango-Okavango Basin:

- Angola and Botswana could potentially reduce communities' reliance on fuelwood and provide better cooking technologies with improved efficiencies, such as solar cookers.
- All three nations could advance Integrated Water Resource Management agreements to safeguard their common usage of water resources.
- Botswana and Angola could reduce the reliance on hunting of wild animals for subsistence through the provision of alternative sources of protein.

Provide Alternative Energy Sources: Promote the adoption of cleaner energy sources instead of fuelwood or charcoal such as solar power or grid electricity. This will alleviate some of the strain on forest resources caused by the widespread use of fuelwood for cooking within the Basin.

Promote Sustainable Tourism: Advocate for tourism and recreational activities that generate economic benefits from wildlife and natural resource conservation. Focus on boosting community-led eco-tourism opportunities throughout the value chain in Namibia and Angola, aiming to unlock local economic potential and support environmental conservation efforts.

Explore the Carbon Value Chain: Investigate opportunities to leverage the carbon value chain as a means of generating additional revenue for the Basin, particularly in Angola, where significant potential may exist for carbon-related initiatives.

Support Implementation of the OKACOM Decision Support System (DSS): The OKACOM Basin Development Management Framework (BDMF) identified the need for development of a basin-wide information sharing tools and DSS designed to support OKACOM in its mandate to provide technical advice that aligns development and land use planning in the Member States with the Cubango-Okavango River Basin (CORB) Vision as well as the harmonisation of national information and data, integration of selected data into the DSS and development of basin-wide information sharing mechanisms.

Long-Term

Integrate Research into Policy Decisions: Support OKACOM in its integration of research-informed natural resource management plans with national policies across Basin member nations. This support to OKACOM can be enhanced through the existing entities of KAZA, SADC, ZAMCOM and other bilateral processes. This holistic approach will ensure alignment and coherence between local and national strategies, enhancing the effectiveness of conservation and sustainable development efforts.

Support Transboundary Cooperation and Resource Management: Support OKACOM in its collaborative efforts to facilitate transboundary natural resource utilisation among Botswana, Namibia, and Angola by fostering cooperation and sharing resources, which may enhance resilience and promote equitable access to Basin resources for all member nations.

Conclusion

The total economic value of the CORB is estimated at approximately 1.2 billion per year at 2022 US$. This significant value underscores the economic importance of the region, emphasising the need for continued conservation and sustainable management efforts to preserve its invaluable contributions to society.

The Okavango Basin encompasses three countries: Angola, Namibia, and Botswana, and it contributes significantly to the economic well-being of the people who live in the basin as well as global climate control. People living in the project area are dependent on the Basin natural resources for their livelihoods.

Despite differences in natural resource endowment and types of ecosystem services, the Okavango Basin provides substantial ecosystem services to people in Angola, Botswana, and Namibia. Crop provisioning services, Livestock provisioning service, Wood provisioning, Water supply, Recreation related services, Wild animals, plants, and other biomass provisioning services, Wild fish, and other aquatic animals, and Global climate regulation are among the ecosystem services of the Basin. Tourism provides a substantial value to the Botswana economy. This leads to increased income and social security for households across the country. Crop provisioning, on the other hand, is very important to the inhabitants of Angola, which is part of the Basin. Wood provisioning makes significant contributions to the people of Angola and Botswana. Based on the calculations in this study, Angola emerges as a significant contributor to the carbon economy.

The management of the Cubango-Okavango River Basin by Angola, Namibia and Botswana will need to balance the needs of residents with its vital contribution to the national economy whilst maintaining the ability to offer a safety net for households experiencing shocks and a risk-spreading mechanism for poor households vulnerable to environmental variability.

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Tourists on a Mokoro activity in the Okavango Delta| Photo by Ger Metselaar

LIST OF ABBREVIATIONS

CORB	Cubango-Okavango River Basin
CSF	Conservation Strategy Fund
km^2	Square kilometres
NGOWP	National Geographic Okavango Wilderness project
KAZA	Kavango-Zambezi Transfrontier Conservation Area
OKACOM	The Permanent Okavango River Basin Water Commission
PPP	Purchasing Power Parity
SOC	Soil Organic Carbon
SADC	Southern African Development Community
TDM	The Transboundary Diagnostic Management
TEV	Total economic value
US$	United States dollar
WBT	Wild Bird Trust

1. Introduction

1.1 Background

The Cubango-Okavango River Basin (CORB) originates in the highlands of Angola, where 95% of the total water flow is generated. The basin covers an area of approximately 225, 649 km² across Angola, Namibia, and Botswana (Turpie et al 2021). The CORB is home to approximately 921,890 people, and the population is projected to increase to more than 1.28 million people by the year 2025, with 62% living in Angola, 16% in Botswana, and 22% in Namibia. The main economic activities in the region are rainfed subsistence agriculture and livestock, indicating that the communities rely on natural resources as a source of livelihood (OKACOM, 2021). Fish, wild fruits, reeds, grass, and firewood are some of the other natural resources relied on by the residents of the basin.

Established in 1994, the Permanent Okavango River Basin Water Commission (OKACOM) serves as a joint management authority to govern and coordinate the national interests of the three riparian states. Studies conducted by OKACOM, and other organizations, have indicated that future development could negatively impact the CORB's environment, as well as its diverse biota and ecosystem services.

The Transboundary Diagnostic Analysis (TDA) (The Permanent Okavango River Basin Water Commission 2011) identified tourism and Community Based Natural Resource Management (CBNRM) as potential growth areas that can produce significant returns and livelihood improvement with minimal impact on the environment and ecological integrity of the basin. Providing improved water and sanitation is also important to the basin's growing population. However, Aylward (2009) suggests that water withdrawals should be approached cautiously. The author argues that there is a trade-off between using water for purposes such as hydropower and irrigation and the provisioning of ecosystem services affected by changes in water flow.

The CORB is transboundary and characterised by four natural processes. First, this region experiences a seasonal flood pulse, which supports productivity of wetlands and forests, fostering high levels of biodiversity and biomass. Second, hydrological variability ensures water reaches all parts of the system, maintaining productivity in riverine and wetland ecosystems, and supporting critical grasslands for wildlife and livestock. This flood variability also resets ecological succession in floodplains, reversing encroachment by woody species (plants that have stems and trunks that survive above ground during winter). Third, the dry season flows ensure perennial water availability in the mid-basin for humans and wildlife. Fourth, the basin maintains low concentrations of dissolved compounds, crucial for sustaining water quality and ecosystem health. These unique characteristics collectively sustain the basin's natural balance and its benefits for both natural and human communities (The Permanent Okavango River Basin Water Commission 2011).

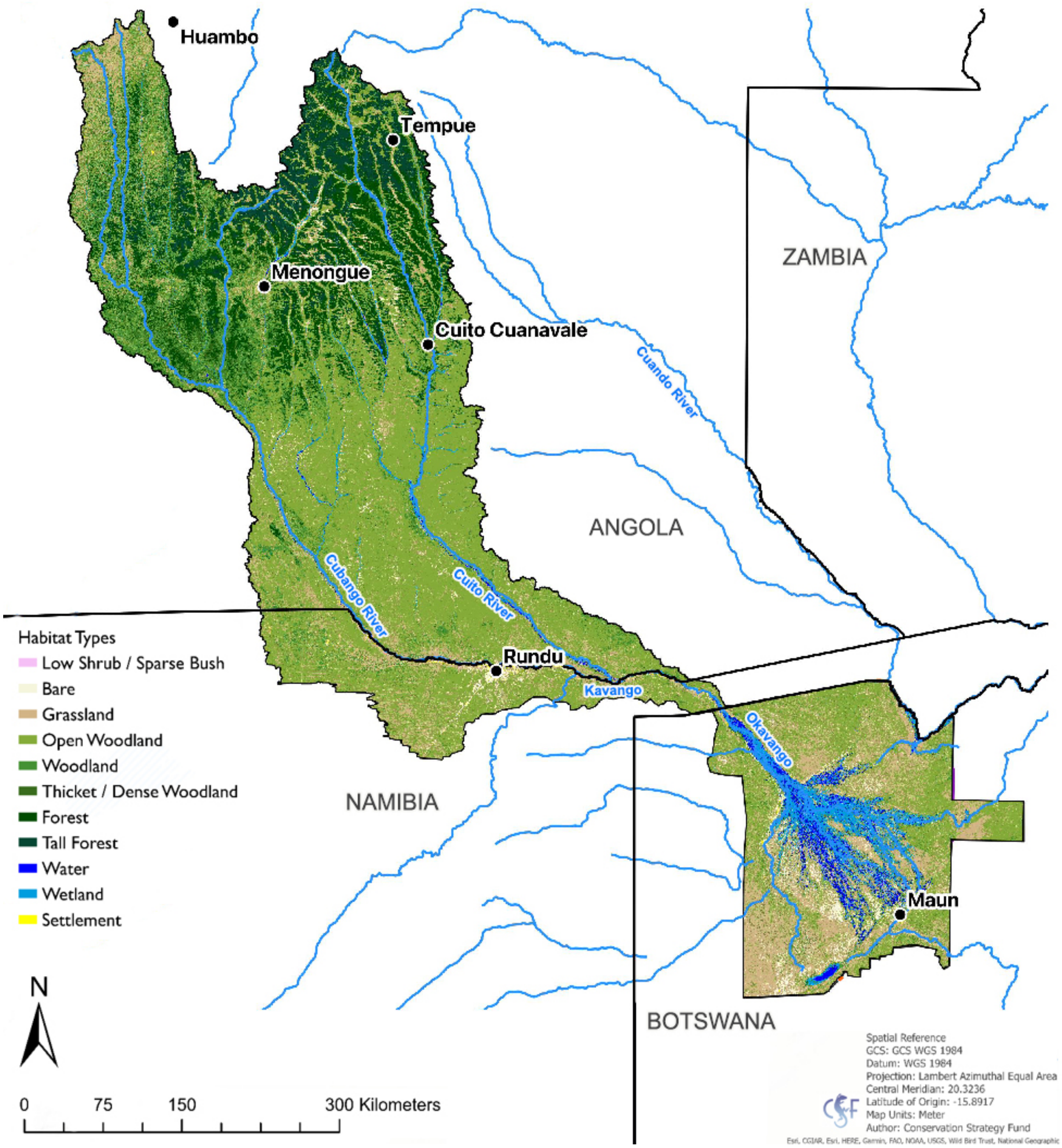

Figure 1. Habitat Types of the Study Area

Figure 1 above outlines the study area consisting of the Cubango-Okavango River Basin across Angola and Namibia and the Okavango Delta Ramsar Site in Botswana with associated habitat types (Habitat map source: Collins et al 2019).

The CORB is well-conserved compared to other river basins; however, it faces significant threats as highlighted in (Turpie et al. 2021). According to the authors, there is a growing pressure on the basin's water resources due to water infrastructure initiatives in Angola, loss of natural vegetation cover in Angola and Namibia, and unsustainable exploitation of groundwater reserves in Namibia and Botswana. The biodiversity and overall ecological integrity are also threatened by activities such as oil and gas exploration, tourism development, and mining. In the case of Angola, the presence of landmines poses additional risks to local communities and conservation efforts.

1.2 Motivation for Study

To address these growing environmental threats most effectively, it is important to monetarily quantify the benefits derived from the ecosystem services provided by the CORB and integrate that value into planning and development decisions across the region. By assigning economic value to the Basin, stakeholders can make more informed decisions regarding sustainable development, conservation efforts, and can negotiate more effectively for funding to protect the basin's ecosystems for future generations.

Conducting a valuation study of the economic services provided by the CORB is crucial for several decision-making purposes. First, it raises awareness of the economic significance of the CORB's ecosystem services to humans and other animals, allowing decision-makers to incorporate this information alongside traditional financial data. Second, the results of this study will facilitate the comparison between traditional (non-sustainable) management and conservation-infused management alternatives in terms of their costs and benefits to each country. Quantifying the benefits provided by the CORB will provide the information needed to choose and develop the most effective financial mechanisms to sustain the high economic value of this region.

Extensive studies have been conducted on the economic valuation of the ecosystem services provided by the CORB. Among the services studied are biomass provisioning (products obtained from the ecosystem such as food), recreational activities (such as ecotourism), water purification, water supply, wild animal and plant biomass, and wood provisioning. While most studies are country-specific (e.g., Turpie et al., (2006), Mopelwa et al., (2006), Turpie, J. (2010)), some explore transboundary economic valuation of the basin's ecosystem services (e.g., Turpie et al., (1999), Aylward (2009), Xialin and Ernst-August, (2021)). Further information on these studies is available in the Literature Review section. Building on the existing literature, this study updates and expands upon the findings of Turpie et al., (2006), while also providing a transboundary economic valuation of the ecosystem services provided by the CORB.

1.3 Objectives

Following the proposal framework, to better understand and capture the economic value provided by the CORB, the objectives of this study are:

1. To build "the economic case for conservation," emphasising the importance of investing funds in the protection of the CORB.
2. To explore the potential for developing financial mechanisms that can enhance funding towards local communities.

The results of this study will:

I. Identify several ecosystem services across the CORB and provide input to develop a long-term plan and conservation policy for the basin.
II. Re-evaluate ecosystem services and fill the gaps in previous valuation studies of the basin.
III. Provide up-to-date information about the economic value of the basin to policymakers and other stakeholders to conserve the basin's resources.
IV. Present economic rationale for conserving the basin, emphasising environmental and social factors, as well as maximising resource use efficiency.

1.4 Limitations

It is important to note that the research used in this study was conducted through a desktop literature review, limited by budget constraints, precluding primary data collection. Consequently, our results relied on existing published studies, data, and updated government census figures. Our priority was to assess the value derived from the direct consumptive use of resources. Estimates of other types of value were based on secondary information. There is a need for additional, more detailed studies to compile recent data and to further investigate the assumptions made using existing data.

2. Study Area and Macroeconomic Context

2.1 Macroeconomic Country Status

Angola has the largest population and economy of the three basin countries with a total GDP of 677 billion USD which is four times greater than the economy of Botswana and six times that of the Namibian economy (Table 2). The Angolan economy is predominantly industrial, contributing about 44 percent of the total GDP, while agriculture, forestry, and fishing account for about 8 percent. The industrial sector in Angola is primarily focused on the extraction and refinement of crude oil and natural gas, which accounts for roughly one third of the country's GDP. However, despite having the largest economy, living standards in Angola are much lower than in Botswana and Namibia. The Gross National Income (GNI) per capita in Angola is about 6,000 USD per year, which is 2.5 times lower than that of Botswana and 1.6 times lower than Namibia.

Botswana has the second-largest economy among the CORB countries, dominated by the export of goods and services, which account for about 44 percent of its total GDP. The GNI per capita of Botswana is approximately 15,000 USD, mainly attributed to its smaller population size and relatively higher GDP, resulting in a higher standard of living for people in Botswana compared to those in Angola and Namibia. The industry sector contributes around 30 percent to Botswana's total GDP, while agriculture, forestry, and fishing account for nearly 2 percent of the GDP in 2021. The tourism sector contributed about 1.4 percent to Botswana's GDP in 2021.

Namibia's economy is the smallest one among the three basin countries. The industry sector contributed approximately 25% to the total GDP in 2021, while agriculture, forestry, and fishing contributed about 10%. The remaining percentage is contributed by the service sector. The GNI per capita of the country is about 10,000 USD per year, which is higher than that of Angola but lower than that of Botswana.

Table 2. Macroeconomic Indicators of Angola, Botswana, and Namibia

Indicator	Angola	Botswana	Namibia	Year
Total population (million)	34.5	2.6	2.5	2021
Population growth (%)	3.1	1.6	1.6	2021
Surface area (million sq. km)	1.2	0.5	0.8	2020
Life expectancy (Year)	61.6	61.1	59.3	2021
GNI per capita, PPP (current US $)	5,980	15,420	9,850	2021
Forest area (million sq. km)	0.66	0.15	0.1	2020
Annual freshwater withdrawals, total (% of internal resources)	0.47	9.18	4.6	2020
CO2 emissions (metric tons per capita)	0.78	2.9	1.7	2019
GDP (billion US$)	67.4	17.6	12.3	2021
GDP growth (annual %)	1.1	11.4	2.7	2021
Inflation, GDP deflator (annual %)	33.6	2.5	1.7	2021
Agriculture, forestry, and fishing, value added (% of GDP)	7.9	1.7	9.5	2021
Industry (including construction), value added (% of GDP)	44.1	29.7	25.3	2021
Exports of goods and services (% of GDP)	44.3	44.6	31.7	2021
Imports of goods and services (% of GDP)	16.2	49.9	47.9	2021
Tax revenue (% of GDP)	10.1	23.7	28.3	2021

Source: World Development Indicators (The World Bank).

2.2 Geographic Boundaries of Study Area

The study area is split into two parts: the Okavango Delta RAMSAR site in Botswana, and the CORB part in Angola and Namibia. The Okavango Delta RAMSAR site area in Botswana spans 55,620 km^2 (or 5,562,000 ha), while the CORB located in Angola (green polygon in below Figure 2) covers an area of 150,405 km^2 (or 15,405,000 ha and the CORB in Namibia (orange polygon) covers an area of 21,787km^2 (or 2,178,700 ha).

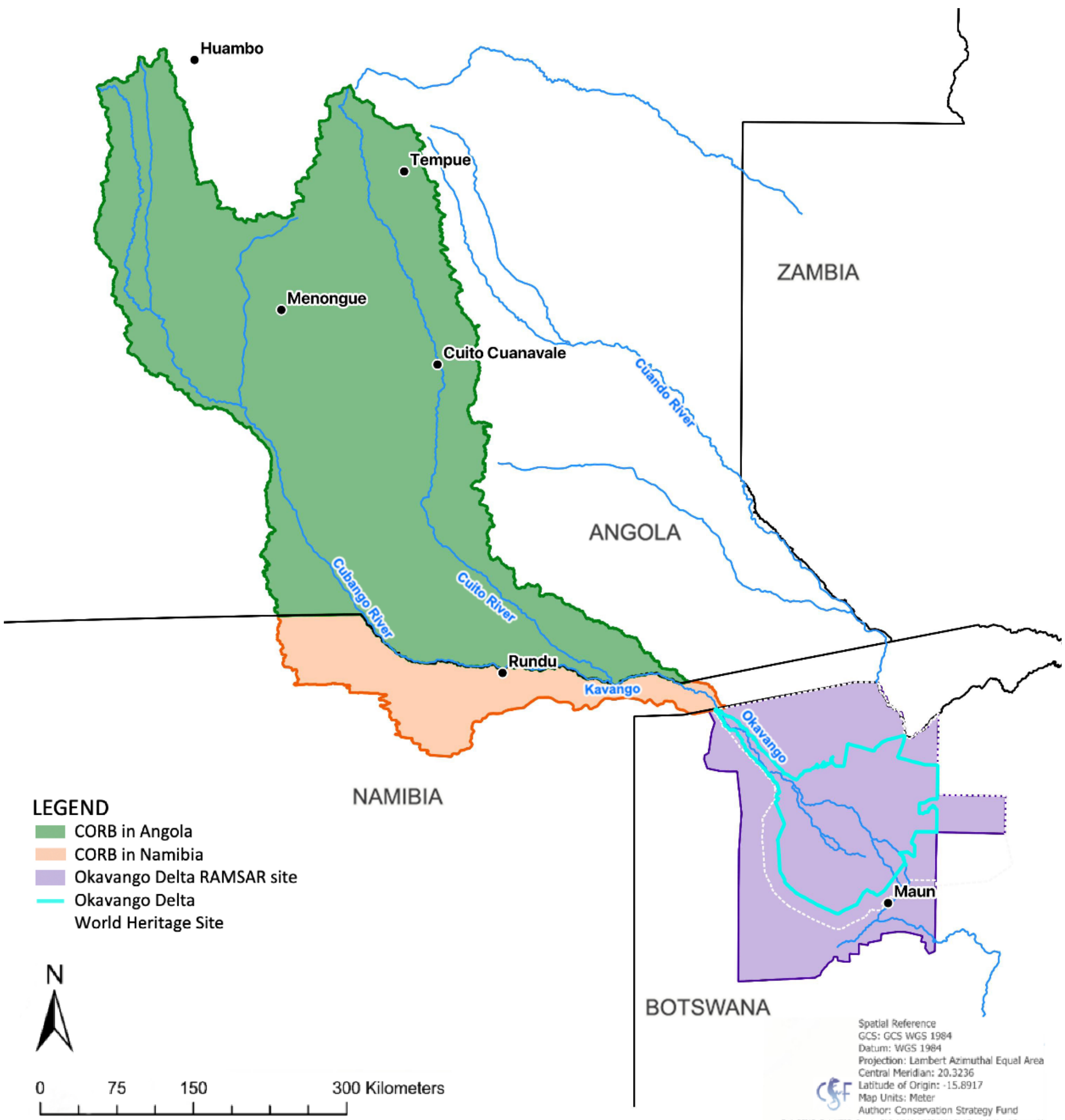

Figure 2. Map showing the Study Area across Angola, Namibia, and Botswana

The study area outlined in Figure 2 consists of the boundary of Cubango-Okavango River Basin (CORB) in Angola and Namibia as well as the Okavango Delta RAMSAR site and the Okavango Delta World Heritage Site.

The Okavango Delta is the biggest inland delta in the world and holds 95 percent of the surface water in Botswana. Waters forming the Okavango River originate in the highlands of Angola, flow southwards, across the Namibian Caprivi-Strip, and eventually spread into the terminal wetlands on Botswana's territory covering the alluvial fan (Milzow et al. 2009).

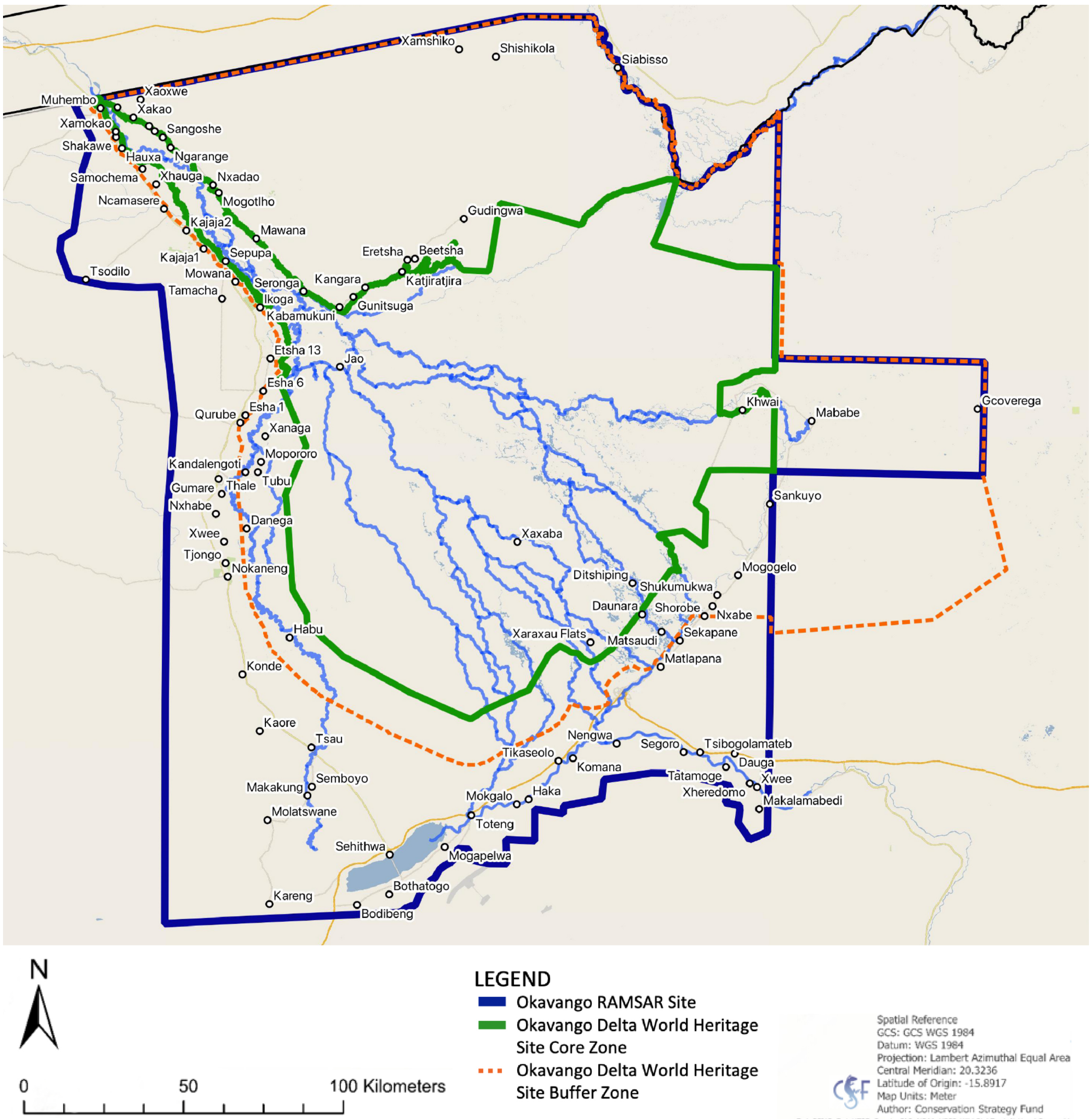

Figure 3. Boundaries of the study area in Botswana consisting of the Okavango Delta RAMSAR site with the Okavango Delta World Heritage Site and its buffer zone indicated.

For Botswana we utilised the Okavango Delta RAMSAR site, which is the same study area outlined in Turpie et al., (2006) so that we could extrapolate with recent population data. We used 2022 population data available at the subdistrict level—Ngamiland West and East, which aligns with the 5 zones defined by Turpie et al., (2006) as in the below adapted map.

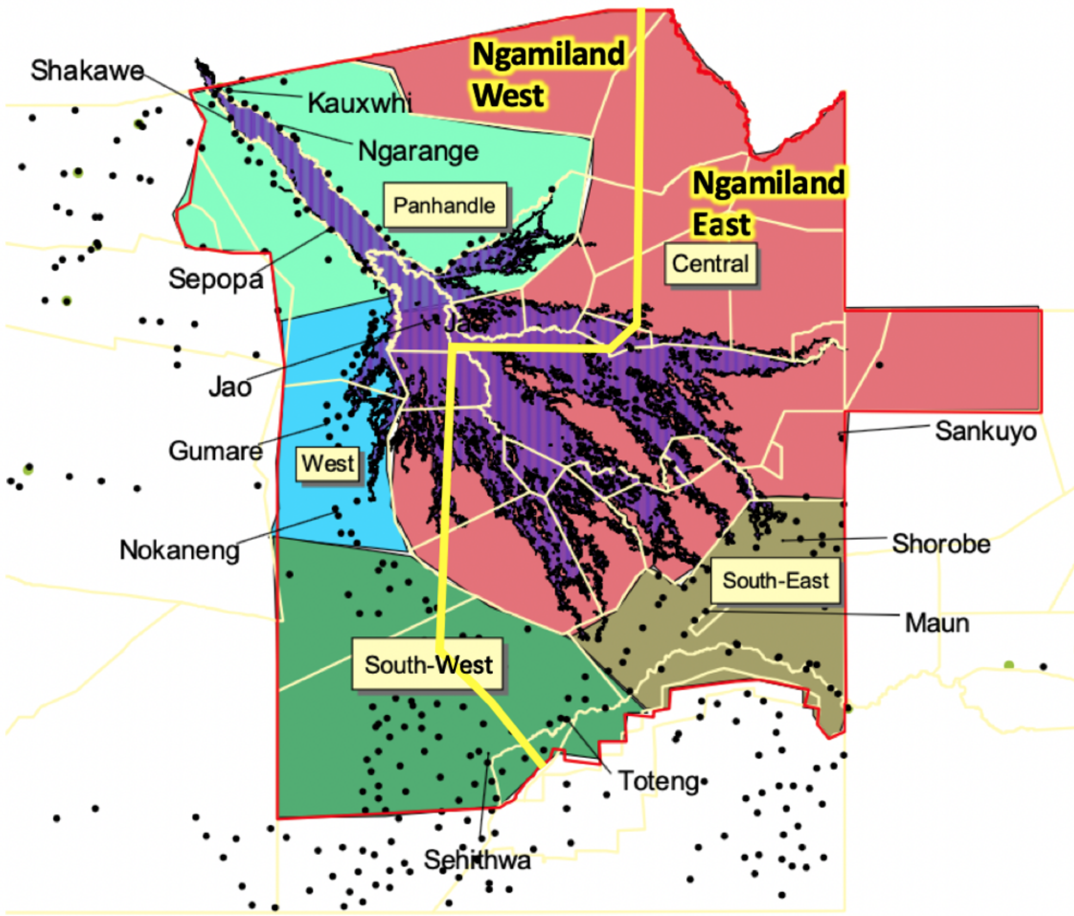

Figure 4. Ngamiland West and East within Turpie et al.'s (2006) five-zone classification

Source: Adapted from Turpie et al. (2006)

Based on Figure 4 above, we note that Ngamiland West comprises the Panhandle and West zones, much of the South-West zone, and a minor portion of the Central zone. Conversely, Ngamiland East encompasses the entire South-East zone, most of the Central zone, and a segment of the South-West zone.

3. Literature Review and Ecosystem Services Selection

3.1 Background

This study began with a review of literature on the economic valuation of the ecosystem services provided by the CORB. The review entailed conducting thorough research using a variety of resources, including Google Scholar, reference lists, Perplexity AI, hand-searching publications (such as the Scopus index), and interviews with relevant experts. In total, CSF reviewed 53 studies, including peer-reviewed articles and reports. Among the studies reviewed, we used Turpie et al., (2006) as a primary reference.

Our research revealed many gaps in data on the CORB, and a disproportionate number of studies conducted in each of the countries. As seen in, Figure 5, out of the 53 studies included in our review, 21 (or almost 40%) were conducted in Botswana, 2 in Angola and Namibia, and only 5 were transboundary studies including Angola, Namibia, and Botswana. We observed a significantly higher number of studies valuing the Okavango Delta in Botswana compared to the number of studies valuing the Angolan and Namibian regions of the CORB. Of the studies reviewed, 21% were conducted in countries outside of the CORB, while the rest were in Eastern Africa (Kenya, Tanzania, and Uganda). While the studies from Eastern Africa could not be wholly relevant to the CORB, our team incorporated economic information from their valuation analyses of the specific ecosystems also present in our study area, such as wetlands and grasslands.

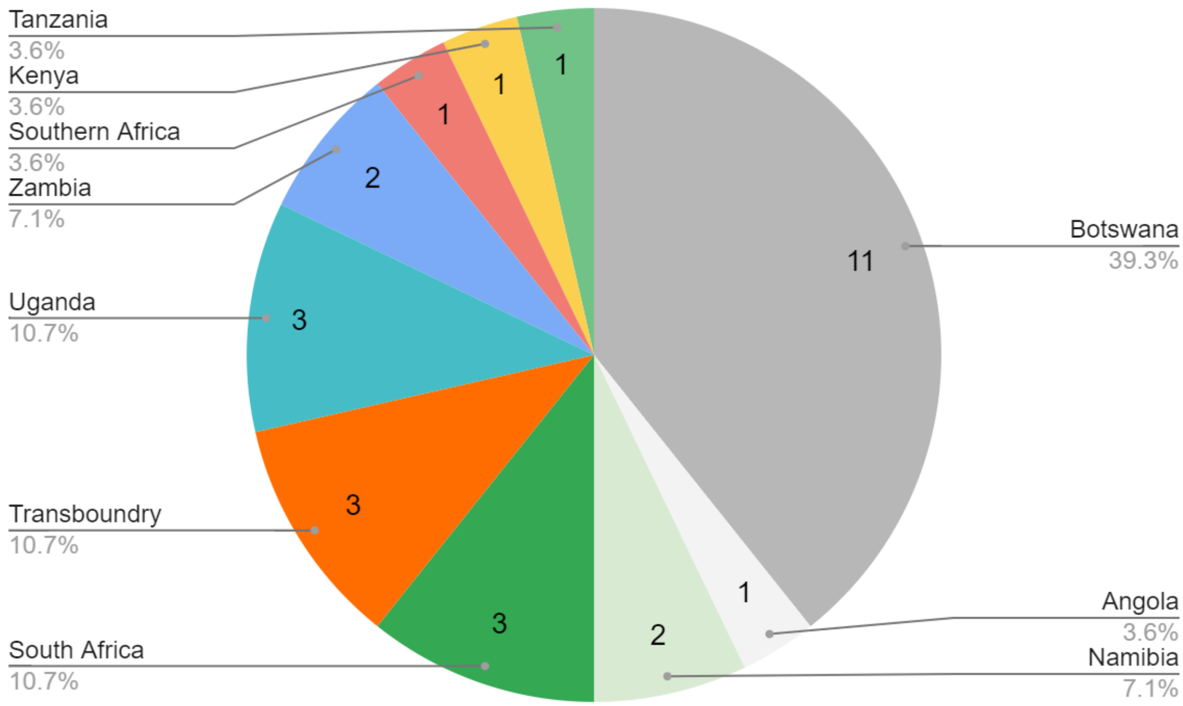

Figure 5. Number of Ecosystem Service Studies by Country included in Literature Review

The studies selected for this literature review predominantly featured data on food provisioning and water purification ecosystem services. Various studies also valued recreational activities, wood provisioning services, fish and other aquatic products provisioning services, water supply and recharge, wild animal and meat provisioning services, and climate regulation services. Most studies emphasise the provisioning services provided by the ecosystems, however, cultural services and non-use values[1] are also subjects of study in this literature.

Throughout this literature review, we found the most data on the ecosystem services of wood and food provisioning, water purification, and the least on the carbon sequestration services provided by the CORB.

[1] Non-use values refer to existence and bequest values.

Table 3. Ecosystem Service Types Valued in Selected Studies

Type of Ecosystem service	Number of Studies
Crop provisioning	3
Wild fish and Others	4
Wild Animals and Plants (Food provision)	10
Recreation Related	8
Water purification	3
Water Supply	2
Wood provisioning	3
Carbon Sequestration	1

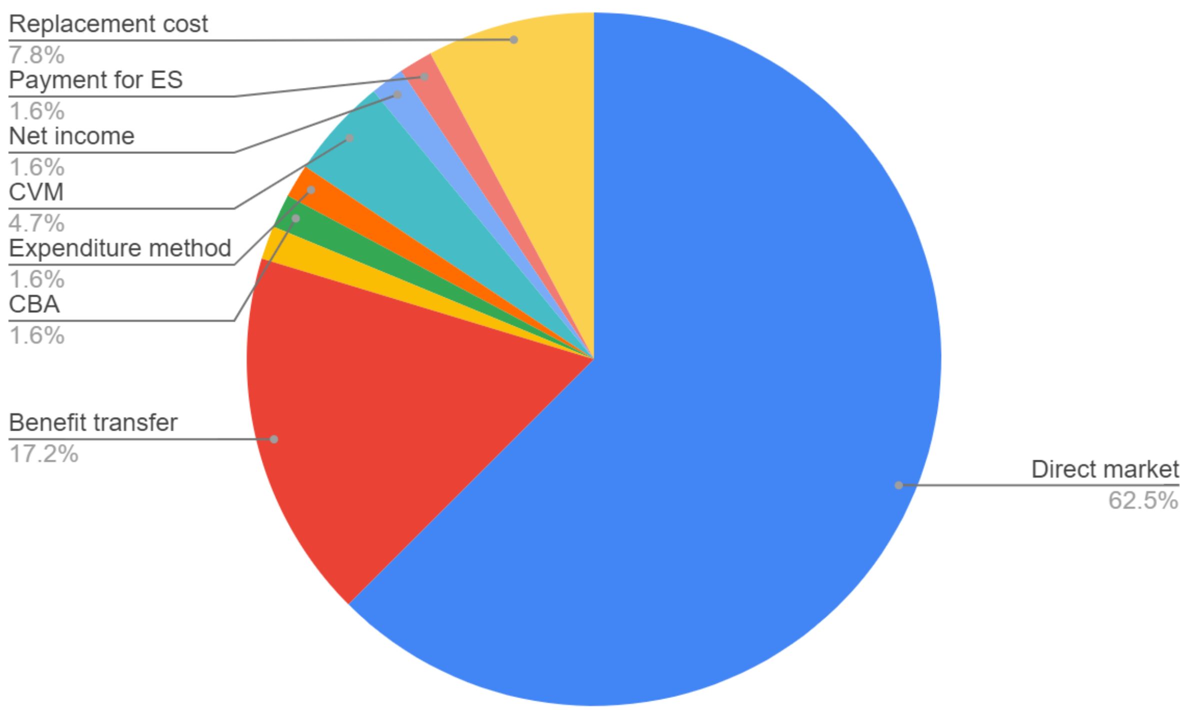

Figure 6. Valuation Studies by Analytical Methodology

About 63% of the studies in our literature review use *direct market* methods to value ecosystem services and about 17% used the *benefit transfer* valuation method. Each valuation method has its own advantages and limitations and while one may work best for a certain type of ecosystem service, another ecosystem service may require a different method. Categorization of ecosystem services is a precondition for any attempt to measure, map, or value ecosystem services and to communicate the findings transparently (Groot et al., 2017) (Figure 4).

Hippopotamus in the Kavango River in Namibia | Photo by Thomas ER, Shutterstock

Table 4. Economic Values Estimated from Literature Review

Ecosystem service	Value per hectare per year (2023 USD)			Reference(s)
	Mean	Min	Max	
Crop provisioning services	313	167	475	Adekola et al., (2008); Kgathi et al., (2005); Seyam et al., (2001)
Climate regulation	6			Turpie et al., (2006)
Education, scientific and research values	52	0.9	154	Seyam et al., (2001); Schuijt (2002); Turpie et al., (2006)
Genetic material services	0.12	0.02	0.26	Seyam et al., (2001); Turpie (2003)
Grazed provisioning services	236			Barrow & Mogaka (2007)
Livestock provisioning services	21			Seyam et al., (2001)
Recreation-related activities	339	0.3	2,314	Barnes (2006); Mmopelwa & Blignaut (2006); Seyam et al., (2001); Schuijt (2002); Turpie et al., (2006)
Water purification	1,037	0.09	3,110	Schuijt (2002); Turpie et al., (1999); Turpie et al., (2006)
Water supply	23	0.46	45	Karanja et al., (2001); Turpie et al., (2006)
Wild animals and other biomass provisioning services	869	1	8,425	Adekola et al., (2008); Barnes (2006); Kgathi et al., (2005); Mmopelwa et al., (2009); Schuijt (2002);
Wild fish, and other aquatic products	44	3	119	Adekola et al., (2008); Schuijt (2002); Seyam et al., (2001);
Wood provisioning services	21	0.6	60	Adekola et al., (2008); Mmopelwa et al., (2009);

Table 4 summarises the economic values obtained from the literature review for this study. The values were initially adjusted to inflation to reflect 2023 prices and, subsequently, converted to US dollars to ensure consistency and facilitate comparison across studies. Among the ecosystem services valued, water purification services have one of the highest average values at US$ 1,037 per hectare per year, with a significant range from US$ 0.09 to US$ 3,110 (Schuijt, 2002; Turpie et al., 1999; Turpie et al., 2006). It is worth mentioning that these values are highly sensitive to the approach and data used to generate them.

Wild animals and other biomass provisioning services have a high estimated value of US$ 833 per hectare, ranging from US$ 1 to US$ 8,425 (Adekola et al., 2008; Barnes, 2006; Kgathi et al., 2005; Mmopelwa et al., 2009; Schuijt, 2002). This range can be explained by the type of ecosystem subservice being valued (e.g., river reeds, thatching grass, palm leaves, wild fruits, etc.). On the lower end, genetic material services have an average value of US$ 0.12 per hectare, with a range from US$ 0.02 to US$ 0.26 (Seyam et al., 2001; Turpie, 2003). This may be attributed to the challenges involved in valuing this ecosystem service.

3.2 Demographic and Socioeconomic Characteristics

3.2.1 The Population of the Cubango-Okavango River Basin in Botswana, Angola, and Namibia

Botswana

According to Statistics Botswana (2022), the Okavango Delta, comprising Ngamiland East (including the Delta) and Ngamiland West, recorded a total population of 196,574 in 2022. Comparing this figure to data from Turpie et al., (2006), which reported a total population of 106,756 in 2001, reveals a growth of 46 %. Specifically, Ngamiland East (55.5%), including the Southeast, and Central zones, while Ngamiland West experienced a relatively smaller increase of 29% growth in two decades.

Please Note: The number of households was calculated by dividing the population data from Statistics Botswana (2022) by the average household size reported in Turpie et al., (2006). In Ngamiland East (Southeast and Central), the average household size is 7.8, while in Ngamiland West (Southwest, West, and Panhandle), it is 7.7.

Table 5. Population and number of households in the Botswana region of the study area

Name of district	2001[(a)]		2022	
	Number of households	Population	Number of households	Population[(b)]
Ngamiland East	6,614	54,972	15,781	123,603
Ngamiland West	6,813	51,784	9,523	73,122
Total	**13,427**	**106,756**	**25,304**	**196,574**

Source: (a) Turpie et al. (2006), (b) Statistics Botswana (2022).

Angola

To estimate the population in Angola, we followed a five-step procedure. First, we identified the provinces within the Angolan portion of the study area, then calculated the area of each province within the study area. Third, we collected population density data from the census (INE, 2016a-d) from a 2014 Census of Angola and used this to calculate the total population in the Angolan region of the study area. Fifth, using the average household size of 6.5 estimated by Turpie et al., (2021), we calculated the number of households (for detailed calculation see Table A.1 in Appendix A). Based on this procedure, we estimated a total population of 746,408 and a total of 114,832 households. In comparison, Turpie et al. (2021) reported a total population of 822,080 and 94,885 households based on OKACOM (2017).

Namibia

For Namibia, we employed a similar method. First, we confirmed that all constituencies in the Kuvango region fall within the study area. We then obtained the population size from the 2023 Namibia Population and Housing Census Release of Preliminary Results. To estimate the number of households, we used the average household size of 6.6, as determined by Turpie et al. (2021). By dividing the total population by this average household size, we calculated a total number of households of 52,074 in the Namibian portion of the study area (see Table A.2 in Appendix A). Using OKACOM (2017) as a reference, Turpie et al., (2021) reported a total population of 232,421 and calculated 21,129 households.

3.2.2 Household Energy Use

Botswana

In developing nations, cooking energy accounts for more than 90% of total household energy usage (GTZ, 2014). Table 6 summarizes the sources of fuel for cooking and heating in Ngamiland East and Ngamiland West of the Botswana districts. About 53% of the households in Ngamiland East used wood, another 27% used gas/liquid petroleum gas (LPG), and 18% used grid electricity for cooking. In the same district, wood is the dominant source of heating (83%), followed by gas/LPG, which is used by 15% of the households.

In Ngamiland West, 82% of the households used wood for cooking, followed by gas/LPG (11%) and grid electricity (6%) (Table 6). In the same district, wood remains the most dominant type of fuel for heating and maintaining the home temperature. The heating system in a home typically serves two functions: keeping the house warm in the colder months and heating up water for residential use.

Table 6. Percentage of Household Fuel use for Cooking and Heating in Botswana

Fuel type	Source fuel for cooking		Source fuel for heating	
	Ngamiland East	**Ngamiland West**	**Ngamiland East**	**Ngamiland West**
Wood	52.8	82	82.9	95.4
Gas/LPG	27.1	10.4	14.8	3.7
Electricity/grid	17.8	5.9	1.04	0.19
Biogas	1.3	0.7	0.33	0.16
Paraffin	0.1	0.4	1.9	0.14

Source: CSF analysis from the data provided by Statistics Botswana, 2011

Figure 7 below shows the sources of energy for lighting in Ngamiland East and West. While paraffin and candles were the main energy sources for lighting in Ngamiland West, grid electricity was the dominant energy source for lighting in Ngamiland East.

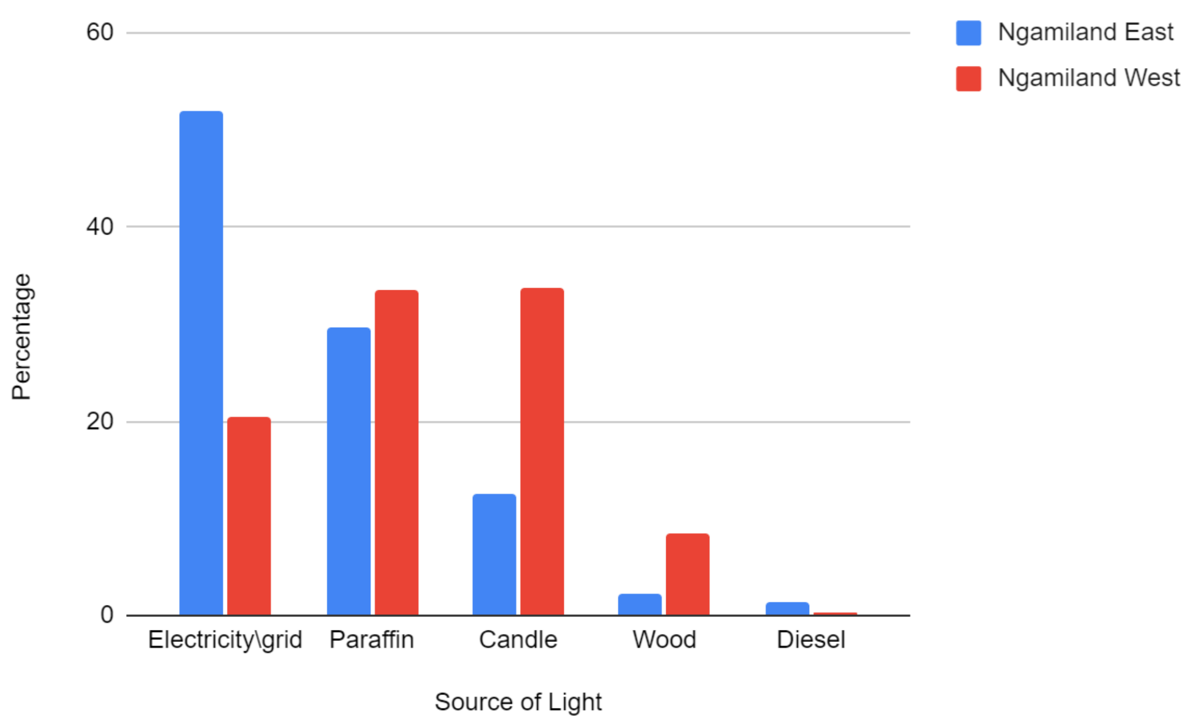

Figure 7. Fuel Types for Lighting in Ngamiland East and West

Source: Analysis from the data of Statistics Botswana, 2011

Angola

About 1.2 million people live along the CORB. Of these, 67% (about 800,000) live in the Angola part of the Basin (OKACOM, 2011). With rapid urbanisation and subsistence livelihood in rural areas, the upper catchment area of the Angola part is the most densely populated, centred at Menongue. The main source of cooking in the urban areas is charcoal, while the rural population uses firewood. The main water sources in Angola are rivers, streams, and wells (Turpie et al., 2021). The bulk of urban dwellers are employed in public services and informal trade, and they mostly reside in low-income, informal housing with little amenities. Angola, among the three Member States, faces the most difficult developmental problems, with poor economic growth in recent years and a low Human Development Index (HDI)[2].

Namibia

The Namibia part of the basin has an estimated total population of 230,000 which is about 19% of the total population of the basin (OKAM, 2019). About 60% of the population in the Namibia part of the Basin live in poverty. The Basin member states have mineral-based economies and are classed as upper-middle income.

3.3 The Climate of the CORB

3.3.1 Climate

The climate in the headwater region is subtropical and humid, with an annual precipitation of up to 1,300 mm, but it is semi-arid in Botswana, with precipitation amounting to only an average of 450 mm/year in the Delta area. Additional information about the climate of CORB is at Appendix A.3.

Botswana

The Okavango Delta is a sizable inland alluvial fan where, instead of flowing towards the ocean, the water of the Okavango River is mostly lost through evapotranspiration with a small portion contributing towards groundwater recharge. Nearly 11 cubic kilometres of water flow into the Delta each year. The water flows continuously into the Delta, and during summer (January- February), the rainfall drains from the Angolan highlands. Between March and June, Botswana experiences a surge of water that travels 1200 kilometres

[2] HDI measures a nation's longevity, education, and income and is widely accepted in development discourse (UNDP, 2019).

a month. It is during this time that the Okavango Delta is at its largest. Most of the water entering the Okavango Delta is lost through evapotranspiration rather than groundwater recharge, with evapotranspiration accounting for about 97% of the water loss compared to only 3% lost through groundwater recharge (Gumbricht et al., 2004 and McCarthy et al., 1998).

In terms of flood and associated vegetation, five zones have been defined in the literature on this region: perennial and seasonal swamps, seasonal grassland, intermittently flooded land, and dry land (Scudder et al. 1993). In addition, Ringrose et al. (1998) classified 12 ecological zones (six aquatic-based zones and another six land-based zones) after a contextual analysis of the regions. The area coverage of these zones changes during rainy and dry seasons.

Angola

Angola’s rich natural resources exhibit a vast and varied land-cover composition, dominated by extensive areas of tall forests covering approximately 1.1 million hectares. These forests are complemented by expansive open woodlands spanning 6.9 million hectares and woodlands covering 2.4 million hectares. Grasslands cover 1.5 million hectares, supporting diverse fauna and serving as vital grazing areas. Thickets and dense woodlands occupy 564,000 hectares, supporting Angola's ecological resilience. Water bodies and wetlands collectively cover approximately 307,000 hectares, essential for freshwater ecosystems and biodiversity conservation efforts. Settlements, although relatively small in comparison, occupy 13,687 hectares (Table 7).

Namibia

In contrast, Namibia's predominant land-cover types include almost 514,000 hectares of grasslands and 1.4 million hectares of open woodlands. Woodlands cover an additional 128,000 hectares, contributing significantly to Namibia's ecological diversity. Water bodies and wetlands collectively occupy 15,000 hectares, crucial for supporting local biodiversity and providing essential ecosystem services. Settlement areas account for almost 25,000 hectares (Table 7).

Table 7. Area of Habitat Types in Namibia and Angola

Country	Habitat type	Area (ha)
Botswana	Bare	7,114
	Forest	410
	Grassland	1,913,551
	Low Shrub / Sparse Brush	255,027
	Open Woodland	2,129
	Settlement	233,132
	Tall Forest	6,432
	Thicket / Dense Woodland	11,510
	Water	295,255
	Wetland	570,275
	Woodland	2,244,998
Namibia	Bare	68,436
	Forest	488
	Grassland	514,115
	Low Shrub / Sparse Brush	2,917
	Open Woodland	1,422,166

	Settlement	25,458
	Tall Forest	78
	Thicket / Dense Woodland	2,410
	Water	7,115
	Wetland	7,760
	Woodland	127,757
Angola	Bare	128,890
	Forest	1,947,294
	Grassland	1,542,743
	Low Shrub / Sparse Brush	18,623
	Open Woodland	6,949,703
	Settlement	13,687
	Tall Forest	1,141,498
	Thicket / Dense Woodland	563,996
	Water	57,615
	Wetland	249,627
	Woodland	2,426,864

3.4 Drainage

The Okavango River system includes the major tributaries Rio Cubango and Rio Cuito, rising in Angola's semi-arid highlands and into the Kavango River through Namibia's dry and semi-arid eastern regions and into Botswana, where it drains into the Okavango Delta. The Cubango-Okavango River Basin upstream of the Delta is approximately 165,470 km². The Cubango River Basin (108,000 km²) and the Cuito River Basin (57,470 km²), both located in Angola and joining the Okavango at 20°47'30"E 18°1'40"S, generate almost 95% of the streamflow entering the Delta (Steudel et al. 2013).

The entire catchment is underlain by sandy, highly permeable, and infertile soils (Mendelsohn & Martins, 2018). This sandy soil allows for rapid recharge and substantial retention of groundwater, contributing to the river's ability to sustain base flows throughout the dry season. In contrast, while peatlands have slow drainage and can retain some water due to organic matter accumulation, their water-holding capacity is comparatively smaller. Therefore, it is not 'despite' the sandy soil, but rather 'due to' its high permeability, that the Cuito River exhibits a flatter hydrograph and maintains water availability for extended periods.

The Cubango River has a drainage area with the soil being either derived from rocks - formed many million years ago - or the same sandy sediments (Mendelsohn & Martins, 2018). As a result of this formation, some of the soils are shallow and more compact, resulting in a faster response to rainfall, and more seasonal water flow towards the Okavango Delta.

3.5 Hydrology

The Okavango Delta is formed by two parallel faults that run perpendicular to each other and are underlain by deep Kalahari sands. It obtains practically all its water as a flood pulse (peaking in April/May) from its headwaters in the Angolan highlands, with a mean annual precipitation and potential evapotranspiration of 450 mm and 2,000 mm respectively (Steudel et al. 2013). Because of the virtually flat topography (slope ratio in metres of 1 in 3,500), the flood takes three to four months to traverse the Delta, around 250 km, arriving at the seasonal Thamalakane River, the Delta's major exit, in July/August. This occurs only when enough water flows into the Mohembo Delta, together with local precipitation and antecedent soil moisture in the Delta. Nearly 95 percent of the inflow water into the Delta is lost due to evaporation (Steudel et al. 2013).

The Cuito River in Angola is known for its wide valleys, meandering watercourses across deep Kalahari sands, and wet grasslands, peatlands, and oxbow wetlands (Conradie et al., 2016). An interesting characteristic of the Cuito River is the presence of springs that form lakes and the constant and consistent inflow from groundwater all along the river course. This groundwater is primarily stored in the phreatic unconfined aquifer formed by the Kalahari sands. Consequently, the Cuito River can maintain a constant flow, feeding all year round, first the Kavango River in Namibia and then the Okavango Delta in Botswana.

While the Cubango River is also partially supplied by springs, its characteristics differ from those of the Cuito River. Unlike the Cuito River, which maintains a constant and steady flow, the Cubango River is known for its rapid flow, a consequence of its relatively rocky terrain and steep gradient, which includes some waterfalls (Conradie et al., 2016). The Cuito River differs from the Cubango River in that it has vast sand aquifers that retain water and slowly release it throughout the year, providing a more consistent flow. In contrast, the Cubango River flows over rocky soils, contributing to the 'flood pulse' that is vital for the seasonal inundation and ecological functioning of the Okavango Delta. This difference in hydrology is critical for maintaining the Delta's diverse habitats and biological productivity (Mendelsohn & el Obeid, 2004) (McCarthy et al., 2000).

The Cubango River is also seasonally flooded and contributes about 55% of the water in the Okavango Delta (National Geographic 2017).[3] Additionally, the Cubango River crosses more developed areas when compared to the Cuito River, and, as a result, human impacts are greater in this catchment.

4. Ecosystem Services Selection

The CORB provides numerous ecosystem services that benefit local communities and have a global impact.[4] CSF used a four-step approach to identify and selection the eight ecosystem services included in this study. First, we identified the ecosystems present in the study area and the resources within each ecosystem. Next, we evaluated the potential human benefits arising from the use of these resources. Subsequently, we mapped these benefits to the ecosystem services classification outlined by the System

[3] This percentage might change from year to year.

[4] Ecosystem services are the benefits that humans derive directly and indirectly from natural ecosystems. These services are broadly categorised into four main types: (1) provisioning services, which are the products directly obtained from ecosystems; (2) regulating services, which are the benefits obtained through the regulation or control of natural processes; (3) cultural services, which are the non-material benefits people derive from ecosystems; and (4) supporting services, which are the services that maintain fundamental ecosystem functions and are necessary for the production of all other ecosystem services.

of Environmental-Economic Accounting (SEEA). Lastly, we conducted a comprehensive literature review to identify ecosystem services that had been previously studied and for which information on their monetary values was available. Based on this approach, the eight ecosystem services selected are:

- Crop provisioning services
- Livestock provisioning services
- Wood provisioning services
- Wild animals, plants, and other biomass provisioning services
- Wild fish and other aquatic product services
- Water supply
- Global climate regulation
- Recreation-related services

We note that these ecosystem services follow the System of Environmental-Economic Accounting (SEEA) classification.[5] Below, there is a description of each one of these services as presented in NCAVES and MAIA (2022).

4.1 Crop Provisioning Services

This ecosystem service encompasses the contributions of the ecosystem to the growth of cultivated plants used for food production, fodder, fibre, and energy generation. In the context of the CORB, the literature review reveals instances of agricultural activities such as maize cultivation, intended for both human consumption and livestock feed (Barnes 2002; Mmopelwa et al., 2009). Additionally, the local population uses plant fibres derived from the ecosystem to craft items like baskets and other artisanal products.

4.2 Livestock Provisioning Services

Livestock provisioning services denote the ecosystem's pivotal contribution to fostering the development of domesticated animals and facilitating the production of various livestock commodities, including meat, dairy, eggs, wool, and leather, which serve as essential resources for economic activities.

[5] The System of Environmental Economic Accounting is a framework created to establish a comparable framework for assessing the connections between the environment and economic and societal well-being. The SEEA Ecosystem Accounting was adopted in 2021 by the United Nations as an international statistical standard (United Nations et al., 2021).

4.3 Wood Provisioning Services

This ecosystem service includes the contribution of the ecosystem to the growth of cultivated or uncultivated trees that are used for timber production and energy generation. In the CORB, there are some references to firewood and charcoal harvested by the local communities (i.e., villages), especially in the Okavango delta.

4.4 Wild Animals, Plants and Other Biomass

This ecosystem service includes the contribution of the ecosystem to the growth of wild animals, plants and other biomass that are harvested under an uncultivated context. In the case of the study area, this would include wild animals harvested for food and wild bees, for example.

4.5 Wild Fish and Other Natural Aquatic Products

This ecosystem service includes the contribution of the ecosystem to the growth of wild fish and other natural aquatic products that are harvested under an uncultivated context by local communities. This use may vary but they are usually harvested for food production. Especially in the Okavango Delta there are some references to fish harvesting.

4.6 Water Supply

This ecosystem service includes the contribution of water flow regulation, water purification, and other ecosystem services to the supply of water that can be used for irrigation, household computation, and energy generation. The literature review suggests that local communities use the water, especially for irrigation and household consumption (e.g., drinking water).

4.7 Global Climate Regulation

This ecosystem service encompasses the contribution of the ecosystem to the regulation of greenhouse gas in the atmosphere, for example. It includes the contribution of the ecosystem to the retention of carbon and the ability of ecosystems to remove carbon from the atmosphere and store it, and to the contribution to the generation of greenhouse gases, such as methane from wetlands and carbon dioxide from wildfires.

4.8 Recreation-related Services

This ecosystem service includes the contribution of the biophysical characteristics and qualities of ecosystems that allow local and non-local people to use the environment. In the case of the CORB, there are a series of recreation-related activities such as recreational hunting, wildlife viewing, and photography tourism, for example.

4.9 Further Study: Medicine, Education & Biodiversity

In addition to the ecosystem services identified above, we note that three additional ecosystem services are mentioned in the literature but lack sufficient information to update their value. These services include: (1) medicinal resources, (2) knowledge and education services, and (3) existence and bequest values.[6] These additional ecosystem services were calculated in Turpie et al. (2006) and are presented in the Discussion section. However, we will not integrate their values into our total in this study due to the lack of data needed for extrapolations.

Furthermore, there is a gap in the natural capital valuation literature on how to account for the role that species (especially keystone species) have in contributing to the provision of ecosystem services. We consider that there is still some confusion between academic fields on how to value this contribution from an economic perspective. We address this in in Appendix A.4 with a methodological framework and provide a preliminary analysis in Appendix B to incorporate keystone species in ecosystem services assessments. The objective of this framework is to better inform wildlife management strategies and quantify the many benefits that wildlife provides to people and the rest of nature.

[6] These ecosystem services are defined as: medicinal resources include the contribution of the ecosystem to the provisioning of traditional medicines; education, scientific, and research services refers to the contribution of the ecosystem to education and research; ecosystem and species appreciation, existence, and bequest falls into the non-use value category. It concerns the well-being of people derived from the preservation and maintenance of the natural resources in their current (or improved) state for current and future generations.

5. Valuation of the Ecosystem Services of the Study Area (CORB)

5.1 Data Sourcing & Description

This section describes the socio-economic and ecological data used to value the eight ecosystem services selected for this valuation study. These data are secondary and were obtained from authoritative sources such as government institutions, peer-reviewed articles, and online literature. When possible, we prioritised data from government institutions that have been formally approved.

5.1.1 Crop provisioning services

The value of these ecosystem services is calculated by multiplying average crop yields by the area planted with each identified crop. Ideally, the biophysical indicator (crop yield) should be adjusted to account for management practices influencing crop yields, such as fertilizer use. This adjustment is necessary to exclude contributions not related to the ecosystem service (United Nations, 2022). However, the absence of detailed data in our dataset prevents such adjustments, potentially leading to an overestimation of the biophysical indicator. Nevertheless, we do not expect a significant bias due to the traditional and low-technology practices applied in the study area. As Turpie et al. (2021) noted, "crop production involves little tillage, and farmers do not use agrochemicals or fertilizers, with very little use of compost or manure." The exception might be in Botswana, where inputs are subsidized by the Government (Turpie et al., 2021). In this case, the values calculated for Botswana might indeed be overestimated.

Based on Turpie et al. (2006), during 2004 and 2005, the total area planted in Botswana was 14,477 hectares. This estimate was derived from a survey that calculated the proportion of households with dryland and molapo fields, as well as the average area planted per household. Assuming the proportion of households and the area planted per household have remained constant over the years, but adjusting for the number of households in 2022, we calculated that the total area planted is now 23,269 hectares, representing an increase of about 61%.[7] However, we acknowledge that various factors, such as weather patterns and farmer migration to cities, might have affected the total area planted. Statistics Botswana (2020) highlight, for example, great variation in the planted area in recent years (refer to Tables A.5 and A.6 in Appendix A for the complete time series).

[7] 17,080 ha of dryland areas and 6,189 ha of molapo fields.

For crop yields in Botswana, Turpie et al. (2006) calculated average yields per crop and per zone for each farming type. The crops considered were maize, millet, sorghum, groundnuts, and beans. Turpie et al. (2006) noted that the average yields reported were lower than in other studies due to a drought that year. Data on crop yields from Statistics Botswana (2020, 2021) (see Table A.7 in Appendix A) show an average crop yield for Ngamiland of 143 kg/ha. In this study, we used this yield to conduct the valuation.

In the case of Angola and Namibia, we used Turpie et al. (2021) as the reference for both crop yield and area planted. While the average yield is presented by crop for Angola, for Namibia, the yield is presented by farming type (upland fields and floodplain recession farms). In total, subsistence agriculture covers an area of 196,245 hectares in Angola, and 16,400 hectares in Namibia. Regarding monetary data, we adjusted the prices in Turpie et al. (2006) for Botswana to account for inflation. For Angola and Namibia, we adjusted the values in Turpie et al. (2021) for inflation.

5.1.2 Livestock provisioning services

To calculate the monetary value of livestock production, we multiply the number of animals (cattle, goats, and sheep) by their sale prices. Ideally, using livestock-related items such as meat and milk would be preferable, as recommended by the United Nations et al. (2021). However, to the best of our knowledge, there is no up-to-date data available on the amount of meat or milk produced in the CORB. Therefore, we followed a similar approach to Turpie et al. (2006) and Turpie et al. (2021). Information on the number of animals in the traditional sector is available for all three countries, as shown below in Table 8.

Cow crossing the river in the Okavango Delta in Botswana | Photo by Lucian Coman

Table 8. Livestock Inventory per Country

Country	Sublocation	Livestock	Number of animals	Year of reference	Source
Angola		Cattle	192,200	2008	Comissão Permanente das Águas da Bacia Hidrográfica do Rio Okavango (2011)
		Goats	66,327		
		Sheep	12,598		
Botswana	Ngamiland East	Cattle	304,976	Not defined	Turpie et al., (2021)
		Goats	116,628		
		Sheep	17,163		
Namibia	Kavango	Cattle	125,972	2008	Comissão Permanente das Águas da Bacia Hidrográfica do Rio Okavango (2011)
		Goats	44,135		
		Sheep	1,472		

Following Turpie et al., (2006), we calculated the number of large stock units (LSU). Using the conversion factor of six sheep/goats to one cow, we calculated a total of 666,201 LSU in the study area. This value is similar to Turpie et al. (2021) that calculates 627,235 LSU in the study area.

To incorporate the monetary data, we calculated the value per LSU based on Turpie et al. (2021) and adjusted it to 2022 prices, considering inflation in all three countries.

5.1.3 Wood provisioning services

The data for fuelwood provisioning of the Okavango Delta, in Botswana is taken from the National Energy use Survey (ministry of minerals and energy of Botswana, 2022/23). At district level, annual fuel consumption per household, total number of households, and percentage of households using fuelwood as main source of cooking was surveyed by the Ministry of Minerals and Energy of Botswana. Using the International system of units (SI) conversion (National Energy use survey, 2022), we use tons as a unit for wood used by households[8]. We also calculate the number of households using fuelwood as a primary source of cooking in each district based on the total number of households in each district and the proportion of households using fuelwood as a primary source of cooking. According to Botswana National Energy Use Survey 2022/2023, in 2022, 35% and 73% of the households in Ngamiland East and Ngamiland West, respectively, were using fuelwood as their main cooking fuel.

For Angola and Namibia, we use data from Turpie et al., (2021). For Angola, fuelwood and charcoal use are merged and reflected as a combined total fuel consumption. The report by Turpie et al., (2021) includes total population, household size and the annual growth rate population of the Angola and Namibia part of the Basin for the year 2020. In this case, the percentage of population using fuelwood and charcoal as a main source of cooking is not mentioned. To address this, we estimated the number of households using fuelwood by calculating the average percentage of the rural population in Angola (about 50%) and applying this figure to our analysis. For Namibia, we extrapolate the value of fuelwood reported in Turpie et al., (2021), considering inflation rate.

Table 9. Annual Fuelwood Consumption for Cooking in Botswana, Angola, and Namibia

Country	District/Area	Fuelwood consumption per household per year (tons)	Number of households using fuelwood as the main cooking fuel	Total amount of fuelwood used (tons) in 2022
Angola	Angola[(a)]	6.9	62,845	**433,629**
Botswana	Ngamiland East[(b)]	4.6	5,444	**25,041**
	Ngamiland West[(b)] Botswana	2.0	6,971	**14,011**
Namibia	Namibia	N\A		**N\A**

Source: (a) Turpie et al., (2021); (b) National energy use survey 2022/2023,

Resources like timber, poles and withies are also harvested from forest, woodland and savanna habitats of Angola and Botswana mainly for construction purposes (e.g., fences, dugout canoes, and houses). The Botswana part of the Basin utilises 4,983 m^3 amount of timber, poles, and withies per year, while Angola part of the Basin uses about 96,615 m^3 of timber, poles, and withies annually (Table 10).

[8] We convert the annual fuelwood use consumption per household into Kilograms (1 Kg of fuelwood = 0.0000149TJ).

Table 10. Annual Estimated Amount of Timber, Poles and Withies Harvested

Country	**Estimated use (m3/year)**	Year
Angola	96,614	2021
Botswana	4,982	
Namibia	N/A	

Source: Turpie & Letley (2021)

Regarding monetary data, we calculated the annual fuelwood expenditure per household by dividing the annual value estimated in Turpie et al., (2006) by the total number of households in the study area for Okavango Delta. Then we multiply this by the number of households in 2022 to get the annual value of fuelwood in Okavango Delta. For Angola and Namibia, we divided the annual value estimated by Turpie et al., (2021) by the reported amount of fuel consumption of the same study. These values were adjusted to account for in-country inflation from 2021 to 2022.

5.1.4 Wild animals, plants, and other biomass provisioning services

The biophysical indicator for this ecosystem service is the level of wild animals harvested for subsistence purposes. Regrettably, we faced challenges in acquiring recent and authoritative data for all three countries under consideration. Furthermore, the ambiguity surrounding the definition of subsistence hunting, as highlighted by Rogan et al. (2015), adds complexity to our understanding. The report suggests that subsistence hunting, whilst contributing positively to household income, does not necessarily imply the consumption of bushmeat by that household but it can imply the sale of bushmeat to consumers. This lack of clarity complicates the definition of illegal hunting as well and poses challenges to conservation policy (Rogan et al., 2017).

To overcome this situation, we use the data from Turpie et al., (2006). Based on surveys, we estimate the total catch of wild animals per household per year in the Okavango Delta region. The data corresponds to the year 2005. It is worth mentioning that Turpie et al., (2006) estimated that between 36 to 61% of households engage in hunting and that most hunted animals are small animals such as hares, spring hares, porcupines, and small antelope. Table 11 shows the authors' findings.

Table 11. Wild Animals Hunted/Harvested per Household per Year in the Study Area

Zone	Percent of Households Engaged in Hunting	Wild Animal Catch (kg/household-year)
North of the Okavango Delta	36%	73
West of the Okavango Delta	49%	6
Southwest of the Okavango Delta	43%	3
Southeast of the Okavango Delta	42%	0.6
Average[(a)]	42.5%	20.7

Source: Turpie et al. (2006). The original table contains the percentage of households in the central part of the Okavango Delta that engage in hunting (61%). However, no information on the catch of wild animals is available. Note: [(a)]Own calculation.

Using the average values presented in Table 11, we update the total catch in Botswana and extrapolate the average values to Angola and Namibia, using the number of households in the study areas in 2022. As detailed in a previous section, the number of households is 25,301 in Botswana, 124,546 in Angola, and 52,074 in Namibia. In Angola, we assume that only households in rural areas participate in hunting activities, reducing the number of participating households to approximately 62,845. In Namibia, most households consume beef instead of wild meat, meaning that rural households in Namibia do not benefit from this ecosystem service. Under the simplified assumption that 42.5% of the households participate in hunting activities, we derive an updated total of 10,753 and 26,709 households in Botswana and Angola, respectively, engaged in this activity. The direction of the bias resulting from this assumption is challenging due to the lack of specific data.

To obtain the biophysical indicator, we multiply the number of households by the average catch (Table 21). Through this calculation, we estimate that households in the study area harvest approximately 245 tons and 608 tons of wild meat annually in Botswana and Angola, respectively. Notably, the calculated value for Botswana is about two times larger than that determined by Turpie et al. (2006). This increase can be attributed to the doubling of the population and households since 2006. We estimated 25,301 households in the Botswana study area extrapolating the Turpie et al., (2006) estimate of 13,427 households in the Okavango Delta in 2001 based on population size increase over the 21-year period between census figures.

Regarding monetary data, information on the market price of wildlife meat was unavailable for all three countries, including similar market prices. In the case of Ngamiland in Botswana, additional details were available on wildlife licences and quotas, which could potentially aid in valuation (Wildlife Conservation and National Parks Act - Chapter 38:01). However, it is important to note that the distribution of these licences and quotas is tightly regulated by the government, resulting in a highly controlled market. Consequently, prices of licences and quotas may not accurately reflect the value of wild animals as meat. The SEEA framework suggests that in the absence of a regulated market (i.e., a secondary market of licences and quotas not subject to government oversight), market prices of these quotas and licences could serve as references (United Nations et al., 2021).

Given these challenges, we have chosen to utilise the Benefit Transfer Method. We have adopted values presented in Turpie et al., (2006) for all three countries. According to the authors, the price of wild meat also known as 'bushmeat', was approximately BWP 4 per kilogram (2005 prices), equivalent to BWP 11.06 per kilogram at the beginning of 2022.[9]

5.1.5 Wild fish and other aquatic product services

For this ecosystem service, the biophysical indicator revolves around the annual quantity of wild fish (i.e., uncultivated fish) harvested within the designated study area. Fishing stands out as a crucial livelihood activity for subsistence fishers, as highlighted by Mosepele et al. (2006). Despite its significance, however, there is a scarcity of data regarding the catch.

In the context of the Okavango Delta, Mosepele et al., (2022) managed to gather annual fish catch data through secondary sources, as detailed in Table 12, which summarises their findings. The observed variations in the data can be attributed to two factors: first, to "the presence of different actors in the Delta's fishery" (Turpie et al., 2006), and second to the "inter-annual variability in flooding patterns" (Mosepele et al., 2017).

[9] WorldData.info, retrieved on 2/22/2024.

Table 12. Annual Fish Catch from the CORB

Year	Catch (tons per year)
2000	152
2001	111
2001	385
2002	114
2003	92
2005	1,850
2006	450
2019	614

Source: Mosepele et al., 2022

In this study, we use the fish catch of 614 tons of fish per year presented in Mosepele et al. (2022) and Mosepele (2019). The data is based on the Catch Assessment Survey of traditional and artisanal fisheries conducted by the Fisheries Division. Information was available for both the Delta Panhandle and for other parts of the Delta.

In the context of Namibia, Morais (2009) estimates that, on the Namibian side of the Cubango River basin, a total of 840 tons of fish are harvested each year, according to Skelton (2001), a secondary source used as a reference by the author.

In Angola, data on artisanal fishing is available from an authoritative source for 2018 and 2019 (Ministério da Agricultura e Pescas 2020). According to the report, the total amount of fish caught in the Cuando-Cubango province in 2018 and 2019 was 1,121 tons and 320 tons, respectively. To avoid capturing outlier years, we consider the average of 721 tons per year.

The three main limitations regarding this data set consist of:

- The inter-annual variability due to the changes in the flood pattern, particularly in the case of Botswana.
- The lack of updated data in Namibia
- The assumption that the traditional and artisanal fishery aligns with the subsistence fishery. While the studies mentioned above partially support this assumption by indicating that the majority of caught fish are consumed, a fraction may be sold by fishermen to augment household income. Consequently, there is a possibility of overestimating the biophysical indicator in such cases.

In our valuation assessment, we employed the benefit transfer method, using a monetary value of BWP 20 per kilogram of wild fish caught (2014 prices), as reported in Statistics Botswana (2015), which we extrapolated to Namibia and Angola. While SEEA guidelines recommend using a market price, such as a tradeable quota, to access wild fish resources, we encountered challenges in implementing this approach. Specifically, we were unable to identify the existence of fishing quotas nor secondary markets of fishing quotas in any of the three countries under study.

In the case of Botswana, the acquisition of fishing resources involves obtaining recreational or commercial fishing licences. A commercial fishing licence, priced at BWP 200 for three consecutive seasons (annually from March to December), is required. However, information regarding the quantity harvested during each season is not available. Moreover, it is important to note that local communities also engage in subsistence fishing for their livelihoods, for which no direct fee is charged.

As a result of these limitations, we proceeded with the benefit transfer method, recognizing that the use of this method is associated with a large margin of error. Previous research has indicated that benefit transfer errors can range from 0% to 172%, with a mean of 42% and a median of 33% (Kaul et al. 2013).

5.1.6 Water supply

There is no comprehensive record of water abstraction and use of the water from the CORB. For this study we use data from FAO report, Cubango-Okavango River Basin (CORB) audit report, and Botswana annual agricultural survey report. We consider water use for commercial irrigation, livestock watering, and multiple use. Most livestock kept around the villages of Okavango Delta rely on natural water sources and about 65% of households with cattle at posts rely on boreholes for water supply (Turpie et al. 2006).

Table 13. Number of Holdings by Reliable Water Sources for Livestock Watering

District name	Borehole	Well	River	Year
Ngamiland East	1,039	251	625	2019
Ngamiland West	365	937	2,130	2019

Source: Annual agricultural survey report - Botswana, 2019

Livestock Watering

Livestock watering is the second largest water consuming sector of the Basin. The amount of water demand for livestock drinking differs from among the Basin countries and animal types. For example, the daily water demand for cattle in Namibia is greater than for cattle in Angola and Botswana (Table 14). As seen below, the daily water demand for cattle is far greater than the demand for goats and sheep.

Table 14. Water Consumption for Livestock Watering

Country	District	Livestock type	Number of animals	Water consumption per animal per day (Litres)	Total water consumption per year (Million m3)
Botswana	Ngamiland East	Cattle	65,041	50	1.19
		Sheep	9,346	5	0.02
		Goat	47,546	5	0.09
	Total				**1.29**
	Ngamiland West	Cattle	49,853	50	0.91
		Sheep	1,020	5	0.00
		Goat	28,687	5	0.05
	Total				**0.96**
Angola	CORB	Cattle	179,743	60	3.94
		Sheep	10,090	12	0.04
		Goat	87,850	12	0.38
Total					**4.37**
Namibia	CORB	Cattle	125,972	67.5	3.10
		Sheep	1,472	15	0.01
		Goat	44,175	15	0.24
	Total				**3.35**

Source: Cubango-Okavango River Basin Water Audit Report, (FAO 2014).

Note: To calculate annual water consumption, we multiplied the number of animals (as detailed in the Livestock Provision Service section) by the average water consumption per animal per day, and then multiplied the result by 365.

Irrigation Water Use

Irrigation is the largest water consuming sector along the Basin (FAO 2014). Based on the estimated amount of water demand for irrigation in 2010 by (FAO 2014), and the average annual increase in water demand for irrigation, the estimated annual water demand for irrigation for Angola, Botswana, and Namibia in 2022 is summarised in the table below (Table 15). Namibia has the highest water demand for irrigation (129.5 million m3) compared to those of Angola and Botswana in 2022.

Table 15. Estimated Water Demand for Irrigation for Angola, Botswana, and Namibia

Country	Annual estimated water consumption (Mm3) in 2010	Average annual increase in Water demand for irrigation (Mm3)	Annual estimated water consumption (Million m3) in 2022
Angola	34.8	-1.7	14.4
Botswana	0.62	0.05	1.22
Namibia	43.1	7.2	129.5

Source: Cubango-Okavango River Basin Water Audit Report, (FAO 2014).

Water Use for Tourism

Botswana and Namibia have considerable tourism facilities outside communities, which must extract and supply their own water supplies (FAO 2014). The annual water demand for tourism along the basin countries for the year 2022 is summarised in the table below (Table 16). Namibia had the largest estimated water demand for tourism (3.38 million m3) of the three basin countries in 2022.

Table 16. Average Annual Water Demand Growth and Total Water Demand for Tourism in Angola, Botswana & Namibia (2022)

Country	Annual estimated water consumption (Million m3) in 2010	Average annual increase in Water demand for Tourism (Million m3)	Annual estimated water consumption (Million m3) in 2022
Angola	0	0	0
Botswana	0.3	0.023	0.58
Namibia	2.5	0.073	3.38

Source: Cubango-Okavango River Basin Water Audit Report, (FAO 2014).

5.1.7 Global Climate Regulation

According to the SEEA framework, global climate regulation services can be considered a single service consisting of two components: carbon retention (above and belowground carbon storage and soil organic carbon) and carbon sequestration (United Nations 2022). The biophysical units consist of tons of carbon per hectare and tons of CO2e per hectare per year, respectively.

In addition to calculating these two services, we also follow the SEEA framework in this section of the study and calculate carbon retention and carbon sequestration per habitat type (described in Section IV). The main reason for conducting the analysis by habitat type is an interest in potentially developing some financial mechanism associated with carbon. A limitation of this section is the lack of a high-resolution peatland land cover dataset and accompanying carbon storage and sequestration data as well as the fact that the carbon estimates are from global studies and not based on site-specific data for the basin. While Lourenco et. al (2022) have contributed a map of peatland extent in the Angolan Highlands, the authors note that further research is necessary to understand the carbon storage and sequestration. Other studies have shown that peatlands are one of the largest and most important carbon stores on the planet, so future studies should attempt to fully account for peatlands in the study area (Limpens et al., 2008; Dargie et al., 2017).

In this study, we use two distinct sources for assessing carbon retention data. Specifically, for below and aboveground biomass carbon, we rely on data sourced from the United Nations Environmental Programme World Conservation Monitoring Centre (Soto-Navarro et al., 2020). This dataset is referent to the year 2010 and has a resolution of 300 metres. Our methodology involves computing the average carbon per hectare for each habitat type by dividing the total carbon content by the habitat's size. The outcomes of this calculation are detailed in Table 17. Notably, for Botswana, we calculate an average of carbon retention encompassing both the dry and wet seasons (refer to the Appendix A.8 for the breakdown of the data).

Table 17. Carbon Retention per Hectare (above and below ground)

Country	Habitat type	Area represented in study area (ha)	Tons of carbon	Average tons of carbon per hectare
Angola	Bare	128,890	1,844,416	14.31
	Forest	1,947,294	100,616,681	51.67
	Grassland	1,542,743	22,308,064	14.46
	Low Shrub / Sparse Brush	18,623	310,259	16.66
	Open Woodland	6,949,703	154,213,910	22.19
	Tall Forest	1,141,498	77,690,354	68.06
	Thicket / Dense Woodland	563,996	18,036,592	31.98
	Water	57,615	848,669	14.73
	Wetland	249,627	5,017,503	20.10
	Woodland	2,426,864	67,952,192	28.00
Botswana	Bare	7,114	79,463	11.17
	Forest	410	11,304	27.57
	Grassland	1,913,551	23,173,103	12.11
	Low Shrub / Sparse Brush	255,027	2,598,725	10.19
	Open Woodland	2,129	31,509	14.80
	Tall Forest	6,432	230,587	35.85
	Thicket / Dense Woodland	11,510	255,292	22.18
	Water	295,255	4,541,022	15.38
	Wetland	570,275	11,736,260	20.58
	Woodland	2,244,998	2,689,812	1.20
Namibia	Bare	68,436	513,270	7.50

	Forest	488	15,577	31.92
	Grassland	514,115	5,665,547	11.02
	Low Shrub / Sparse Brush	2,917	36,433	12.49
	Open Woodland	1,422,166	24,631,915	17.32
	Tall Forest	78	3,029	38.83
	Thicket / Dense Woodland	2,410	61,310	25.44
	Water	7,115	171,898	24.16
	Wetland	7,760	163,891	21.12
	Woodland	127,757	2,644,570	20.70

Source: CSF calculation based on Soto-Navarro et al., (2020).

For soil organic carbon, we rely on data from Innovative Solutions for Decision Agriculture Ltd (iSDA), which employs machine learning to predict various soil properties, including the amount of carbon stored in the soil, using more than 130,000 soil samples from the African continent (Miller et al., 2021). The data is provided at a 30-metre resolution and covers two soil depths: 0 to 20 cm and 20 to 50 cm. Since our focus is on determining the total amount of carbon stored in the soil, we aggregate the carbon amounts (in tons) from both layers and then divide the result by the total area to obtain the average amount of carbon per hectare. Table 18 illustrates the results.

Table 18. Carbon Retention: soil organic carbon

Country	Habitat type	Tons of carbon (0-20 cm)	Tons of carbon (20-50 cm)	Average tons of carbon per hectare (0-50 cm)
Angola	Bare	3,737,810	1,844,416	29
	Forest	62,313,408	100,616,681	32
	Grassland	50,910,519	22,308,064	33
	Low Shrub / Sparse Brush	800,789	310,259	43
	Open Woodland	208,491,090	154,213,910	30
	Tall Forest	38,810,932	77,690,354	34
	Thicket / Dense Woodland	18,611,868	18,036,592	33
	Water	2,592,675	848,669	45
	Wetland	10,733,961	5,017,503	43
	Woodland	80,086,512	67,952,192	33
Botswana	Bare	156,508	79,463	22
	Forest	13,530	11,304	33
	Grassland	47,838,775	23,173,103	26
	Low Shrub / Sparse Brush	9,691,026	2,598,725	38
	Open Woodland	51,096	31,509	24
	Tall Forest	263,712	230,587	41
	Thicket / Dense Woodland	391,340	255,292	34
	Water	12,695,965	4,541,022	43
	Wetland	22,811,000	11,736,260	41
	Woodland	60,614,946	43,957,061	27
Namibia	Bare	1,642,464	513,270	24
	Forest	15,616	15,577	32
	Grassland	13,366,990	5,665,547	26
	Low Shrub / Sparse Brush	75,842	36,433	26
	Open Woodland	35,554,150	24,631,915	25
	Tall Forest	2,964	3,029	38
	Thicket / Dense Woodland	77,120	61,310	32
	Water	263,255	171,898	37
	Wetland	271,600	163,891	35
	Woodland	3,577,196	2,644,570	28

Note: The amount of soil organic carbon in Botswana during the wet and dry season is presented in *Appendix A.9*.

In the case of carbon sequestration, we use Harris et al. (2021). The authors map forest-related carbon emissions worldwide, combining ground data with satellite imagery from 2001 to 2019. The resulting data has a moderate spatial resolution of 30 metres. The main data limitation, however, is the focus on forests. As a result of this, habitat type representation is low in most non-forest habitat types (Table 19). Thus, caution is advised when interpreting this data. Additionally, it is worth mentioning that, as before, in the case of Botswana, the amount of carbon sequestered was also calculated considering the dry and wet seasons. However, for the calculation, we opted for using the average. Thus, for more details on the amount of carbon sequestered in both seasons, refer to Appendix A.10. In the cases of Namibia and Angola, no seasonality was considered.

Seasonal floodplains and islands of the Okavango Delta in Botswana | Photo by Vadim Petrakov, Shutterstock

Table 19. Carbon Sequestration per Habitat Type

Country	Habitat type	Data coverage	Tons of CO2e/ha-year
Angola	Bare	1.00%	-1.17
	Forest	89.91%	-1.82
	Grassland	5.74%	6.98
	Low Shrub / Sparse Brush	1.66%	0.87
	Open Woodland	7.98%	-0.34
	Tall Forest	98.21%	-1.92
	Thicket / Dense Woodland	45.53%	-0.38
	Water	7.96%	-1.22
	Wetland	9.43%	-0.5
	Woodland	39.24%	-0.86
Botswana	Bare	0.04%	-3.3
	Forest	13.10%	-3.54
	Grassland	0.27%	-3.12
	Low Shrub / Sparse Brush	0.09%	-3.22
	Open Woodland	0.12%	-3
	Tall Forest	47.96%	-3.58
	Thicket / Dense Woodland	4.22%	-3.55
	Water	0.67%	-3.7
	Wetland	1.86%	-3.71
	Woodland	1.53%	-3.5
Namibia	Bare	0.01%	-0.65
	Forest	23.29%	-3.38
	Grassland	0.03%	0.62
	Low Shrub / Sparse Brush	0.09%	-3.81
	Open Woodland	0.18%	-2.46
	Tall Forest	37.94%	-3.48
	Thicket / Dense Woodland	6.96%	-3.47
	Water	0.84%	-3.67
	Wetland	1.29%	-3.48
	Woodland	1.45%	-2.97

Source: CSF calculation based on Harris et al. (2021).

Note: The positive sign indicates that the habitat type is a source of CO_2, while the negative sign indicates that the habitat type is a sink.

Based on Table 19, most habitat types are CO_2e removers (i.e., active sequesters). The exceptions would be the grassland habitat type in Namibia and Angola and the low shrub / sparse brush habitat in Angola. Further research is needed to better understand the reasons why grassland and low shrub habitats are net emitters, as well as the impact of seasonality on these estimates. The data indicates that the grassland habitat in Namibia emits 0.62 tons of CO2e per hectare per year, while in Angola, the emission is higher at 6.98 tons of CO2 per hectare per year. Despite the higher representation in Angola compared to Namibia, both emissions are relatively low. Therefore, caution is advised in interpreting these findings.

In terms of limitations, we highlight four:

- The use of global satellite data instead of site-specific data.
- The estimation of carbon and CO_2, excluding gases such as methane from the analysis.
- Peatlands are considered an important carbon sink but are underrepresented in this data.
- The lack of reliable non-forest data in the case of carbon sequestration.

In terms of monetary data, we gathered information from various sources. When it comes to assessing carbon stock, it is common for valuation studies to reference the market price of carbon since it is a tradable commodity. However, to our knowledge, such markets are not operational in any of the three countries considered in this study. We acknowledge the emergence of a voluntary market in Africa, led by the Africa Carbon Markets Initiative, but it is still being developed. Additionally, there is a carbon tax in South Africa, which could potentially serve as a proxy for a market price. However, because it is a government policy subject to policy pressures, we opted not to use it. Ultimately, we chose to utilise the Marginal Abatement Cost from the IPCC (M. Pathak 2022). This figure reflects the "cost of an intervention that reduces greenhouse gas emissions by one tonne" (World Bank 2023). Under a scenario that limits warming to 2 Celsius degree, the Marginal Abatement Cost was estimated to be US$ 90 per tCO_2 (2015 prices)--or US$ 419 per tC O_2 (2022 prices)---with a low of US$ 60 per tCO_2 and a high of US$ 120 per tCO_2.

For carbon sequestration analysis, we employ the Social Cost of Carbon (SCC), which refers to the economic damage caused by each additional ton of CO_2 emitted into the atmosphere. Specifically, we use the country-specific SCC, referred to as CSCC, as calculated by Ricke et al. (2018). According to the authors, "the CSCC represents the marginal damage (or benefit, if negative) expected in an individual country due to additional CO_2 emissions." Table 20 presents the values derived from this study, along with additional costs, providing readers with insight into the variability associated with SCC.

Table 20. Social Cost of Carbon

Country	Average SCC	Unit	Year of reference	Source(s)
Angola	5.5	1 to 10 US$/t$CO_2$	2018	Ricke et al., (2018)
Botswana	0.5	0 to 1 US$/t$CO_2$		
Namibia	0.5	0 to 1 US$/t$CO_2$		
Global estimate	100	US$/t$CO_2$	2018	Rogelj et al., (2018)
Global estimate	185	US$/tonne$CO_2$	2020	Rennert et al., (2022)
Global estimate	24.02	US$/tC	2019	Tol (2019)
Africa	1.03	US$/t$CO_2$	2010	Nordhaus (2017)
United States	120-340	US$/tonne$CO_2$	2020	EPA (2022)

5.1.8 Tourism-related services

Angola's tourism in the CORB is limited, primarily due to the aftermath of the Angola Civil War. However, the basin's biodiversity and wilderness make it a potential tourist destination. In contrast, Namibia has established attractions along the Kavango River, where a variety of lodges and communal campsites are located (Turpie et al. 2021). While the Okavango Delta in Botswana remains the primary destination for tourists, tourism services began in the late 1970s. The Delta, a distinctive feature of Botswana, is now home to an estimated 85 commercial tourism lodges, offering a diverse range of activities that vary depending on lodge location, size, and degree of service (Magole & Gojamang 2005, Turpie et al. 2006, Turpie et al. 2021).

Despite the developed tourism sector in Namibia and Botswana, there is a lack of reliable and up-to-date data, we used the value estimates from Turpie et al., (2021) adjusted to inflation. The authors first calculated a total attraction-based tourism value for all three countries and then spatially allocated these values proportionally to photo density, considering the natural areas within the CORB. By following this approach, Turpie et al., (2021) were able to estimate the total nature-based tourism value.

5.2 Valuation Methodology

What is the "value" of an ecosystem service?

The value of an ecosystem service encompasses the benefits humans derive from natural ecosystems, measured in economic, social, and ecological terms. This value reflects the importance of services like clean water, air purification, climate regulation, and recreational opportunities. Unlike market prices, which are determined by supply and demand dynamics for goods and services traded in markets, the value of an ecosystem service includes both market and non-market benefits. Thus, while market prices capture some aspects of an ecosystem's worth, they often miss the broader, non-market values that contribute to human well-being and ecological health.

In this report, we employed the Total Economic Valuation (TEV) framework to assess the economic value of the ecosystem services. This framework comprises two types of values: non-use values and use values (Figure 8). While **non-use values** are primarily known as existence values and bequest values, **use values** are linked to both the direct and indirect use of the ecosystem. The latter being further categorised into direct and indirect use values. **Direct use values** relate to the direct benefits people gain from the ecosystem. In this case, the consumption of ecosystem services typically reduces the availability of these services. Examples of direct use values include harvesting food products like wild animals and plants, aquatic resources, and timber for purposes like firewood production. **Indirect use values** pertain to the indirect benefits derived from the ecosystem, such as those associated with cultural services and recreational activities like ecotourism. Importantly, in the case of indirect use values, the consumption of ecosystem services does not deplete these services for current and future generations.

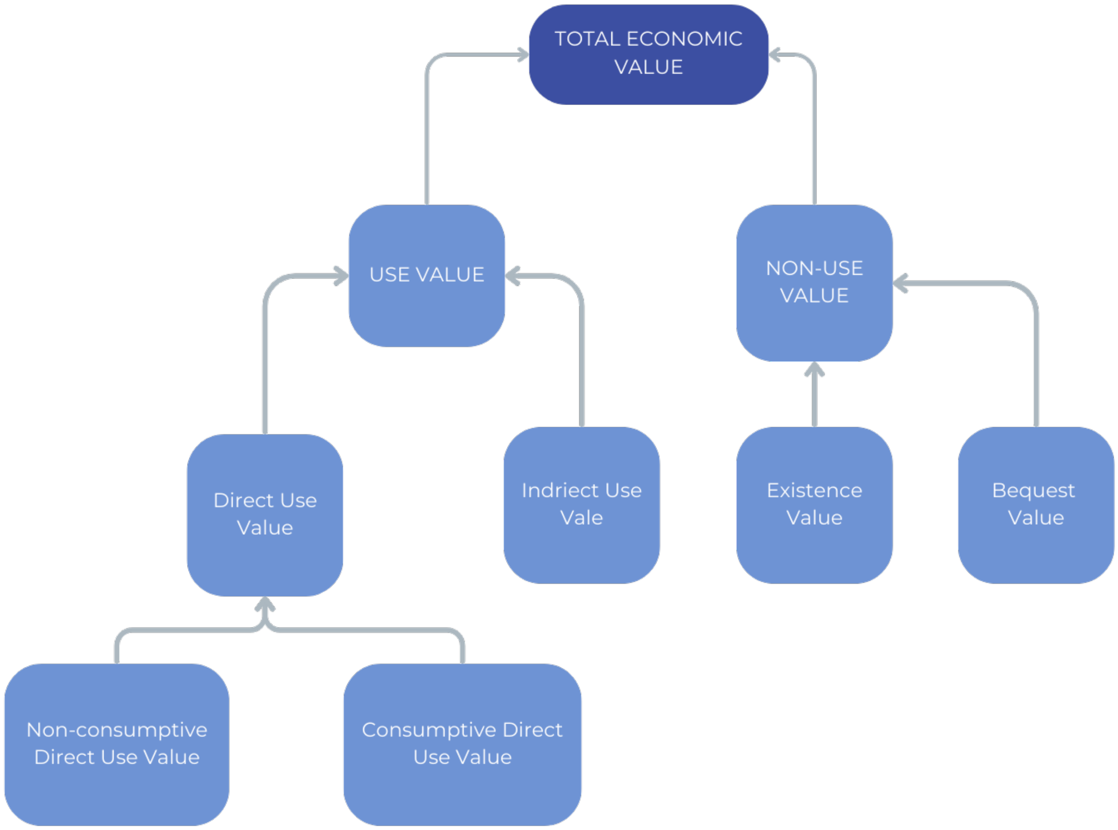

Figure 8. Total Economic Value

In the context of this study, we focused the economic valuation on use values. TEV is primarily focused on evaluating changes in consumer welfare, typically analysed using the concept of consumer surplus. This surplus denotes the extra benefit that consumers obtain from an environmental good or service beyond what they pay for it. However, a significant challenge arises in assessing TEV for many environmental goods and services because their cost is often zero, and consumers' willingness to pay is frequently unknown.

In this context, techniques for valuing environmental goods and services are typically categorised into three main approaches: (a) direct market valuation, (b) revealed preference methods, and (c) stated preference methods (Pascual et al., 2012). In addition to these approaches, we also consider the benefit transfer method (Brander 2019).

5.2.1 Direct market valuation

This approach is often employed when the environmental good or service is tradable or when a comparable product is tradable. It is particularly suitable for valuing provisioning services, such as crop and livestock provisioning services. The direct market valuation method relies on data from real markets, including prices and costs. This method can be further categorised into three subtypes: (a) market price-based valuation, (b) cost-based valuation, and (c) production function-based valuation (Table 34).

Table 21. Direct Market Valuation Approach

Approach	Description
Market price-based	In well-functioning markets preferences and marginal cost of production are reflected in a market price, which implies that these can be taken as accurate information on the value of commodities. The price of a commodity times the marginal product of the ecosystem service is an indicator of the value of the service, consequently, market prices can also be good indicators of the value of the ecosystem service that is being studied.
Cost-based valuation	Estimations of the costs that would be incurred if ecosystem service benefits needed to be recreated through artificial means. Different techniques exist, including, (a) the avoided cost method, which relates to the costs that would have been incurred in the absence of ecosystem services, (b) replacement cost method, which estimates the costs incurred by replacing ecosystem services with artificial technologies, and (c) mitigation or restoration cost method, which refers to the cost of mitigating the effects caused by to the loss of ecosystem services or the cost of getting those services restored.
Production function-based	Estimations of how much a given ecosystem service contributes to the delivery of another service or commodity which is traded on an existing market. This approach generally consists of the following two-step procedure. The first step is to determine the physical effects of changes in a biological resource or ecosystem service on an economic activity. In the second step, the impact of these changes is valued in terms of the corresponding change in marketed output of the traded activity.

Source: Pascual et al., 2012.

5.2.2 Revealed Preference Method

Under the revealed preference method, the estimation of the value of an ecosystem service is based on observable choices and behaviours of individuals. The revealed preference method analyses actual consumer behaviour to infer preferences and values. The key principle behind the revealed preference method is that individuals reveal their preferences through the choices they make. Two common applications of this method are the (a) travel cost method, and (b) hedonic pricing method (Pascual et al., 2012). While the former estimates the value of recreational sites such as parks based on the costs incurred by individuals to visit these sites, the latter estimates the value of environmental amenities (such as clean air or scenic views) based on the prices of goods or properties that incorporate these amenities.

5.2.3 Stated Preference Method

Unlike the revealed preference method, the stated preference method relies on surveys or experimental methods to directly elicit individuals' preferences and willingness to pay for environmental attributes. Under this approach, participants are presented with hypothetical scenarios or choices and asked to express their preferences or willingness to pay for different environmental attributes or outcomes. Two common techniques within the stated preference method are (a) contingent valuation, and (b) choice experiments. Contingent valuation involves asking participants about their willingness to pay (or willingness to accept compensation) for changes in environmental quality or the provision of specific environmental services. On the other hand, choice experiments involve presenting participants with a series of hypothetical choices between different bundles of environmental attributes or policy options. By analysing participants' choices across different scenarios, researchers can infer their preferences and estimate the value they place on specific environmental attributes or outcomes. It is worth mentioning that the stated preference method is the only one capable of estimating non-use values.

5.2.4 Benefit Transfer Method

Benefit transfer involves adapting benefit estimates from one context to another, aiming to provide insights into the economic value of ecosystem services in different areas. The accuracy of benefit transfers depends on the quality and relevance of the initial study used for estimation. The benefit transfer method is usually used when there are important time and financial resources limitations (King & Mazzotta 2000).

Under the scope of this study, we prioritised the direct market approach whenever possible. However, depending on the data available, a simple benefit transfer method was used instead. Table 22 synthesises the methodologies used to calculate the monetary value of each one of the ecosystem services identified here.

Table 22. Valuation Method by Ecosystem Type

Ecosystem service	Method
Crop provisioning services	Market approach
Livestock provisioning services	Market approach
Wood provisioning services	Market approach
Wild animal and plants provisioning services	Benefit transfer method
Wild fish provisioning services	Benefit transfer method
Water supply provisioning services	Market approach
Recreation-related services (photography and wildlife viewing tourism)	Market approach and Benefit transfer
Global climate regulation services (carbon sequestration)	Avoided damage cost approach (social cost of carbon)
Global climate regulation services (carbon storage)	Marginal abatement cost

5.2.5 Beneficiaries

It is worth mentioning that regardless of the specific method employed, an initial step involves identifying the beneficiaries of these services.[10] This identification is pivotal as it allows for the measurement of the economic benefits that ecosystem services generate for human wellbeing. Within this framework, Table 23 delineates the beneficiaries identified for each ecosystem service. It is noteworthy that these beneficiaries remain consistent across all three countries---Botswana, Namibia, and Angola.

[10]The beneficiaries were identified based on the literature review and no consultative or participatory framework was carried out.

Table 23. Ecosystem Services Beneficiaries

Ecosystem service	Beneficiaries
Crop provisioning services	Local households
Livestock provisioning services	Local households
Wood provisioning services	Local households
Wild animal and plants provisioning services	Local households
Wild fish provisioning services	Local households
Water supply provisioning services	Local households, and farmers (if different)
Recreation-related services	Tourists (non-local visitors)
Global climate regulation services	Local and global communities

6. Ecosystem Services Valuation

This section shows the results from the environmental valuation. The values presented in this report are expressed in US$, which standardizes purchasing power parity across countries for a more equitable comparison. When comparing our findings with other studies, such as Turpie et al., (2021), it is important to note that these studies often present their results in US dollars. Here we assume that the values in Turpie et al., (2021) can be directly comparable to our findings.

6.1 Crop provisioning services

Based on the data and methodology described in the previous section, we calculated the monetary value of crop provisioning services to be US$ 689 million (2022 prices). Table 24 shows the monetary values by country.

Table 24. Annual Value of Crop Provisioning Services (2022 US$)

Country	Annual value (US$ million)
Angola	618
Botswana	26
Namibia	45

The total value differs from Turpie et al., (2021)[11] by 29%. In the cases of Angola and Namibia, this difference is attributable to annual inflation rates of 25.75% and 3.62%, respectively, from 2021 to 2022. In Botswana, in addition to a price variation of 176% from 2005 to 2022, we calculated a 60% increase in the planted area over the same period.

6.2 Livestock provisioning service

Using the LSU and the value per LSU, we estimated an annual value for the CORB of approximately US$41 million (Table 25). This value is 11% higher than the one reported by Turpie et al., (2021), primarily due to inflation.

Table 25. Annual value of livestock provisioning services (2022 US$)

Country	Annual value (US$ million)
Angola	14.1
Botswana	19.1
Namibia	7.5

6.3 Wood provisioning

While woody resources in the Okavango Delta are used for fuel, building materials, fencing material, and wooden canoes (Turpie, et al. 2006), this section examines the consumption of firewood for cooking and its corresponding market value in Ngamiland East and Ngamiland West. This emphasis is driven by findings from Turpie et al., (2006), indicating the economic value of fuel wood in the Okavango Delta to be about five times greater than the economic value of wood for poles and timber. In addition to this finding, we also note that most households in the Okavango Delta harvest fuelwood mainly for cooking.

The share of households relying on fuelwood as their main cooking fuel has exhibited a declining trend over time in the Okavango Delta. Table 26 shows that while in 2005 the share of households using fuelwood as their primary cooking fuel ranged from 77 to 98 % in both districts, in 2022 the share decreased to approximately 35% and 73% in Ngamiland East and Ngamiland West districts respectively.

[11] Turpie et al., (2021) estimate an annual value of US$ 491 million in Angola, US$ 11 million in Botswana, and US$ 33 million in Namibia for crop provisioning services.

The rate of decline in fuelwood usage remains slow in Ngamiland west. This might be due to limited access to alternative energy sources such as electricity, as well as the tendency of households to use multiple types of fuel as they transition through the energy ladder.[12]

Table 26. Share of households using fuelwood as a main source of cooking

Country	District/Area	Share of hh using fuelwood as a main cooking (%)		
		2005[a]	**2011[b]**	**2022[b]**
Botswana	Ngamiland East	77-98	53	35
	Ngamiland West		83	73

Source: (a) Turpie et al. (2006), and (b) Botswana, National energy use survey 2022/2023.

In the case of Angola and Namibia, we assumed that all households in rural areas use fuelwood as cooking fuel. For Angola, this means considering that about half of the households use fuelwood. For Namibia, we assumed all households use fuelwood since they are in rural areas.

In terms of fuelwood consumption per household, we relied on data from the Botswana National Energy Use Survey (2022/2023) and Turpie et al. (2021). The use of fuelwood per household in the Angolan part of the basin, estimated at 399,807, is higher than in Ngamiland East and Ngamiland West of Botswana, which is estimated at 39,056. Due to a lack of data on fuelwood usage per household in Namibia, we could not estimate the total annual fuelwood usage for this country. Thus, for Namibia, we just adjusted the value in Turpie et al., (2021) for inflation.

To estimate the fuelwood value, we multiplied fuelwood consumption by the price (in 2022 US$). The estimated values of fuelwood consumption by households in the study area is summarised in Table 27. This value refers to the amount of fuelwood used for cooking by households within the study area. These values do not include the income of households generated from selling fuelwood. For Botswana part of the CORB, we estimate the value based on the study by Turpie et al., (2006) to be US$ 3.4 million per year.

[12] The energy ladder concept assumes households will move to higher energy density carriers as their income increases (Kroom et al. 2013)

By extrapolating fuelwood consumption per household from Turpie et al., (2021) for the Angola region within the study area and adjusting it with PPP conversion factor for 2022, the total annual value of wood provisioning services amounts to approximately US$ 81 million (Table 27).

Table 27. Estimated Annual Value of Wood Provisioning Services (2022 US$)

Country	District/Area	Total amount of fuelwood used (tons) in 2022	Total value in (million US$)
Angola	CORB	399,807	**65**
Botswana	Ramsar site	39,609	**3.4**
Namibia	CORB	N/A	**12.8**

In addition to fuelwood usage, Angola and Namibia exhibit significant involvement of community forest management and foreign investment within their timber industries (Nott et al., 2022). Both countries have official exit points facilitating timber trade between them. In this context, to calculate the economic value of timber, poles, and withies, we use extrapolations based on estimates provided by Turpie et al. (2021), adjusted with the 2022 PPP conversion factor. Table 28 presents the estimated value of timber for Botswana and Angola, but for Namibia, the value of timber was not estimated separately in the previous study, which made the analysis unfeasible.

Table 28. Estimated Values of Timber, Poles, and Withies

Country	Estimated use (m3/year)	Estimated value million US$ (2022 US$)
Angola	96,614.6	25
Botswana	4,982	0.5
Namibia	N/A	N/A

Source: Turpie et al. (2021)

The total value (2022 US$) of fuelwood and timber provisioning services is US$ 106 million distributed as follows:

- Angola: US$ 90 million
- Botswana: US$ 3.8 million
- Namibia: US$ 12.8 million

The total estimated value is about 16% lower than the value reported by Turpie et al., (2021), which was US$ 127 million at 2021 prices. The difference is mainly due to the number of households in Angola consuming fuelwood. It appears that Turpie et al., (2021) included all households, while we assume that only half of the households in Angola (those located in rural areas) use fuelwood as cooking fuel.

6.4 Water Supply Provisioning

Water supply is one of the key ecosystem services of the CORB, serving various purposes such as irrigation, livestock maintenance, human settlements, mining, and other uses or needs (FAO report, 2014). The CORB provides water supply to the beneficiaries in member countries in different ways. While households in Angola and Namibia rely on rivers and streams for their daily water needs, households in Botswana rely primarily on boreholes (Turpie et al., 2021). Concerns regarding increased water abstractions, change in river flows and erosion, change in water quality, and change in distribution and abundance of biota pose significant challenges, potentially jeopardising both ecological services and associated livelihoods (OKACOM, 2011). These threats might result in loss of natural capital, loss of ecosystem services, livelihood disruptions, and reduced economic productivity (FAO report, 2014). To overcome these challenges, the three-member countries have initiated the Cubango-Okavango River Basin (CORB) fund, aimed at preserving and enhancing the natural resources of the basin for the collective benefit of all its inhabitants (CORB, 2021).

In this study, to calculate the annual value of water supply, we use data from the Annual Agricultural Survey of Botswana, (2019), Cubango-Okavango River Basin Water Audit Report (2014), Turpie et al. (2021), and Wang & Nuppenau, (2021). The analysis is done following three main steps. Firstly, we identify water demand within the study area, considering livestock watering (which depends on livestock holdings), irrigation, and water demand for the tourism sector. Second, by using the average water price from Wang & Nuppenau (2021) for Angola and Namibia, and water prices from Turpie et al., (2006) for Botswana, we estimate the annual value of water use across these sectors. All prices were adjusted using the PPP conversion factor specific to each country. We note that this study does not include the estimated value of domestic water consumption due to insufficient data available for this sector.

The annual water consumption in Botswana for livestock watering, irrigation and tourism was 0.08, 1.22, and 0.58 million m^3 respectively (Table 29). In the Angola portion of the study area, annual water consumption for livestock watering is significantly higher at 14.4 million m^3 compared to Botswana and Namibia. Conversely, in Namibia's portion of the study area, annual water consumption for irrigation is notably higher, reaching 129.5 m^3, surpassing both Angola and Botswana.

Table 29. Annual Water Consumption of the Basin Countries by Sector 2022

Country	Annual estimated water consumption (Mm^3) in 2022		
	Livestock	**Irrigation**	**Tourism**
Angola	5.82	14.4	0
Botswana	2.25	1.22	0.58
Namibia	3.5	129.5	3.376

Sources: Cubango-Okavango River basin water audit report (2014).

The estimated value of annual water consumption for Angola amounts to US$ $0.069 million, based on unit prices derived from Wang & Nuppenau (2021). Similarly, using the same unit prices, the estimated annual water consumption value for the three sectors in Namibia is nearly US$ 0.5 million. In the case of Botswana, the estimated value of the annual water consumption amounts to about US$ 5.9 million. This estimation was calculated by extrapolating the unit price of water from Turpie et al., (2006), who determined unit prices based on the willingness to pay of residents near the Okavango Delta. It is important to note that, in the case of Botswana, the water price analysis accounts for both wet and dry season prices, with the average price of the two seasons being used here.

Table 30. Annual value of water by sector in 2022 (US$ million)

Water supply for	Angola	Botswana	Namibia
Livestock	0.017	3.285	0.012
Irrigation	0.052	1.777	0.469
Tourism	0	0.839	0.012
Total	**0.069**	**5.901**	**0.494**

According to this estimation, the total value for water provisioning services for the Basin is $ 6.463 million which is nearly the same as in Turpie et al., (2021), which estimate a total value of $ 6.5 million. However, in their study, the value of water supply is more equally distributed between Angola and Botswana, with $ 2.2 million and $ 4 million, respectively.

6.5 Recreation-related Services

Table 31 presents the annual values calculated by Turpie et al. (2021) for all three countries. After adjusting these estimates for inflation, we derived annual values of approximately US$6 million for Angola, US$186 million for Botswana, and nearly US$4 million for Namibia.

Table 31. Estimated Value of Nature-based Recreation Value of Tourism in the Angola, Botswana and Study Area in 2019 (2021 US$)

Country	Total annual Value nature-based tourism per country (million US$)	Spatial allocation of tourism value (%)	Nature based tourism value of the area (million US$)
Angola	**87.51**	5.5	**4.8**
Botswana	**309.65**	60	**186**
Namibia	**177.31**	2.1	**3.7**

Source: Turpie et al., (2021)

The contribution of tourism to GDP varies significantly across countries within the CORB. In 2022, Angola had a GDP of US$106.78 billion, with tourism contributing 0.03%, or approximately US$3.2 billion (WTTC 2023). Within the CORB, nature-based tourism accounts for only 0.19% of the total tourism contribution to Angola's GDP. In Botswana, tourism plays a more substantial role, contributing 0.098% to its GDP of US$20.36 billion, which amounts to around US$1.995 billion, with 10% attributed to the CORB. Namibia has the highest percentage contribution from tourism at 0.153% of its US$12.91 billion GDP, equating to roughly US$1.975 billion, with the CORB contributing 0.2% to this figure.

6.6 Wild animals, plants, and other biomass provisioning services

The valuation of wild animal provisioning services entailed adjusting the data on wild meat harvested by households, originally presented in Turpie et al., (2006), based on the current number of households in the study area. Employing the methodology detailed in the Methodological section, we determined an annual value of $ 1.6 million (in 2022 US$) for the CORB—$ 470,477 in Botswana and approximately $ 1.2 million in Angola. It is noteworthy that in the Namibian section of the study area, we assumed households did not benefit from this ecosystem service as there is no data on the consumption of wild meat for that region.

As anticipated, the monetary value calculated for Botswana surpasses the figures in Turpie et al., (2006) and Turpie et al., (2021) due to the increase in the number of households over the past two decades. However, for the other countries, the values fall short of those in Turpie et al., (2021). In our study, we extrapolated the number of wild animals harvested in Botswana to Angola and Namibia, potentially leading to an underestimation of the harvested levels---and consequently an underestimation of the monetary value in these two countries.

6.7 Wild fish, and other aquatic animals

Using the data and methodology outlined in the Methodological section and adjusting prices to reflect 2022 US$, we calculated an annual value of $2,134,146 in Botswana, $2,506,057 in Angola, and $2,919,678 in Namibia for wild fish provisioning services. As anticipated, the values of wild fish in each country are comparable due to similar fish yields ranging from 600 to 840 tons per year and the application of a single value transfer of BWP 20 per kilogram (at 2014 prices). Cumulatively, these values amount to $7,559,882 for the CORB.

It is worth noting that the values calculated here differ from the ones in Turpie et a., (2006) and Turpie et al., (2021). As with the other provisioning services, these values are anticipated to vary significantly due to changes in effort and productivity across countries and different rainfall years.

6.8 Global climate regulation

The valuation of the global climate regulation service is divided into two distinct components: carbon retention and carbon sequestration. Carbon retention encompasses both above and belowground carbon as well as soil organic carbon, representing a static stock (e.g., tC). On the other hand, carbon sequestration embodies a dynamic flow, or rate (e.g., tCO2 per year).

6.8.1 Carbon stock

In total, the ecosystems of the CORB retain high levels of carbon. In total, across the three countries, 686 million tonnes are stored in the 0 – 50 cm layer of as Soil Organic Carbon, while the above and belowground biomass contains carbon stocks of 569 million tonnes. Botswana accounts for 241 million tonnes, Namibia 90 million tonnes and Angola the bulk at 926 million tonnes. These volumes indicate the condition of the ecosystems, and highlight the importance of their effective conservation, ensuring that such carbon stocks are retained. There are currently no markets or pathways to monetize this these carbon stocks however their vast quantities underline the importance of maintaining the Ecosystem Services that create and protect these stocks so that they are not released into the atmosphere.

Table 32. Total Mass of Carbon Stocks

Country	Total Soil Organic Carbon (million tons)	Total above and belowground carbon (million tons)
Angola	477	449
Botswana	155	87
Namibia	55	34

6.8.2 Carbon sequestration

To determine the monetary value of carbon sequestration, similar to our approach in valuing carbon stocks, we multiply the CO2 sequestered in each habitat and country by the corresponding social cost of carbon (US$ per tCO2). The social costs of carbon are US$0.66 per tCO2 for Botswana and Namibia, and US$6.59 per tCO2 for Angola. Notably, negative values are calculated for some habitats in Namibia and Angola, indicating these countries have habitat that has the potential to emit more than they sequester, as detailed in the methodology section.

To compute the overall value of carbon sequestration in each country, we calculated an annual value of US$71 million in Angola, US$11 million in Botswana, and approximately US$ 2.4 million in Namibia (Table 33). We excluded some habitats such as grassland as these have the potential to emit carbon due to annual fire damage so this could be considered in future calculations.

Table A.12 in Appendix A provides a detailed breakdown of the monetary value assigned to carbon sequestration across the analysed countries.

Table 33. Annual Value of Carbon Sequestration (2022 US$ Million)

Country	Annual value US$ estimated by excluding the habitats that are a potential source of CO_2
Angola	71
Botswana	11
Namibia	2.4

6.9 Summary of Valuation Results

The total economic value of the CORB is estimated at approximately 1.2 billion per year at 2022 US$ (Table 34). These services provide substantial benefits to the local population, the country, and have global significance. The high value underscores the economic importance of the study area, emphasising the need for continued conservation and sustainable management efforts to preserve its invaluable contributions to society.

Table 34. Summary of the TEV of the CORB (US$ 2022)

Country	Ecosystem services	Annual value (US$ million)
Angola	Crop provisioning services	617.6
	Livestock provisioning services	14.1
	Wood provisioning services	89.9
	Wild animals provisioning services	1.1
	Water supply provisioning services	0.1
	Wild fish provisioning services	2.5
	Recreation-related services	6
	Global climate regulation services (carbon sequestration)	70.8
Botswana	Crop provisioning services	25.8
	Livestock provisioning services	19.1
	Wood provisioning services	3.8
	Wild animals provisioning services	0.5
	Water supply provisioning services	5.9
	Wild fish provisioning services	2.1
	Recreation-related services	200
	Global climate regulation services (carbon sequestration)	10.7
Namibia	Crop provisioning services	45.4
	Livestock provisioning services	7.5

	Wood provisioning services	12.8
	Wild animals provisioning services	0
	Water supply provisioning services	0.5
	Wild fish provisioning services	2.9
	Recreation-related services	3.8
	Global climate regulation services (carbon sequestration)	2.4

In terms of country-specific contributions, Botswana emerges as a significant contributor, with an annual valuation of almost $268 million representing 23% of the total. Angola's ecosystem services are valued at $802 million, constituting 70% of the total assessment. In contrast, Namibia's ecosystem services hold a comparatively smaller economic value, estimated at $75 million, comprising 7% of the overall valuation. The distribution of benefits changes when considering the annual value per capita. Upon dividing the total economic value by the total population in each country, we find an annual economic benefit of US$1,363 per capita in Botswana, US$219 per capita in Namibia, and $1,075 per capita in Angola.

For Botswana, the annual value calculated here is comparable to Turpie et al., (2006) that estimate an annual value of almost US$ 228 million (2022 prices). In the case of Angola and Namibia, focusing on national values, Turpie et al., (2021) estimate an annual value of US$ 535.4 million and US$ 47.3 million, respectively (or US$ 673 million and US$ 49 million in 2022 prices). Therefore, all values are of the same magnitude, underscoring the significance of the CORB to the three countries.

In addition to annual assessments, we also calculated the value of carbon stocks, encompassing aboveground, belowground, and soil organic carbon. There are vastly varying values for existing carbon stocks but there are no current pathways for carbon stocks to be monetized hence more important than the value, is the actual tonnage of carbon stored in these ecosystems, with Botswana, Namibia and Angola holding 241 million, 89 million and 926 million tonnes respectively. These figures underscore the economic importance of carbon storage in these nations, highlighting the critical need to manage carbon resources for both environmental sustainability and economic prosperity. It is crucial to note that currently there is no pathway for either the carbon stocks or carbon sequestration values to be monetized hence it is important that while the proportional values of carbon sequestration to the overall Ecosystem Service Valuation is relatively high, the other Ecosystem Services represent a much more immediate financial risk if their functioning is compromised.

Hippopotamus in the Okavango Delta | Photo by Kai Collins

7. Discussion

7.1 Values and Data

This study valued a subset of ecosystem services for which only secondary data was available for all three countries. We acknowledge that the ecosystem services provided by the CORB are more extensive than those listed here. For example, the existence value of ecosystems, an economic concept used to quantify the value that people place on simply knowing that a particular environmental resource or natural asset exists, even if they never use it directly. This value reflects the importance people assign to the mere existence of certain species, ecosystems, or natural features, irrespective of any direct, indirect, or future use they might have. The most common approach to value this ecosystem service consists of the contingent valuation method which requires surveying users and non-users.

According to Turpie et al., (2021), only two studies - Mmopelwa & Blignaut (2006) and Mladenov et al. (2007)—have used the contingent valuation method to assess the existence value of the Okavango Delta, a portion of the CORB. Based on these studies, the estimated existence value ranges from US$ 3.8 million to US$ 34 million (2021 US$). However, Turpie et al., (2021) highlights that these estimates are likely underestimates, as they were calculated based on samples of users and did not account for non-users. Moreover, to provide an alternative estimate, Turpie et al., (2021) used an approach that spatially distributes global willingness-to-pay for biodiversity conservation in proportion to mammal species richness. Using this method, they calculated an annual existence value of US$ 4.1 billion, distributed as US$ 1.7 billion in Angola, US$ 247 million in Namibia, and US$ 2.1 billion in Botswana.

Honey Production as an Ecosystem Service

Honey production in the Miombo woodlands of Angola serves as a vital livelihood for local communities, merging ecological sustainability with economic benefits. The Miombo woodlands, a dominant vegetation type in southern Africa, cover approximately 2.7 million square kilometres across several countries, including Angola. These woodlands are characterized by a rich biodiversity and provide essential ecosystem services such as carbon sequestration, soil fertility enhancement, and habitat for wildlife (Campbell, 1996). The flowering plants in Miombo woodlands offer abundant nectar resources, making them ideal for apiculture (Ncube & Munsaka, 2010). These woodlands are characterized by a unique biodiversity and play a crucial role in carbon sequestration, water regulation, and soil fertility (Frost, 1996).

Socioeconomic Impacts of Honey Production

In Angola, honey production is an essential income-generating activity for rural communities. It contributes to poverty alleviation and provides a source of food security. Beekeeping requires relatively low capital investment compared to other agricultural practices and offers both direct and indirect economic benefits. Direct benefits include the sale of honey and other hive products such as beeswax, while indirect benefits include pollination services that boost agricultural productivity (Ngulube, 1997).

Traditional Beekeeping Practices

Traditional beekeeping in the Miombo woodlands of Angola often involves the use of bark hives and log hives, which are typically placed high in trees to safeguard against predators and theft (Clauss, 1992). These traditional methods are deeply ingrained in the cultural practices of local communities and have been passed down through generations. However, they are often associated with low productivity, deforestation, and limited access to formal markets.

Modern Beekeeping Interventions

Recent efforts have been made to introduce modern beekeeping techniques to improve honey yield and sustainability. These include the adoption of movable-frame hives, better hive management practices, and training programs aimed at enhancing the skills of local beekeepers (Klein et al., 2013). Additionally, initiatives focusing on value addition, such as processing and packaging honey for both local and international markets, have shown potential in increasing the economic returns from honey production (Ngonga, 2011).

Valuation of the Ecosystem Service of Honey

In addition to the existence value, local experts have emphasised the importance of other biomass provisioning services, particularly honey and medicinal plants. The production of honey by wild bees is especially important in Angola. According to Turpie et al., (2021), while wild honey production was estimated at 421 litres per year in Botswana, in Angola, the annual production was estimated at 336,732 litres. In terms of monetary value, Turpie et al., (2021) estimate an annual value equal to US$ 1,000 in Botswana and US$ 5.9 million (2021 US$) in Angola. If we were to extrapolate these values based on the number of households in Botswana, we would get an annual value of US$ 1,443.[13]

Challenges and Opportunities

Several challenges hinder the full realization of honey production's potential benefits in Angola. These include:

1. **Market Access**: Limited access to markets and inadequate marketing skills restrict the economic benefits that local beekeepers can derive from honey production (Mulenga, 2015).
2. **Climate Change**: The increasing frequency of droughts and changing rainfall patterns negatively impact the flowering cycles of plants, thereby reducing nectar availability and honey yields (Chidumayo, 2019).
3. **Deforestation**: Ongoing deforestation for agricultural expansion and charcoal production poses a significant threat to the sustainability of the Miombo woodlands and the apiculture industry (Munthali & Chirwa, 2020).
4. **Anthropogenic Fires:** There is anecdotal evidence that the high anthropogenic fire frequency as well as the timing of the burns (early or late in the dry season) has a negative impact on bee populations and the associated honey production but this needs to be more thoroughly investigated.

Despite these challenges, there are numerous opportunities to enhance honey production in Angola through sustainable forest management, community-based conservation programs, and supportive policies that promote apiculture as a viable economic activity.

Honey production in the Miombo woodlands of Angola holds substantial promise for supporting rural livelihoods and conserving biodiversity. While traditional beekeeping practices offer a strong cultural foundation, modern interventions and sustainable management strategies are essential for addressing current challenges and maximizing the sector's potential. Future research should focus on evaluating the long-term impacts of these interventions and developing resilient beekeeping systems in response to climate change.

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[13] Based on discussions with local experts, we have identified that a subset of villages in Angola outside our current study area participate in honey production

In the case of medicinal plants, according to local surveys, Turpie et al. (2006) highlights that between 10% and 19% of households engage in this activity, with approximately 23% of them selling these plants. Based on survey data, the authors estimated an annual value of around P280,000 (2005 prices) (equivalent to approximately US$148,276 in 2022).[14]

Lastly, Turpie et al. (2006) also calculated the annual scientific and educational values in Botswana, considering estimates on the costs of research, filming, and educational activities within the Okavango Delta. However, extrapolation from the household data calculated here based on Turpie et al., (2006) was not feasible. Specifically, the annual values estimated by Turpie et al. amounted to P24 million (US$ 12.7 million in 2022) for the Ramsar site, with P18 million (US$ 9.5 million in 2022) allocated to the wetland area.

Although we used a proven robust methodology to estimate the value of natural capital in the CORB, we relied on secondary data, in some cases at a district or provincial level, which might not capture the local context, and therefore, to obtain a more accurate measure of the importance of the ecosystem services valued in this report, conducting multiple field surveys and stakeholder consultations would be necessary. We also note that in the case of tourism (or recreation-related activity services), we opted for using official data on the number of tourists based on border crossings under the assumption that most tourists entering Botswana will visit the Okavango Delta. However, according to local experts those official numbers might not accurately reflect the true number of tourists visiting the Delta, which might bias the value of this ecosystem service. Indeed, the main challenge in conducting an environmental valuation is obtaining the most reliable and accurate data possible. In remote places, such as some villages in Angola, data is usually scarce, creating an additional layer of difficulty in the analysis. Furthermore, the valuation results typically consist of an annual value. However, in places such as the Okavango Delta, where the provision of ecosystem services changes depending on seasonality, an annual value might not be the best metric. Nevertheless, it is required by the SEEA economic accounting framework that countries are using to quantify the value of their natural assets.
Within the context of data scarcity, we highlight the lack of information on methane and CO_2 emission. In this report, we focused on carbon sequestration and storage. We acknowledge that a more

[14] The 2005 value was adjusted for inflation from 2005 to 2023, resulting in a value of P774,000 in 2022 prices. Subsequently, we converted it using a purchasing power parity conversion factor of 5.22 in 2022.

comprehensive assessment would require detailed data on all greenhouse gas emissions to fully understand the carbon dynamics and their impact on the CORB and the provision of ecosystem services.

An important discussion in the environmental valuation context revolves around the monetization of environmental values. For ecosystem services like climate regulation, their value is often estimated based on the benefits they provide to local and global communities. However, it is important to note that this value is often an abstract measurement, as it does not involve direct transactions in traditional economic terms. To monetize these values, financial mechanisms such as carbon markets, green bonds, and incentives for sustainable practices could be developed.

In policymaking, the monetization of environmental values might serve as a critical tool for integrating environmental considerations into decision frameworks. By quantifying the economic benefits of ecosystem services, policymakers can prioritize investments in conservation and sustainable resource management. For example, governments can use these valuations to justify the implementation of regulations that protect natural habitats or reduce greenhouse gas emissions. Moreover, environmental values can guide the development of economic instruments such as carbon pricing mechanisms, where the cost of carbon emissions is internalized to incentivize low-carbon technologies and practices.

In the business sector, understanding the monetary value of ecosystem services is increasingly important for corporate sustainability strategies and risk management. Companies can use these valuations to assess their dependence on natural resources and their impacts on ecosystems. This information might help businesses optimize resource use, reduce environmental risks, and enhance their reputation among stakeholders and consumers committed to sustainability.

An essential aspect in the development of financial mechanisms is the identification of hotspots where ecosystem services are most abundant, and threats are most severe. This strategic identification not only prioritises conservation efforts but also facilitates the development of financial mechanisms that require targeted intervention and support.[15]

[15] In the context of environmental economics, many financial mechanisms and policies require additionality. This concept asks whether an action or project contributes new environmental benefits that would not have happened naturally or without specific funding or policy support. It ensures that investments or actions aimed at conservation protection are making a positive difference beyond what baseline conditions would provide.

8. Key Insights and Conclusion

8.1 Key Insights

Considering the value provided by the ecosystem services of the CORB to human wellbeing, it is crucial that it remains in a healthy and functioning state to continue delivering such benefits to human well-being. As such, our recommendations align with reducing threats and pressures on the ecosystem and its function, either through reducing reliance of human populations on its natural resources, or by improving resilience through enabling resource provision for effective long-term management. In addition, considering the transboundary nature of the CORB, we suggest continued efforts towards strengthening bilateral efforts to address data and knowledge gaps, align policy across the region and carry out collaborative management interventions. This can be achieved through existing structures and initiatives.

Short-Term

Addressing the data gaps: There is a need to address numerous data gaps which would allow a much more accurate and granular assessment of the ecosystem services provided by the CORB. By closing such data gaps, the methodology can be adapted to assess these values more specifically. One such example is the tourism data of the study area in Botswana. Tourism has been shown to be a major contributor to the value provided, however, there is limited data on the tourism arrivals, and we recommend that the sector undertakes a more coordinated and collaborative approach to recording tourism arrivals and time spent in the Delta itself.

Improved Management of Natural Resources: Prioritise efforts to reduce the reliance on wild animals and fuelwood for sustenance among Basin communities. This could involve initiatives to improve alternative livelihoods and promote sustainable resource management practices like fisheries reserves, reforestation projects and improved methods of charcoal production. For countries involved in the management and use of the Cubango-Okavango Basin:

- Angola and Botswana could potentially reduce communities' reliance on fuelwood and provide better cooking technologies with improved efficiencies, such as solar cookers.
- All three nations could advance Integrated Water Resource Management agreements to safeguard their common usage of water resources.

- Botswana and Angola could reduce the reliance on hunting of wild animals for subsistence through the provision of alternative sources of protein.

Provide Alternative Energy Sources: Promote the adoption of cleaner energy sources instead of fuelwood or charcoal such as solar power or grid electricity. This will alleviate some of the strain on forest resources caused by the widespread use of fuelwood for cooking within the Basin.

Promote Sustainable Tourism: Advocate for tourism and recreational activities that generate economic benefits from wildlife and natural resource conservation. Focus on boosting community-led eco-tourism opportunities throughout the value chain in Namibia and Angola, aiming to unlock local economic potential and support environmental conservation efforts.

Explore the Carbon Value Chain: Investigate opportunities to leverage the carbon value chain as a means of generating additional revenue for the Basin, particularly in Angola, where significant potential may exist for carbon-related initiatives.

Support the further implementation of the OKACOM Decision Support System (DSS): The OKACOM Basin Development Management Framework (BDMF) identified the need for development of a basin-wide information sharing tools and DSS designed to support OKACOM in its mandate to provide technical advice that aligns development and land use planning in the Member States with the Cubango-Okavango River Basin (CORB) Vision as well as the harmonisation of national information and data, integration of selected data into the DSS and development of basin-wide information sharing mechanisms.

Long-Term

Policy Integration: Support OKACOM in its integration of research-informed natural resource management plans with national policies across Basin member nations. This support to OKACOM can be enhanced through the existing entities of KAZA, SADC, ZAMCOM and other bilateral processes. This holistic approach will ensure alignment and coherence between local and national strategies, enhancing the effectiveness of conservation and sustainable development efforts.

Transboundary Resource Utilisation: Support OKACOM in its collaborative efforts to facilitate transboundary natural resource utilisation among Botswana, Namibia, and Angola by fostering cooperation and sharing resources, which may enhance resilience and promote equitable access to Basin resources for all member nations.

8.2 Conclusion

The CORB encompasses three countries: Angola, Namibia, and Botswana, and it contributes significantly to the economic well-being of the people who live in the basin as well as global climate control. People living in the project area are dependent on the Basin natural resources for their livelihoods.

Despite differences in natural resource endowment and types of ecosystem services, the CORB provides substantial ecosystem services to people in Angola, Botswana, and Namibia. Crop provisioning services, Livestock provisioning service, Wood provisioning, Water supply, Recreation related services, Wild animals, plants, and other biomass provisioning services, Wild fish, and other aquatic animals, and Global climate regulation are among the ecosystem services of the Basin. Tourism provides a substantial value to the Botswana economy. This leads to increased income and social security for households across the country. Crop provisioning, on the other hand, is very important to the inhabitants of Angola, which is part of the Basin. Wood provisioning makes significant contributions to the people of Angola and Botswana. Based on the calculations in this study, Angola emerges as a significant contributor to the carbon economy.

The management of the Cubango-Okavango River Basin by Angola, Namibia and Botswana will need to balance the needs of residents with its vital contribution to the national economy whilst maintaining the ability to offer a safety net for households experiencing shocks and a risk-spreading mechanism for poor households vulnerable to environmental variability.

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10. Appendix

Appendix A: Population of the Study area

Table A.1 Population size and number of households in Angola

Province	GIS Area (km^2)	Intersection with the study area (km^2)	Population density ($\#/km^2$)	Population	Number of households
Katchiungo	2,790	1,792	59[c]	105,702	16,516
Kuvango	9,019	7,990	3[b]	23,971	4,056
Dirico	18,344	8,045	3[b]	24,134	4,084
Calai	7,923	7,923	3[b]	23,770	4,022
Cuangar	18,954	15,602	3[b]	46,805	7,920
Nankova	10,101	10,061	3[b]	30,182	5,107
Mavinga	43,967	6,149	3[b]	18,446	3,121
Cuito Cuanavale	35,643	31,171	3[b]	93,512	15,823
Luchazes	42,990	13,730	3[d]	41,191	7,382
Chitembo	19,632	9,118	21[a]	191,481	32,399
Cuvelai	15,432	800	3[b]	2,399	406
Menongue	23,376	21,701	3[b]	65,102	11,016
Chinguar	3,073	2,106	21[a]	44,216	6,689
Cuchi	11,832	11,832	3[b]	35,497	6,006

Note: (a) INE (2016a); (b) INE (2016b); (c) INE (2016c); (d) INE (2016d).

Table A.2 Population size and number of households in Namibia

Region	Constituency	Population 2023[(a)]	Number of households
Kavango	Kapako	27,823	4,216
	Mankumpi	6,910	1,047
	Mashare	19,478	2,951
	Mpungu	21,098	3,197
	Mukwe	39,170	5,935
	Musese	15,659	2,373
	Ncamagoro	8,449	1,280
	Ncuncuni	10,943	1,658
	Ndiyona	13,800	2,091
	Ndonga Linena	14,936	2,263
	Nkurenkuru	15,887	2,407
	Rundu Urban	118,632	17,975
	Rundu Rural East	12,405	1,880
	Tondoro	18,497	2,803
	Total	343,687	52,074

Source: [(a)]2023 Namibia Population and Housing Census Release of Preliminary Results.

A.3 Climate

Okavango Delta (in Botswana)

The climate in the headwater region is subtropical and humid, with an annual precipitation of up to 1,300 mm, but it is semi-arid in Botswana, with precipitation amounting to only 450 mm/year in the Delta area. The Okavango Delta's climate is the semi-arid subtropical type, included in the "wet-dry tropical" and "wet-dry subtropical" designations of Vladimir Köppen's climate types. Changing wet tropical air masses and dry tropical air masses usher in the Delta's wet and dry seasons. The Delta is unique, however, in that the rainfall in the upstream catchment in Angola only arrives in the Delta during its dry season, flooding the wetland during the winter months from April and receding in July, taking about 3–4 months to travel the 250 km from Mohembo (the border of Namibia and Botswana) to Maun. In Maun, the nearest town to the Okavango Delta, temperatures reached maximum from October to March (Figure 9 (a)) coupled with higher precipitation (Figure 9 (b)). The higher precipitation level is 105mm, which occurs in January, and the lower precipitation level is 0 mm, which occurs from July to August (Figure 9 (b)). The lower temperature in the town is about 18°C from June to July (Figure 9 (a)).

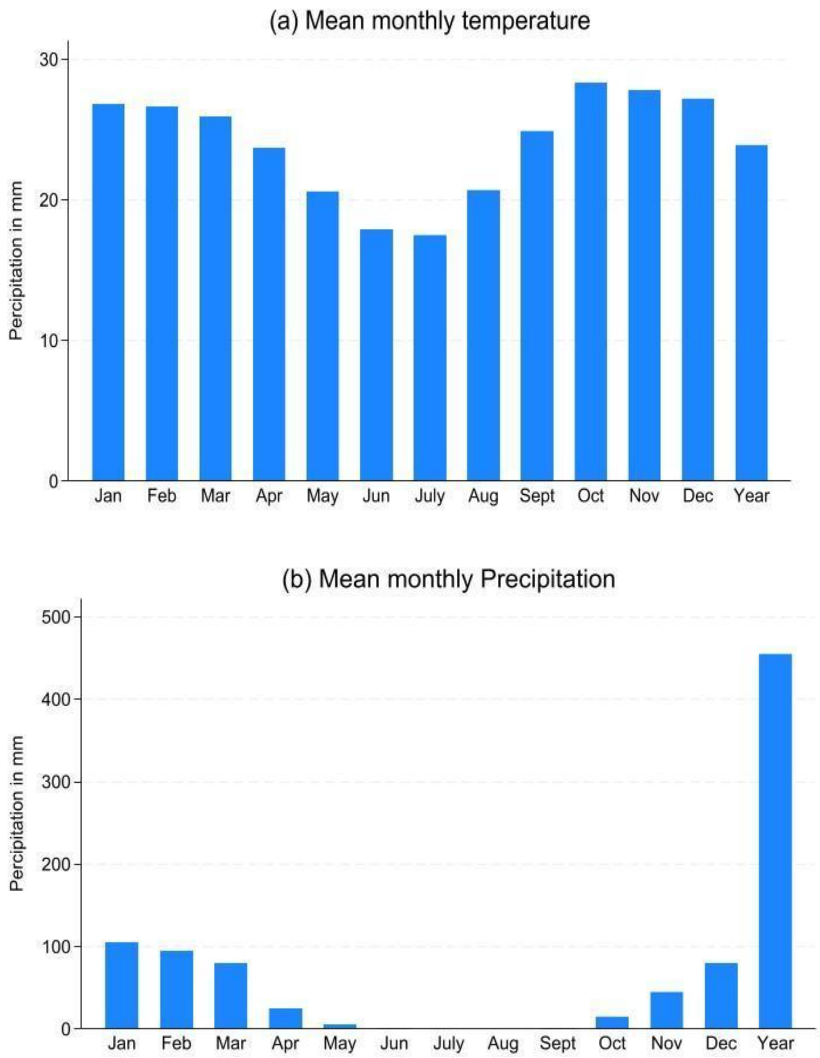

Figure A1. (a) The mean monthly temperature (°C) of Maun (1991- 2020) and (b) the mean monthly precipitation of Maun (Source: World Climate Guide).

A.4 Methodological Framework for Valuing Species

1. **Species Selection:** Identify species based on their ecological importance, conservation status, and the availability of data.
2. **Spatial Scope:** Define the study area considering all relevant ecological and physical boundaries.
3. **Role Identification:** Use dynamic ecological models to map the interactions of species with their environments and estimate their roles in ecosystem functions.
4. **Beneficiary Identification:** Determine who benefits from the ecosystem services provided by the species, helping prioritise conservation efforts.
5. **Economic Analysis:** Apply appropriate economic methods to quantify the value of ecosystem services, incorporating scenarios such as environmental changes or different management strategies.
6. **Redundancy:** How replaceable is the function of the species concerned? What is the functional pool of similar taxa in the ecosystem? What is the likelihood that the "species" may be lost?
7. **System Modelling**: Simulation of ecosystems with and without the species of interest, to help understand the "ecological importance". (Similar to 3, but more focussed).

Table A.5. Area planted (ha) in the traditional sector

Ngamiland West	Sorghum	Maize	Beans / Pulses	Millet	Sunflower	Ground nuts	Water melons	Melons	Sweet Reeds	Other Crops	Source
2019	1131	1566	495	1175		30	78	25	120	29	Annual Agricultural Survey Report 2019
2017	620	1104	445	668		64	110			230	" 2017
2015	979	1727	792	1079	2	151	127	71	122	37	Agriculture Census Report Final 2015
2014	817	2025	628	1309		74	119			202	" 2014
2013	1934	2810	874	2883	0	53	127			115	Annual Agriculture Survey Report 2013

2012	1174	1927	795	2849		27	64			132	Annual Agriculture Survey Report 2012
2011	1 625	1 424	428	2 065		110	13			46	Annual Agriculture Survey Report 2011

Table A.6. Area planted (ha) in the traditional sector

Ngamiland West	Sorghum	Maize	Beans / Pulses	Millet	Sunflower	Ground nuts	Watermelons	Melons	Sweet Reeds	Other Crops	Source
2019	70	459	193	32		13	37	8	58	21	Annual Agricultural Survey Report 2019
2017	101	1206	357	49		11	49			81	Annual Agricultural Survey Report 2017
2015	74	495	172	22	1	5	27	23	30	4	Agriculture Census Report Final 2015
2014	385	2053	452	165		24	70			93	Annual Agriculture Survey Report 2014
2013	216	2521	415	102	0	8	53			98	Annual Agriculture Survey Report 2013
2012	222	1965	365	125		16	56			120	Annual Agriculture Survey Report 2012
2011	162	2414	330	138		9	58			69	Annual Agriculture Survey Report 2011

Table A.7. Annual crop yield (kg/ha) for the Okavango Delta Botswana in 2005 (Turpie et al., 2006)

(a) Dryland fields

Region	Beans	Groundnuts	Maize	Melons	Millet	Pumpkins	Sorghum	Sweet reeds
North	10.19	7.72	74.16	3.05	74.9	7.09	67.75	68.33
West	21.79	3.43	152.35	2.84	N/A	19.4	N/A	31.11
Southwest	6.28	N/A	53.25	9.21	0.43	0.17	9.81	394.01
Southeast	15.23	6.85	73.37	1.35	18.91	2.93	29.28	58.5
Central	1.69	N/A	48.32	0.45	3.74	N/A	4.46	147.37
Average	**11.04**	**6.00**	**80.29**	**3.38**	**24.50**	**7.40**	**27.83**	**139.86**

Note: N/A refers to Not Available.

(b) Molapo fields

Region	Beans	Groundnuts	Maize	Melons	Millet	Pumpkins	Sorghum	Sweet reeds
Panhandle	4.72	N/A	107.32	13.95	47.01	N/A	N/A	47.01
West	20.45	1.69	285.93	2.9	4.6	43.2	10.29	225.67
Southwest	5.08	1.07	77.23	1.6	N/A	N/A	N/A	385.6
Southeast	14.32	N/A	189.88	1.48	28.4	35.06	9.38	452.59
Central	6.62	1.3	101.43	0.24	N/A	7.33	N/A	145.06
Average	**10.24**	**1.35**	**152.36**	**4.03**	**26.67**	**28.53**	**9.84**	**251.19**

Note: N/A refers to Not Available.

Tables A.8. Carbon retention (above and belowground carbon)

Country	Habitat type	Area represented in study area (ha)	Tons of carbon	Average tons of carbon per hectare
Botswana	Bare	7,114	79,463	79,463
	Forest	410	11,304	11,304
	Grassland	1,913,551	23,173,103	23,173,103
	Low Shrub / Sparse Brush	255,027	2,598,725	2,598,725
	Open Woodland	2,129	31,509	31,509
	Tall Forest	6,432	255,292	230,587
	Thicket / Dense Woodland	11,510	4,541,022	255,292
	Water	295,255	11,736,260	4,541,022
	Wetland	570,275	43,957,061	11,736,260
	Woodland	2,244,998	79,463	43,957,061

Table A.9. Carbon retention (Soil Organic Carbon)

Country	Habitat type	Area (ha)	Tons of carbon (0-20 cm)	Tons of carbon (20-50 cm)	Average tons of carbon per hectare (0-50 cm)
Botswana	Bare	7,114	156,508	79,463	22
	Forest	410	13,530	11,304	33
	Grassland	1,913,551	47,838,775	23,173,103	26
	Low Shrub / Sparse Brush	255,027	9,691,026	2,598,725	38
	Open Woodland	2,129	51,096	31,509	24
	Tall Forest	6,432	263,712	230,587	41
	Thicket / Dense Woodland	11,510	391,340	255,292	34
	Water	295,255	12,695,965	4,541,022	43
	Wetland	570,275	22,811,000	11,736,260	41
	Woodland	2,244,998	60,614,946	43,957,061	27

Table A.10. Carbon sequestration

Country	Season	Habitat type	Tons of CO2e/ha-year	Data coverage
Botswana	Wet	Bare	-3.30	0.04%
		Forest	-3.54	13.12%
		Grassland	-3.12	0.03%
		Low Shrub / Sparse Brush	-3.22	0.09%
		Open Woodland	-3.00	0.13%
		Tall Forest	-3.58	47.93%
		Thicket / Dense Woodland	-3.55	4.22%
		Water	-3.70	0.67%
		Wetland	-3.71	1.94%
		Woodland	-3.50	1.53%
	Dry	Bare	-3.30	0.04%
		Forest	-3.54	13.08%
		Grassland	-3.69	0.52%
		Low Shrub / Sparse Brush	-3.23	0.09%
		Open Woodland	-2.99	0.12%
		Tall Forest	-3.58	48.00%
		Thicket / Dense Woodland	-3.55	4.22%
		Water	-3.70	0.66%
		Wetland	-3.70	1.78%
		Woodland	-3.50	1.52%

Table A.11. ***Monetary value of SOC and above and belowground carbon (2022 US$) (lowercase value) and below, comparing values at two different prices, either Carbon tax price or marginal abatement cost***

Country	Habitat type	Value of above and belowground carbon	Value of SOC
Angola	Bare	60,865,725	123,347,730
	Forest	3,320,350,472	2,056,342,464
	Grassland	736,166,105	1,680,047,127
	Low Shrub / Sparse Brush	10,238,553	26,426,037
	Open Woodland	5,089,059,016	6,880,205,970
	Tall Forest	2,563,781,678	1,280,760,756
	Thicket / Dense Woodland	595,207,539	614,191,644
	Water	28,006,075	85,558,275
	Wetland	165,577,589	354,220,713
	Woodland	2,242,422,336	2,642,854,896
Botswana	Bare	2,622,292	5,164,764
	Forest	373,022	446,490
	Grassland	764,712,386	1,578,679,575
	Low Shrub / Sparse Brush	85,757,929	319,803,858
	Open Woodland	1,039,804	1,686,168
	Tall Forest	7,609,378	8,702,496
	Thicket / Dense Woodland	8,424,629	12,914,220
	Water	149,853,723	418,966,845
	Wetland	387,296,564	752,763,000
	Woodland	1,450,583,008	2,000,293,218
Namibia	Bare	16,937,910	54,201,312
	Forest	514,040	515,328
	Grassland	186,963,061	441,110,670
	Low Shrub / Sparse Brush	1,202,300	2,502,786
	Open Woodland	812,853,199	1,173,286,950
	Tall Forest	99,948	97,812
	Thicket / Dense Woodland	2,023,243	2,544,960
	Water	5,672,647	8,687,415
	Wetland	5,408,410	8,962,800
	Woodland	87,270,807	118,047,468

Table A.12. Monetary value of carbon sequestration (2022 US$ per year) per country and habitat

Country	Habitat type	US$ per year
Angola	Bare	993,781
	Forest	23,355,455
	Grassland	-70,963,401
	Low Shrub / Sparse Brush	-106,771
	Open Woodland	15,571,505
	Tall Forest	14,443,146
	Thicket / Dense Woodland	1,412,359
	Water	463,213
	Wetland	822,521
	Woodland	13,754,009
Botswana	Bare	14,086
	Forest	871
	Grassland	3,582,167
	Low Shrub / Sparse Brush	492,712
	Open Woodland	3,832
	Tall Forest	13,816
	Thicket / Dense Woodland	24,516
	Water	655,466
	Wetland	1,269,432
	Woodland	4,714,496
Namibia	Bare	26,690.04
	Forest	990
	Grassland	-191,251
	Low Shrub / Sparse Brush	6,668
	Open Woodland	2,099,117
	Tall Forest	163
	Thicket / Dense Woodland	5,018
	Water	15,667
	Wetland	16,203
	Woodland	227,663

Appendix B: **The Economics of Species Protection and Restoration to Support the Well-being of People and the Rest of Nature**

Introduction

Biodiversity is declining at an unprecedented pace, with more than 1 million species under extinction risk (IPBES, 2019), crossing the threshold of the safe operating space of the planetary boundary for biodiversity (Rockstrom). The causes of biodiversity loss have been widely recorded, including overharvesting, climate change, human population, habitat destruction, pollution, and invasive species (EO Wilson). Nevertheless, we would argue these are more the events and patterns in the iceberg model of systems thinking, and there's still a significant gap on the structures (i.e., what influences those trends) and mental modes (i.e., our way of thinking towards biodiversity) that underlines the causes of nature loss and degradation.

In this section, we address one of what we consider to be one of the key mental modes, the value of species for people's wellbeing. Although the multidisciplinary field of natural capital valuation has been well established for decades (Hernandez-Blanco and Costanza, 2019), there is still some confusion in the literature on how to account for the value of species in supporting the provision of ecosystem services.

This section will provide a theoretical framework on the economic value of the role keystone species has in contributing to the provision of ecosystem services. This will help inform more effective management strategies of natural capital, including conservation, restoration/rewilding, and sustainable use. Furthermore, understanding the cascading negative effects to our wellbeing from losing keystone species due to anthropogenic drivers of change, can provide a sound justification for the investments needed to protect and restore keystone species populations, and create financial solutions to address the funding gap in keystone species conservation, among others.

Ecosystem Health and Ecosystem Services

Ecosystem services are produced through the interaction of natural capital with social, built, and human capital (Hernández-Blanco & Costanza, 2019). The provision of ecosystem services is also dependent on the condition of the ecosystem (as well as on the condition of the rest of capital), which is often referred to as ecosystem health (Rapport, 1995). Costanza (1992) argues that "an ecosystem is healthy if it is stable and sustainable, that is, if it is active and maintains its organization and autonomy over time and is resilient to stress."

Considering this definition, the main features of ecosystem health are **vigour, organization, and resilience** (Costanza, 1992; Hernández-Blanco et al., 2022). The vigour of a system is a measure of its activity or metabolism and can be measured through indicators such as gross primary production and net primary production. The organization of an ecosystem refers to the number and diversity of interactions among the components of the system, which can be measured through its biological diversity and by the number and strength of pathways of exchange among components of the system. Finally, resilience refers to the ecosystem's ability to maintain its **structure (i.e., organization)** and **function (i.e., vigour)** in the presence of stress (Mageau et al., 1995; Costanza & Mageau, 1999).

The role that organization and vigour play in providing ecosystem services is also addressed in the ecosystem service cascade proposed by Haines-Young & Potschin (2010), highlighting the production of ecosystem functions by the ecosystem structure which can lead to the provision of benefits to society (Figure 1). Although the ecosystem cascade has received criticism due to its over simplistic description of how social-ecological systems operate, as well due to the overcomplication of making a difference between ecosystem services and benefits (Costanza et al., 2017), Haines-Young & Potschin nevertheless provides a useful initial framework to start thinking a way of linking both end points of natural capital assessment, from ecosystem health to benefits.

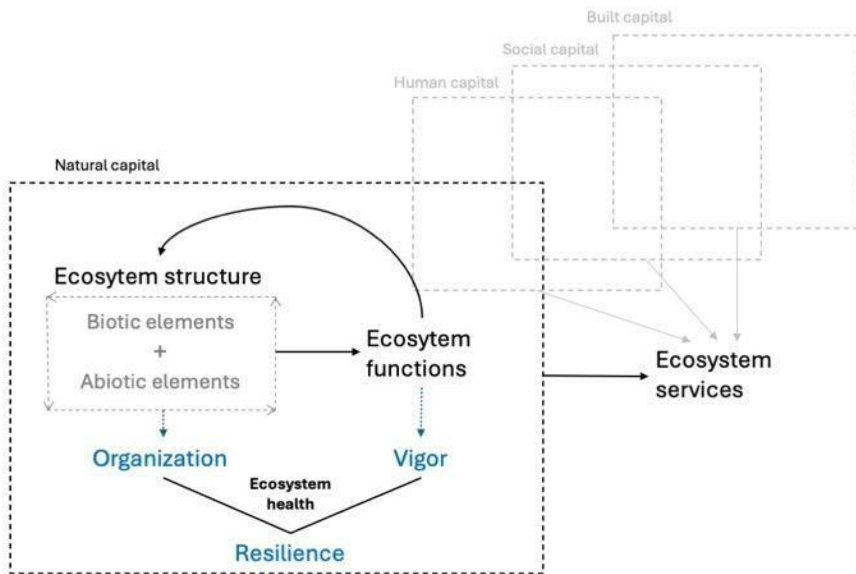

Figure B1. *Production of ecosystem services determined by the interaction of the four types of capitals. In the case of natural capital, the ecosystem structure determines the ecosystem functions. These two components of the ecosystem service cascade can also be assessed as the organization and vigour (respectively) of ecosystem health.*

The structure of the ecosystem, composed by the interaction of its abiotic and biotic components (i.e, producers, consumers, and decomposers), is determined by different ecological processes that produce the flow of ecosystem functions and potential ecosystem services (Mace et al., 2012). Therefore, changes in ecosystem health will be largely driven by changes in the system dynamics between biotic and abiotic components, as well as within biotic components. Although ecosystems are dynamic and therefore their health, its structure is maintained within the levels of the ecosystem resilience and therefore the system stays in a stable state. Significant stressors can move the ecosystem to another stable state by significantly altering its structure and resilience, and this new stable state could also have different functions and services.

Hernández-Blanco et al. (2022) proposed a logical framework to estimate changes in ecosystem health and the provision of ecosystem services, composed by (1) a development or conservation policy (which could be at different geographical scales), (2) a series of management decisions (i.e., origin of the driver of change), (3) the driver of change itself, (4) the change in ecosystem health and consequently, (5) the change in the provision of ecosystem services, and (6) their value. Therefore, the change in the value of the benefits we obtain from ecosystems is dependent (among other things) on the health of the system which is dependent on the biotic and abiotic factors that define its structure. For example, a country could promote an unsustainable agricultural production scheme (1), based on an excessively use of harmful agrochemicals (2), which will produce a significant level of chemical pollution (3), that changes one or more components of ecosystem health, such as biodiversity (4) that provide key ecosystem services like pollination (5), which will impact at the same time agricultural productivity (i.e., change in the ecosystem service value) (6). This general framework of course applies for positive changes as well.

The rest of this section is dedicated to exploring the role of the biotic components in providing ecosystem services.

The Role of Species in Supporting Ecosystem Services

The provision of ecosystem services requires the whole ecosystem, which is not only defined by its components, but mainly by the interaction webs built within which species can potentially influence other species, and these interactions can include both biological processes (e.g., competition, predation, and mutualism) and physicochemical processes (e.g., nutrients, impact on water limitation, temperature) (Estes et al., 2011). Therefore, the species that play a role in supporting ecosystem functions and services at the same time depend on the other species and abiotic elements in the ecosystem (Mace et al., 2012). For example, in the case of pollination, pollinators, such as bees in crops like coffee (Ricketts et al., 2004), depend on healthy forests (e.g., without stressors such as agrochemicals or land use change) as habitat.

Nevertheless, some have argued that species directly provide ecosystem services (Berzaghi et al., 2022; Cook et al., 2020), but this is fundamentally incorrect. First, and the most obvious reason, is that species are not ecosystems, and therefore species cannot be compared with ecosystems in the level of provision of benefits to society. Second, there is a lack of understanding on the ecological dynamics behind the provision of ecosystem services, and therefore it is assumed that species can be entirely responsible for the provision of services (e.g. climate regulation). Finally, the economic valuations of species are based on provisioning services such as food and raw materials. For example, Cook et al. (2020) assess benefits from whales such as meat and materials from the whale's bones and baleens. These uses from species such as whales are derived from the extraction of one element (i.e., the species) from the ecosystem, which is often done in an unsustainable way. Following with the example of whales, saying that food is an ecosystem service from these marine mammals is like saying that salmon provides a direct ecosystem service when it is finished, whereas food provisioning is a service from the entire marine or freshwater system that sustains the populations of these fishes of commercial interest.

The approach we present in this section considers the network dynamics of nature, and therefore the value of species based on maintaining the balance and function of the system to keep providing benefits, rather than on the disruption of this network. This approach was considered briefly in Haines-Young & Potschin (2010), who calls for the incorporation of functional traits from species (specially keystone species) on ecosystem services assessments, since these traits determine the effect of species on ecosystem processes or services and its response to stressors (i.e., resilience) (De Bello et al., 2008).

Each species plays a different role in supporting different ecosystem services. As a starting point to develop a valuation approach to this supporting role, we focus in this section on animals, recognizing that plants also have a key role, but also taking in consideration that animals can significantly impact primary productivity. Animals, regardless of the type of ecosystem, species, or functional types, influence ecosystems mainly through (1) predation, (2) foraging, (3) frugivory and seed dispersal, (4) grazing effects (5) nutrient deposition (e.g., defecation, urination, and (6) ecosystem engineering (Estes et al., 2011; Schmitz & Sylvén, 2023; Roman, 2023). Each one of these ecological processes that influence ecosystems have different impacts in one or more ecosystem functions, mainly (1) biological control, (2) pollination, (3) carbon sequestration, (4) fire regulation, (5) water regulation and (5) nutrient cycling. Finally, these ecosystem functions determine the provision of (1) food productivity, (2) water provision and regulation for different purposes, (3) climate regulation, and (4) disease control (Figure 2, Table 1).

All of these ecosystem services supported by species are regulating services (Millennium Ecosystem Assessment, 2005; TEEB, 2018; Costanza et al., 2017). Even in the case of food production, instead of being considered a provisioning service, in this context we consider it as a regulating service since we are interested in the changes in productivity from changes in animal's population and hence their influence. Our analysis could be expanded to provisioning services as well, although this would be a different analysis because it would assess the extraction of the components of the ecosystem, rather than the analysis on how the dynamics of these components supports the provision of benefits. Cultural services could also be considered, but from an economic point of view, the current available methods to assess these services do not properly reflect the role of biodiversity in supporting those services (Farnsworth et al., 2015).

Nevertheless, it is worth highlighting that estimating the economic value of activities based on species, especially umbrella species, such as the assessment from Wei et al. (2018) on the ecosystem services provided by giant panda reserves in China can be an effective complement to our approach for policy making. In this particular case, instead of valuing pandas through their recreational and tourism benefits (estimated through a benefit transfer function based on contingent valuation surveys), and bequest and existing values (through contingent valuation) our approach would focus on estimating the value of the influence of pandas on the ecosystem through bamboo consumption and its impact in these reserves in altering and/or maintaining the health of the ecosystem of these areas so they can provide different ecosystem services such as the ones valued by Farnsworth et al (2015) (e.g., climate regulation, hydrologic benefits, sediment retention).

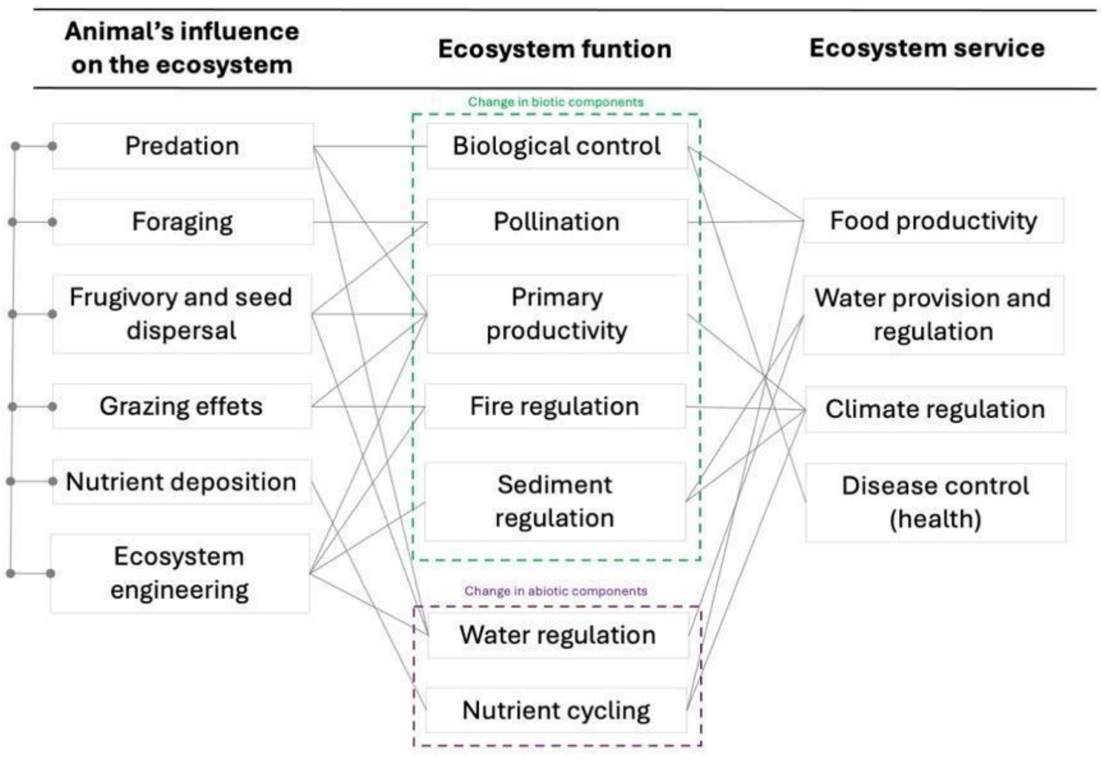

Figure B2. Relationship between ways in which animals can influence ecosystems, and the production of ecosystem functions and services.

Table B1. List of examples on how species play a role in supporting the provision of ecosystem services (not an exhaustive list).

Species role on supporting ecosystem services	Example	
1. Predation – Biological control – Disease control	Decrease in lions and leopards in sub-Saharan Africa has led to the increase of olive baboons, which transmitted intestinal parasites to humans	(Brashares et al., 2010)
2. Predation – Primary productivity – climate regulation	Salamanders reduce invertebrate populations leading to increased leaf litter retention, increasing carbon storage	(Best & Welsh, 2014)
3. Predation – sediment regulation – Water regulation	The role of large predators in maintaining riparian plant communities and river morphology	(Beschta & Ripple, 2012)
4. Predation – Primary productivity – Climate regulation	Sea otters control herbivory pressure from sea urchins on kelp forests	(Estes & Palmisano, 1974)
5. Foraging – Pollination – Food productivity	Forest-based pollinators increased coffee yields by 20% within 1 km of forest, as well as improving coffee quality by reducing the frequency of peaberries by 27%.	(Ricketts et al., 2004)
6. Grazing effects – Fire regulation – Climate regulation	Rinderpest decimated native ungulate populations in the late 1800s, causing an increase in plant biomass, fueling wildfires during the dry season.	(Holdo et al., 2009)
7. Nutrient deposition – Primary productivity – climate regulation	Whale feces transport limiting nutrients from the aphotic to photic zones, enhancing primary productivity and carbon sequestration, a process often call "the whale pump"	(Roman & McCarthy, 2010)
8. Ecosystem engineering – Primary productivity – climate regulation	African forest elephants reduce the density of trees smaller than 30cm in diameter while moving through the forest and foraging, leading to the increase in the proportion and the average size of late succession trees with a higher carbon density.	(Berzaghi et al. 2022) (Berzaghi, et al., 2022b)

Species role on supporting ecosystem services	Example	
9. Ecosystem engineering – Sediment regulation – multiple services	Role of fiddler crab (*Uca spp.*) burrowing on the growth and production of the white mangrove, *Laguncularia racemosa*	(Smith et al., 2009)

It is worth saying that these seven interactions do not happen linearly or in isolation, making the examples of Table 1 an oversimplification of the reality, but it is useful nevertheless for the purposes of better understanding the economic value of these species. Many of these interactions will produce a mix of ecosystem functions that depend on them (e.g., predation on herbivores to maintain plant biomass).

Also, it is important to take into consideration the timeframe and the main supplier of the ecosystem service. For example, Berzaghi et al. (2022) considered as part of the study the carbon stored in the elephant population, which, in our opinion this is more a flow than a stock, since this carbon will only be kept in the animals when they are alive (~60-70 years), and will end up in different stocks or flows depending on the pathway it follows after the animal die. For example, it could be deposited in the ground, which then we would account for as the contribution of elephants through nutrient deposition to nutrient cycling or primary productivity. On the other hand, part of the carbon could also be transferred to other animals through consumption, and therefore we need to model the potential pathways and quantities of stocks and flows of carbon so we can take this type of role into consideration.

Another key point to address in assessing the role of species in supporting the provision of ecosystem services is the role that keystone species play, which are most examples described in Table 1. Through their activities and abundance, keystone species have a disproportionate impact on the stability of the ecosystem structure (Paine, 1969), and therefore on the production of ecosystem functions. Keystone species, therefore, maintain the health of an ecosystem by maintaining its structure and vigour which determines the ecosystems resilience. One of the roles that has been the most assessed of keystone species is its dynamic influence in the trophic level, often producing a cascade of effects (i.e., trophic cascade), which can be direct or indirect (Paine, 1995), as most examples on predation listed in Table 1. Nevertheless, other types of keystone species that should also be considered in an economic analysis of the role of species in supporting ecosystem services are ecosystem engineers (examples 8 and 9 from Table 1), mutualists (example 5 from Table B1) and herbivores (example 6 from Table B1).

Finally, it is worth noting that the contribution of species to the ecosystem health and ecosystem services is multi spatial, since one species can play a role in different types of ecosystems through different biological functions, which can have an economic impact, especially for local communities. For example, the parrot fish spends most of their time grazing on algae and other calcified surfaces in coral reefs, keeping the health of the ecosystem and therefore its resilience (Bellwood & Choat, 1990; Bonaldo et al., 2014). In their absence, the system would shift to another stable state (i.e., dominated by algae) and hence there would be a significant change in some ecosystem functions such as the provision for habitat for these and many other species, as well as high value ecosystem services such as tourism and recreation, and provision of food (UN Environment et al., 2018). Aside from the role of grazers on coral reefs, parrotfish are also ecosystem engineers, playing a key role as bioerosion agents and therefore producing large quantities of carbonate sediment as a by-product of their grazing (Morgan & Kench, 2016). For example, in the Maldives, parrotfish generate more than 85% of the 5.7 kg m^2 of new sand-grade sediment produced on the outer reef flat each year (Perry et al., 2015). In this way, parrotfish contribute to the building of these islands that are visited by many people per year, and therefore their role on beaches also have a significant value (Figure B3).

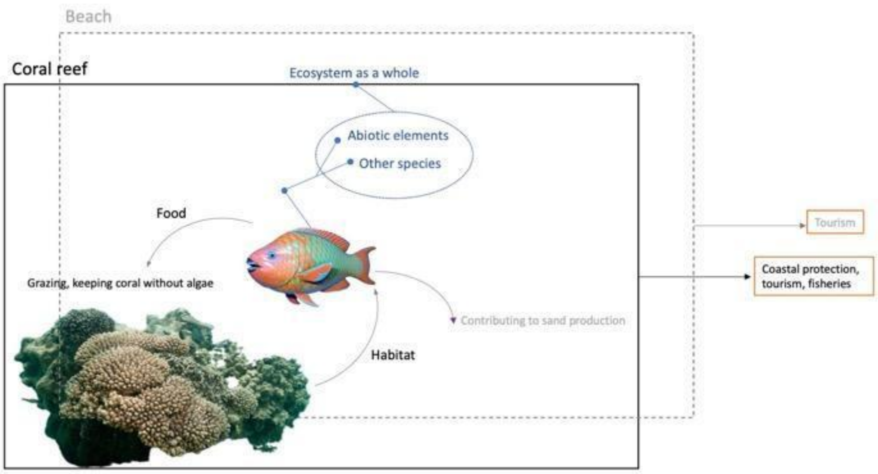

Figure B3. *Multi-spatial influence of parrotfish on two ecosystems, supporting the provision of different ecosystem services in each of these ecosystems.*

This multi spatial influence on ecosystems from some species can also be explained by a stock and flow analysis. For example, the supply of guano in Perú is dependent on the population (stock) of birds (e.g., Guanay Cormorants, Peruvian Pelicans, and Peruvian Boobies) producing guano (stock) (the nutrient deposition role). At the same time, the population depends on food availability, which in this case can come from different ecosystems, and therefore these stocks are multi-spatial. The case of guano collection is different from the other examples we have provided which are based on the support of regulating services, and in this case the analysis would be on the provisioning service of fertilizers for agriculture (Collyns, 2022). Beyond the provision service, among other roles we could consider from seabirds (e.g. seed dispersal, predation), the nutrient deposition role is an interesting example of the multi spatial influence of species because it links the dynamics of two ecosystems, where seabirds export nutrients from the ocean (where they feed) to land (where they nest), and therefore it is a key nutrient subsidy for the health of latter (Figure B4).

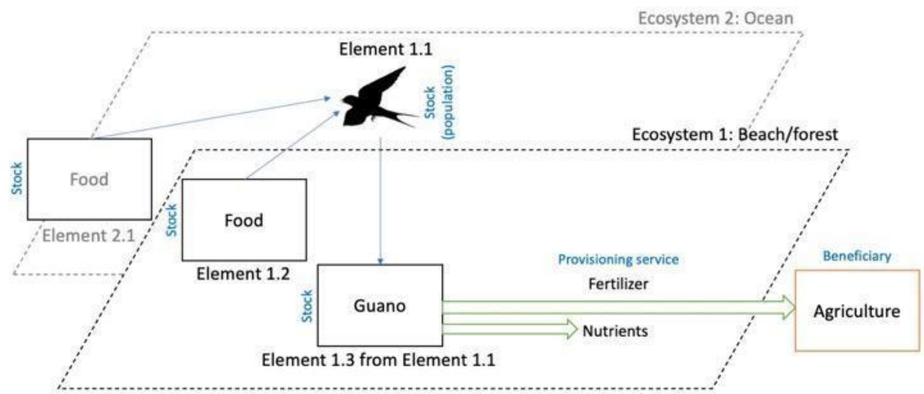

***Figure B4**. Stock and flow schematic analysis of the multi spatial influence of seabirds on terrestrial and marine ecosystems, which supports the production of guano that is used as a fertilizer in agriculture.*

General Methodological Framework

As stated before, ecosystem services are the benefits people derive from ecosystems; they are provided by natural capital in combination with built, social, and human capital. The value of ecosystem services is therefore the relative contribution of ecosystems to well-being (Turner et al. 2016). This contribution can be expressed in various units (any units of the four types of capitals), where monetary units are often the most used and convenient since most people understand values in these units.

Valuation allows a more efficient use of limited funds by identifying where environmental protection and restoration is economically most significant, supporting the determination of the amount of compensation that should be paid for the degradation and/or loss of ecosystem services and improving the financial mechanisms (e.g., incentives) for the conservation and sustainable use of natural capital (e.g., Payment for Ecosystem Services), among other uses (De Groot et al., 2012). The value of ecosystem services can also be estimated by determining the cost to replicate them by artificial means (Costanza et al. 1997), for example how much it would cost a farmer to pollinate his crops artificially. It is useful to attempt to calculate the impact on human well-being from changes in quantity or quality of natural capital that can occur due to different development decisions (Costanza et al. 1997).

Valuation is therefore a tool for evaluating the trade-offs required to achieve a shared goal, where in the past and in the present these trade-offs have been addressed mainly through marketed goods and services (e.g., fuel or food) using commodity prices, excluding from the equation, other goods and services that currently do not have a price but that contribute equally or even more greatly to well-being (Turner et al. 2016). Moreover, the role that species play in supporting these services has not been assessed extensively in the economic literature. The following is a general methodological framework to estimate the economic value of this role, consisting of a five-step process.

Step 1. Select the species of interest.

The first step is to select the species for which the role in supporting ecosystem functions wants to be valued economically. This can be in different ways, and can also depend on the context and policy objectives of which the study is embedded in, but the following selection criteria can provide some guidance: (1) Status of the population (especially if it is vulnerable or endangered), (2) potential changes in population in the future, (3) if the species is a keystone species and/or umbrella species, (4) if there are already ecological and economic data that can be used in the analysis, and (5) the level of dependency from human beneficiaries on the functions that these species support.

Step 2. Set the spatial scope.

This involves setting the physical and ecological limits within the ecosystem(s) of interest. The selected species range needs to be mapped out, considering all the possible biotic and abiotic components of the structure of the system (1) on which the species depend and (2) have an impact on (recognizing that in many occasions these two would be the same). It is important to recognize that the limits of the study will be to some degree arbitrary since these limits do not really exist in nature.

Step 3. Identify the role the species play in supporting ecosystem functions.

From an economic perspective, this means estimating the supply. This will be done by developing a dynamic ecological model to identify the interactions of the targeted species with other biotic and abiotic elements of the ecosystem. This could also include, among other things, a trophic dynamics analysis. The goal is to identify the roles of the species (as listed in Table 1) in supporting ecosystem functions in the spatial scope of the study, or to determine if the species have an impact on a partial or complete bundle of functions (e.g., sea otters protect the entire bundle of functions and services provided by kelp forests). There are several visual programming languages that can be used to build these models, such as Vensim and Stella.

Step 4. Identify the main beneficiaries of the supported functions.

The beneficiaries of the functions that are supported by the selected species represent the demand, which will lead to the identification and prioritization of the ecosystem services. The role of species will then be a portion of the value of these ecosystem services.

Step 5. Conduct an economic analysis.

Finally, depending on the function that the species supports, there are basically two types of economic methods that are the most appropriate to use (Farnsworth et al., 2015). On one hand, there are the production approaches where the economic value of the service is estimated from the impact of those services on economic outputs, such as in the case of an increased availability of nutrients from the whale pump and its impact on the productivity of the local fishing industry. On the other hand, cost-based approaches such as replacement cost and avoidance cost can also be adapted to estimate the role of species on the provision of ecosystem services (Table 2). In the case of the first one, the loss of a natural system service is evaluated in terms of what it would cost to replace that service (e.g., public health strategies to substitute the biological/disease control that species such as lions perform for free to society). In the second case, a service is valued based on costs avoided (e.g., mitigation of the damage to public and private property from extreme weather events from healthy ecosystems such as wetlands can be supported significantly by species such as beavers) (Turner et al., 2016; Hernández-Blanco & Costanza, 2019).

Table 2. Economic valuation methods to use for each of the ecosystem services that have been described in this analysis that are dependent on the role of one or more species.

Ecosystem service supported by selected species	Production approach	Cost-based approaches
Food productivity	X	
Water provision and regulation	X	
Climate regulation		X
Disease control		X

The main goal is to measure the change of benefits under different scenarios using the dynamic ecological model from Step 3. The stocks and flows of this model can be modified by both natural and anthropogenic drivers of change that will impact the species population and consequently the value of species contribution to the provision of ecosystem services. Examples of scenarios that can be modelled include "Business As Usual", rewilding efforts, conserving current population, population decrease (at different levels), and local extinction, among others. The modelling of the selected scenarios will be ideally complemented with participatory approaches of scenario planning with a wide set of actors, including especially the beneficiaries of the services dependent on the elected species for the assessment, those who might bear costs of the changes in the species population (including human wildlife conflicts).

Other similar methodological approaches have been developed, most notably the one from Daniels et al. (2018). Nevertheless, our approach differs in two main points. The first one is that Daniels et al. (2018) focus on functional groups rather than species, which can represent both benefits and limitations. The second one is that their approach considers only marketed services, while ours considers both marketed and non-marketed.

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