



Climate Change, Biodiversity, and Tipping Points in Botswana

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Contents

Introduction	2
Tipping Points and Emergence	3
Emergence and Innovation	4
ISEET Analysis Framework	6
Institutional-Socio-Earth-Economical-Technical (ISEET) systems	6
The Working Definition of a Subsystem	7
Case Study: Botswana’s Biodiversity Sector	8
Biodiversity and Tipping Points	10
Baseline Biodiversity in Botswana	15
Biodiversity, Ecosystem Services, and Tourism	18
Climate Change Impacts on the Biodiversity in Botswana	20
One Example: The Okavango Delta	21
Tipping Points for Climate Change for the Biodiversity Sector	22
Results and Recommendations	22
Summary and Conclusion	30
References	31

Abstract

Climate adaptation planning requires new ways of thinking and approaching the analysis of risks. Such thinking needs to be systemic in nature and practice/action-oriented while respecting the complexity of the physical and social sciences. Through this chapter on climate tipping points in Botswana, it is proposed

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that a generic and practice-oriented analysis framework be applied with a mathematical foundation including modeling methods based on complex science. The objective is to promote a framework that privileges a worldview to avoid biased and partial explanations of risks. An Institutional-Socio-Earth-Economical-Technical systems (ISEET) approach is based on a systems science philosophy for risk governance analysis, with particular emphasis on tipping points and emergence which are some of the key elements that can support sound adaptation planning. Through the lens of the biodiversity sector in Botswana, the complex interrelationships of ISEET principles are explained. They provide a new, efficient, and practical framework for moving rapidly from theory to action for planning and implementing climate change adaptation projects.

Keywords

Tipping points · System dynamics · Climate change · Risk assessment · Biodiversity · Action research

Introduction

Humanity has modified the earth systems in significant ways and has initiated unprecedented Anthropocene risks (Keys et al. 2019; Baer and Singer 2018). Changes include fundamental aspects of the earth system such as all layers of the atmosphere, hydrosphere, and cryosphere through changes in weather patterns, climate, land surfaces, ocean chemistry, and geological structures. Anthropocene risks such as global connectivity either have reached or are approaching tipping points of various earth systems at different temporal and spatial scales (Steffen et al. 2018). Meanwhile, the emergence of new knowledge, technologies, and institutions has led to new approaches for problem-solving. An example of collective action is the Paris Agreement ratified by the United Nations Framework Convention on Climate Change (UNFCCC). However, progress in mitigating climate risk has not been satisfying. Responses are uneven and uncoordinated, and CO₂ emissions continue to increase globally, even with green energy and other technological advancements. New approaches to the analysis of risks need to be articulated systemically and be practice-oriented while respecting the complexity of the physical and social sciences (Sterner et al. 2019; Lucas et al. 2018).

The existing initiatives and frameworks are limited, such as the Sendai Framework for Disaster Risk Reduction, the Paris Agreement, and international programs such as IRGP-IDHP (Integrated Risk Governance Project-International Human Dimension Programme). These limitations transcend the research frameworks as well, such as SES (socio-ecological system), STS (science technology and sustainability), and IAD (institutional analysis and development). The weaknesses of these existing frameworks as analysis and practice tools are being more widely debated and are modified as society seeks a better understanding of systemic risks posed by climate change and large-scale socio-physical disasters (Cole et al. 2014; McCord et al. 2017).

A more generic and practice-oriented analysis framework is explored from a mathematical foundation, including modeling methods based on complex science. A structure of systems thinking applicable in the Anthropocene is proposed whereby analysis privileges a worldview and earth-view that attempt to avoid biased and partial explanations of risks.

Tipping Points and Emergence

There are standard features of systemic risks in different domains. These include the character of agents and emergence phenomena, tipping parameters indicating instability, and more noncommittal empirical observations. Instead, these features can be related as Lucas et al. (2018) describe on fundamental theory for relatively well-understood and straightforward systems in physics and chemistry. A crucial mechanism is the breakdown of macroscopic patterns of whole systems due to feedback reinforcing actions of agents on the microlevel, whereby the role of complexity science forms the basis for unifying the phenomena of systemic risks in widely different domains.

Tipping points sometimes also refer to shifting points. For example, the shift from an unsustainable to a sustainable society requires a radical historical change in the form of a profound transition which could involve a series of connected transitions in many socio-technical systems (e.g., energy, mobility, and food) toward sustainability. People who work from an SES point of view, studying the profound transition and radical change issues, use different expressions (Schot and Kanger 2018; van der Vleuten 2019).

According to Lenton et al. (2008: 1786), the term tipping point refers to a “critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system.” The following attributes are identified as tipping points in the Anthropocene:

- Tipping points could impact the whole planetary scale, everything living on Earth.
- Tipping points could impact the transition or the change of regime.
- Interaction crosses boundaries, including administration and nature systems and ISEETS boundaries.
- Both collective and individual social actions operate in multiple sociocultural, technological, governance, biophysical, and knowledge systems which interact with many other systems at the same time and many levels.
- Tàbara et al. (2018) focused on the complexity of attribution and a reductionist approach about systems thinking and the historical drive to an oversimplified explanation of solutions, drivers of tipping points that could improve the likelihood of limiting global warming to either the 1.5 °C or 2 °C target.
- When social and natural scientists collaborate and integrate their studies, new patterns and previously unforeseen relationships that can accentuate understanding have been achieved. Such studies often reveal intricate causes and effects as

such works are based on well-defined spatial, temporal, and organizational units, be they culturally, physically, or politically determined. Another finding in such studies is their non-stationary and as Liu et al. (2009) feedback loops lag in effects from a range of identified causes and their relationship with resilience and thresholds can reveal new insights. It is also recognized that past interrelationships can have spillover effects that can continue to impact on not only a present state of a system but also its future.

- Tipping points are likely to be breached in the future; however, the underlying conditions are challenging to predict, and the accuracy in defining the time and place makes policy and decision-making currently inadequate for either mitigating or possibly avoiding transgressions.
- Thresholds are not constant. Instead, the position of a threshold along a determining variable can change. The consequences of crossing a threshold are context-dependent. The threshold is sometimes known, and the decision-making depends on the effects of crossing it.
- Tipping points or regime shifts are intricately related to the concept of system resilience.

Emergence and Innovation

Emergence plays a central role in theories related to integrative levels and complex systems. Emergence and emergent phenomena are essential concepts in complexity studies (Goldstein 2018). Emergence can be described as either the development or the presence of the existence or formation of common behaviors, whereby the collective actions within a system would not lead to a similar outcome if applied as individual, constituent parts with no recognized interaction. Emergence is also used to describe the properties of a system – what the system does under its relationship with the environment that it would not otherwise complete itself and is coupled to the scope and system boundaries (Ryan 2007). Emergence also refers to the ability of individual components of a system to collaborate, thus leading to rapid and diverse behavioral changes and new features. For the ISEET, more linkages and communication between subsystems, or the building of more relationships among the ISEET subsystems, could lead to new features emerging. These would then reflect the application of the more complex system and possibly more innovative systems thinking. Emergence is typically not reducible to, nor readily predictable from, the properties of individual system components. Therefore, it may appear surprising or unexpected (Halley and Winkler 2008). Emergent phenomena exist in all subsystems, which could provide solutions or options to the existing challenges in all subsystems if the emergence is managed properly (Ceccarelli et al. 2019; Lichtenstein 2014; Roundy et al. 2018).

Emergence could be applied in a conceptual framework. This framework could improve the understanding of scientific and technological progress (Alexander et al. 2012), innovation, and economic growth (Du and O'Connor 2019). Such a holistic innovation system could improve productivity through the diverse knowledge of

business resources available. Emergence also could be scored to identify the topics and drivers of innovation (Porter et al. 2019).

The technology innovation process is central to effective adaption to climate change and development challenges. However, models from business and management tend to dominate innovation theory, which sits outside the adaption-development paradigm (Hope et al. 2018). The goal is, however, to support the development of sectoral and technologically detailed and policy-relevant country-driven strategies consistent with the UNFCCC Paris Agreement.

An ISEETS framework can be used to engage stakeholder input and buy-in; design implementation policy packages; reveal necessary technological, financial, and institutional enabling conditions; and support global stock-taking and ratcheting of ambition (Waisman et al. 2019).

Macro-level agreements, such as the UNFCCC Paris Agreement, should be designed to encourage debate on how to tackle climate change through the notion of innovation, applying both technological innovation and marketing issues. Innovation of a technical nature is part of the equation, but it is not the only requirement. It has been suggested by Asayehegn et al. (2017) that an enabling sectoral system of innovation (SSI) be prioritized where some technological innovations contribute to adaptation actions for climate change. Technological impact analysis could be included based on the following approaches: historical sectoral application and improvement on the systems, such as agriculture technology, live-stock breeding and feeding technology, ICT technology, carbon sequestration technology, and others where appropriate.

With the emergence of adaptation technology, it can be defined as “the application of technology to reduce the vulnerability or enhance the resilience, of a natural or human system to the risks of climate change” (UNFCCC 2005: 5). Technologies are defined as either “hard” that includes equipment and infrastructure or “soft” such as institutions and management systems (Christiansen et al. 2011). However, some technologies, such as new crop varieties, are not so easy to categorize. Many technologies can be used to address current vulnerabilities to climate and other environmental, economic, and societal concerns and to reduce future exposure to climate change impacts. Some can also be used to address several types of climate change impact in different sectors.

ISEET modeling seems too big to be handled by either a single model or an existing framework. However, when considering specific modeling for a risk governance issue, the data, variables, and parameters could be selected and refined according to their importance and their functionalities. The modeling approaches from different disciplines could be either simplified or reorganized to fit specific purposes. For the subsystem in this chapter, the modeling approaches have been developed for specific contexts, which can be either absorbed or integrated into the ISEET modeling processes.

Modeling systemic or structural change in socio-environmental systems is not new. Tipping point modeling has been carried out by scientists from SES, climate systems, social systems, network analysis, and agent-based modeling disciplines.

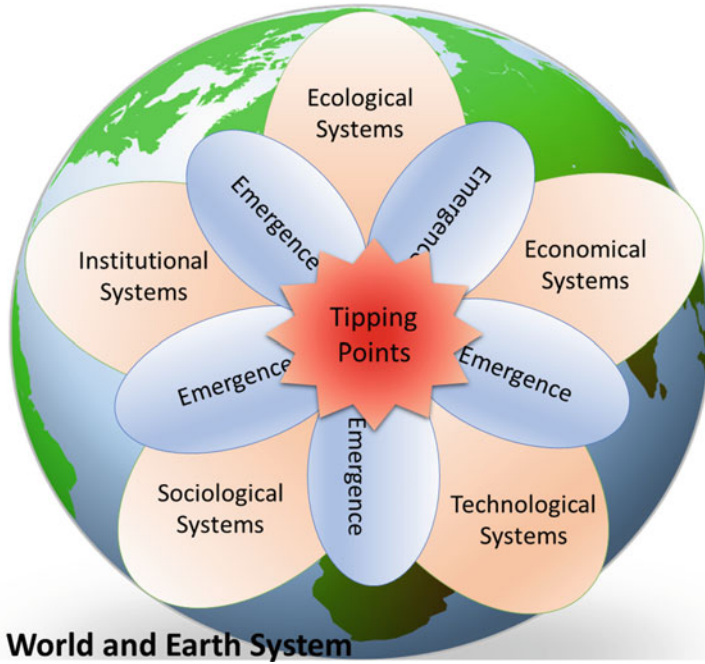


Fig. 1 The framework of Institutional-Socio-Economic-Ecological-Technological Systems (ISEETS) for a climate change tipping point study. (Source: authors)

Based on the ISEET system analysis framework, Fig. 1 depicts an overview of an ISEET structure for tipping points and the emergence of, and linkages between, five subsystems.

Tipping points and regime shifts are being studied within various disciplines applying a range of modeling approaches and analysis frameworks. One of the first obstacles in any study of systemic change is the terminology. Environmental and social science disciplines have engaged in relevant ideas of regime shift, structural change, non-marginal change, and transition theory, and each claims ownership (Polhill et al. 2016).

ISEET Analysis Framework

Institutional-Socio-Earth-Economical-Technical (ISEET) systems

ISEET describes five intrinsically interlinked systems formed around the Anthropocene. The method has at its foundation systems science concepts and mathematical methodologies for risk governance analysis, with emphasis on tipping points and emergence, which are the key characteristics that need to be analyzed for risk governance.

ISEET represents a dynamic system. Their elements, functions, and relationships change with time and across spatial scales. Historical evidence and future prediction are essential for risk governance. Human beings do not always passively react to risks. With new and different technologies and the extension of knowledge, the risk may become more manageable. Opportunities could be created through the emergence mechanism in ISEET.

ISEET systems can be characterized as the coupling of natural laws with world rules. The goals are to support mutual well-being of the earth (physical) and world (social) systems. To describe risk governance issues in the Anthropocene, ISEET framework subsystems are indispensable. ISEET risk governance is either realized or implemented by institutions. They require the full engagement of societies and apply certain economically viable technologies that should encompass sustainable ecosystem service support from the earth environment and its resources.

From the subsystem point of view, the interrelationship could be described as:

- An institution that must have close collaboration with its relational society, using environmentally and ethically sound and economically viable technologies.
- Societies that could live with the environment, given effective and efficient institutions, and be economically healthy, with controllable risks on the earth system.
- Societies that need to work together to advance and apply technologies with economic endeavors, to live sustainably with the earth system.
- The sustainable development of economic systems that could be achieved by a well-designed and well-operated institution, which include social capital and earth resources.
- Technology that may need to be advanced and applied and that does not harm the environment and is ethically healthy. In this way, societies are more likely to promote institutions, with the input from their constituent economic systems.

The Working Definition of a Subsystem

- An institution in ISEET implies a body that operates within regulations, laws, policies, and conventions. Such institutions can represent cross-sectoral entities established when either developing or implementing a related risk governance framework. For example, emergency management laws and emergency management ministries are all part of a larger institutional system.
- Social systems in ISEET refer to all the elements, functions, and relationships in societies, including the population and its age and gender composition, culture, religion, educational level, and connectivity. Complexity theory offers the toolkit needed for this paradigm shift in social theory (Walby 2007).
- Earth system refers to the biophysical existence of the Earth planet, including the living support environment, from top air to deep earth.
- An economic system, as defined by Gregory and Stuart (2013: 30), “is a system of production, resource allocation and distribution of goods and services within

a society or a given geographic area. It includes the combination of the various institutions, agencies, entities, decision-making processes and patterns of consumption that comprise the economic structure of a given community.”

- Technological systems are sets of interconnected components that transform, store, transport, or control materials, energy, and information for specific purposes. Machines, software, and the hardware they run on are considered part of a technological system. Similarly, how humanity organizes itself to apply such technology are broader arrangements based on the organization’s structures to exploit technology and techniques developed to optimize their application.

Case Study: Botswana’s Biodiversity Sector

Time is of the essence for engaging in the intersection between climate change and the biodiversity extinction crisis. The Global Deal for Nature (GDN) is one opportunity as it is science-driven with the goal of saving the diversity and current relative abundance of life on the planet. The linkage of the GDN with the Paris Climate Agreement might help humanity avoid catastrophic climate change while conserving species and their increasingly recognized values, including ecosystem services.

Compelling recent findings add additional urgency to the issue as less than half of the globe’s terrestrial realm is intact. The application of global climate points toward a tipping point. Habit conversions continuing as they were historically while greenhouse gas emissions maintaining its current trajectories may exceed humanity’s chances of limiting global warming to the 1.5 °C target. Over the next 10 years, currently expanding conversion and poaching rates need to be slowed down considerably to avoid “points of no return” for some floral and faunal species (Fig. 2).

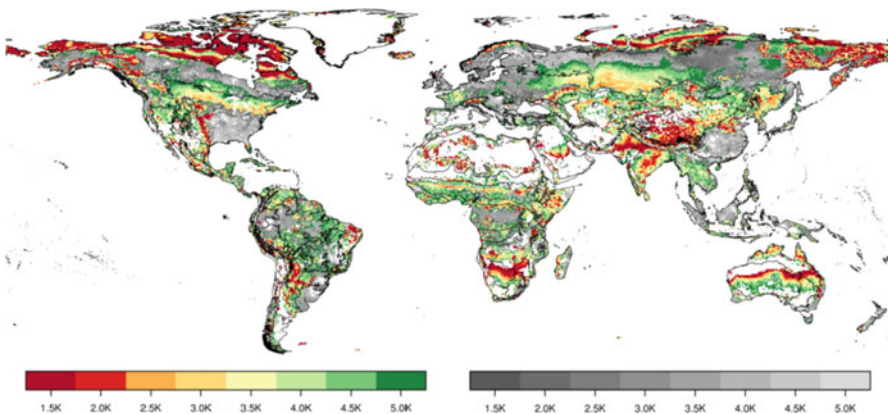


Fig. 2 Thresholds of temperature anomaly that could lead to significant local changes in land-based ecosystems. Colored areas (left legend) represent regions with severe transformation; gray areas (right legend) are likely to experience moderate transformation. Dark red transformation at 1.5 °C and light red at 2.0 °C. (Courtesy of Gerten et al. 2013)

If global mean temperatures are permitted to rise above 1.5 °C, it is widely believed that fundamental aspects of ecosystems, both large and small, could unravel. Continued unsustainable use of the natural environment threatens our global health as witnessed by the rising risk of global pandemics, while mass migration owing to the lack of access to resources such as clean water and productive and uncontaminated land become more widespread. Global climate change and its increase in extreme events could accelerate the degradation of land and societies. For example, climate change-induced sea level rise and extreme still high-water events, which inundate coastal zones and droughts, may displace at least 100 million people by 2050. Most of those people currently live in the southern hemisphere (Dinerstein et al. 2019).

Botswana, as part of Southern Africa, is home to an appreciable portion of global biodiversity, and many of its ecosystems retain relatively intact species assemblages across all trophic levels. The region possesses an established network of protected areas that contribute both to conservation targets and to nature-based tourism. Pressure on biodiversity can result from regional and highly localized developments concerning extractive resource use. Anthropogenic climate changes are more widely accepted as a profound driver of such impacts for Africa's biodiversity, including Botswana, and it is increasingly likely to be harmful from both ecological and economic perspectives.

Worldwide, the United Nations is committed to mainstreaming biodiversity planning in a wide range of policies and programs and with the inclusion of climate change. In a country such as Botswana, mainstreaming biodiversity and/or wildlife management at the local, regional, and country level is critical to its economy and its place as a critical biodiversity REDD hotspot for several primary faunal species.

Botswana, in terms of biodiversity, is a country of contrasts. The diversity ranges from the wetlands of the north, dependent on water arriving season from neighboring Angola, to the broad and arid Kalahari Desert in the center and southwest. Each area is part of a systematic protected area system with the Okavango Delta representing the world's largest inland delta which is also a Ramsar site. At the same time, Chobe National Park has many varieties and populations of game and a considerable density of elephants. The country has innovated the first formally declared trans-boundary park in Africa, the Kgalagadi Transfrontier Park. There is also the Central Kalahari Game Reserve and the distinctive prehistoric lake that now consists of salt pans called the Makgadikgadi and Nxai Pans National Park system. This area has important habitats for migratory birds.

Botswana is developing a National Climate Change Policy, Strategy and Action Plan (NCCPSAP) with the framework for such being only recently devised. The policy will be implemented through the Ministry of Environment, Wildlife and Tourism in cooperation with the United Nations Development Programme. Among other objectives, the NCCPSAP aims to develop and implement appropriate adaptation strategies and actions that will lower the vulnerability of Botswana and various sectors of the economy to the impacts of climate change.

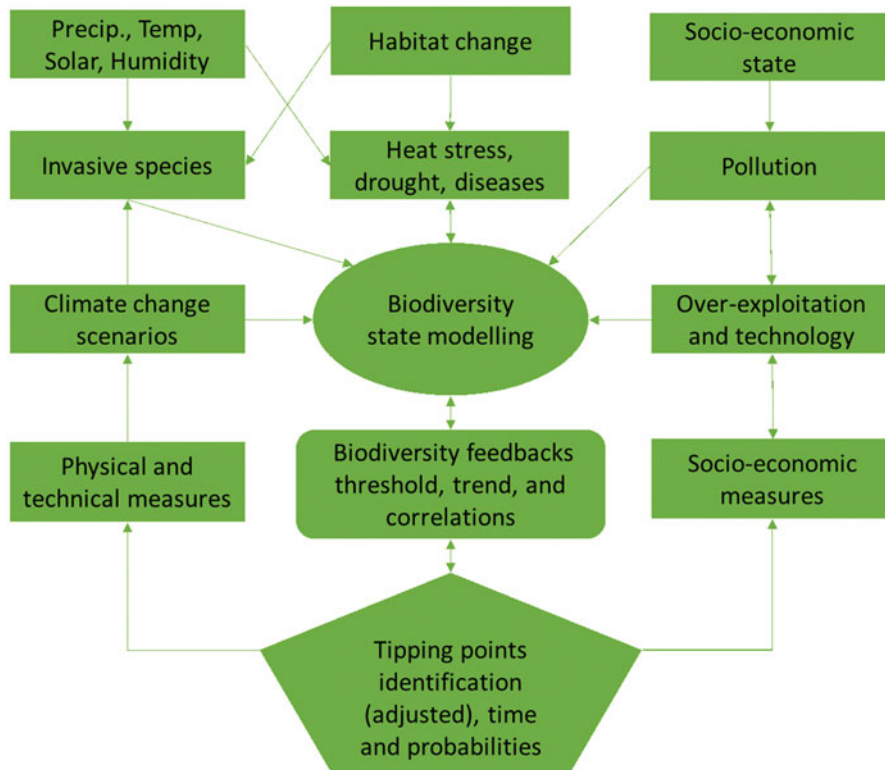


Fig. 3 Tipping point analysis framework for biodiversity in Botswana. (Source: authors)

Biodiversity and Tipping Points

Biodiversity in the context of tipping points is a complex area for investigation. Alternate stable states are associated with abrupt shifts in ecosystems, tipping points, and hysteresis, all of which challenge traditional approaches to ecosystem management (Oliver et al. 2015). Ecosystems often maintain their stability through internal feedback mechanisms. Environmental perturbations (natural and enhanced by climate change) can change the frequency and magnitude of regime shifts leading to fundamental changes in the assemblages of species providing functions.

Systems can be more susceptible to environmental randomness/irregularity and perturbations/fluctuation close to these critical tipping points and can lead to sudden changes and foster a new equilibrium. Such evolved alternative stable states might be unsupportive in terms of ecosystem functions with a return to a previous state only possible through substantial and costly management interventions (hysteresis). Therefore, the recovery capacity of ecosystem function can be compromised. Alternative conditions have been documented in a wide variety of ecosystems

from local to global scales. However, how stable and persistent these will be in the future, under rapid changes in climate, remain uncertain.

It is exceedingly difficult to understand how complex ecosystems, for example, the Okavango Delta, will behave as they either approach or surpass tipping points (Fig. 3). Exceedingly small changes in one or more conditions can lead to a cascade of other changes resulting in a large shift in the state of the system. Sometimes this process can be played out very slowly and therefore less perceptibly by society, and at other times, extreme events lead to radical shifts that exceed the capability of systems to slowly recover, and hence it is forced to find a new stasis; this is a natural process with volcanic eruptions, earthquakes, and flood events often leading to abrupt changes. However, climate change and its speed of onset, which varies from location to location, and the uncertainty in future projections can lead to management paralysis. The slowing down of a potentially catastrophic collapse of individual and highly relevant parts of a system is therefore preferred to prolong the sustainability of the large system.

Ecosystem management depends on monitoring and maintaining resilience because the loss of resilience renders ecosystems more vulnerable to undesirable shifts. Several works summarized by Dai et al. (2012) suggest that a set of generic indicators may aid in the sustainable management of fragile ecosystems. Signals of critical slowing down based on time series demand observations over a long span. Compiling such data is often tricky; therefore, if other indicators based on the spatial structure can be identified, they could be complementary to the early warning signals.

Tipping points are often driven by either complex feedback mechanisms or interactions between multiple drivers. Some of these triggers or drivers are found to be new and thus are not well represented in models currently in use (Leadley et al. 2010). An example is a relationship between dying back in Amazon forests and deforestation and climate change processes that resulted in an underestimation of impacts in earlier global biodiversity assessments. This situation may pertain in the case of the Okavango Delta where the sustained integrity of the Miombo woodlands on neighboring country of Angola leaves the well-established ecotourism focal areas such as the Okavango swamps in Botswana critically dependent on the sustained flow of sediment- and nutrient-free water from those upland parts of the wider river basin (Leadley et al. 2010).

Ecosystem service degradation can be linked with species extinctions, eroding species abundance, or as shown in this chapter potential shifts in biomes and associated species distributions. However, conservation of biodiversity and provision of some types of ecosystem services can conflict. The following tables list the already identified changes (from 2008 to 2019) in red category lists for plants and animals in Botswana in a limited African context (Tables 1, 2, and 3).

Midgley and Thuiller (2011) suggest significant impacts from unrestrained climate change for the southern part of the African region. However, overestimates of the speed of change and extent of those impacts may be the case owing to underlying assumptions of bioclimatic modeling. The analysis of a diverse range of studies does, however, support the rationale for a high level of concern as there is a signal

Table 1 Red List Category summary country totals (plants) by the number of extinct, threatened, and other species of plants in each Red List Category in each country (IUCN 2008, 2019)

	EX	EW	Subtotal	CR	EN	VU	Subtotal	LR/cd	NT	DD	LC	Total
Sub-Saharan Africa												
Angola 2008	0	0	0	0	2	24	26	0	6	1	6	39
Botswana 2008	0	0	0	0	0	0	0	0	3	0	3	6
Angola 2019	0	0	0	0	4	32	36	14	0	38	859	947
Botswana 2019	0	0	0	0	1	2	3	2	0	8	398	411

IUCN Red List Categories: *EX* extinct, *EW* extinct in the wild, *CR* critically endangered, *EN* endangered, *VU* vulnerable, *LR/cd* lower risk/conservation-dependent, *NT* near threatened (includes *LR/nt* lower risk/near threatened), *DD* data-deficient, *LC* least concern (includes *LR/lc* lower risk/least concern)

Table 2 Red List Category summary country totals by numbers of threatened species (critically endangered, endangered, and vulnerable categories only) in each major taxonomic group by country (IUCN 2008, 2019)

Sub-Saharan Africa	Mammals	Birds	Reptiles*	Amphibians	Fishes*	Mollusks*	Other inverts*	Plants*	Fungi and protists*	Total*
Angola 2008	14	18	4	0	22	4	1	26		89
Botswana 2008	6	7	0	0	2	0	0	0		15
Angola 2019	19	32	7	0	53	7	4	36	0	158
Botswana 2019	11	16	1	0	2	0	0	3	0	33

*Reptiles, fishes, molluscs, other invertebrates, plants, fungi & protists: please note that for these groups, there are still many species that have not yet been assessed for the IUCN Red List and therefore their status is not known (i.e., these groups have not yet been completely assessed). Therefore the figures presented below for these groups should be interpreted as the number of species known to be threatened within those species that have been assessed to date, and not as the overall total number of threatened species for each group

Table 3 Red List Category summary country totals (animals) by the number of extinct, threatened, and other species of animals in each Red List Category in each country (IUCN 2008, 2019)

Sub-Saharan Africa	EX	EW	Subtotal	CR	EN	VU	Subtotal	LR/cd	NT	DD	LC	Total
Angola 2008	0	0	0	9	19	35	63	0	50	114	1,384	1,611
Botswana 2008	0	0	0	1	1	13	15	0	21	12	847	895
Angola 2019	0	0	0	12	33	77	122	60	0	233	2,493	2,908
Botswana 2019	0	0	0	4	7	19	30	29	0	10	1,010	1,079

IUCN Red List Categories: *EX* extinct, *EW* extinct in the wild, *CR* critically endangered, *EN* endangered, *VU* vulnerable, *LR/cd* lower risk/conservation-dependent, *NT* near threatened (includes *LR/nt* lower risk/near threatened), *DD* data-deficient, *LC* least concern (includes *LR/lc* lower risk/least concern)

across the available research that unmitigated changes in climate threaten a considerable portion of southern African biodiversity. It is the underlying shifts in ecosystem structures, for example, increases and decreases in woody plant cover, that have a secondary impact on faunal diversity that is likely to alter the dominant savanna vegetation type of the region. Midgley and Thuiller (2011) pointed to the winter rainfall areas of the broader region that could suffer the most significant biodiversity loss. The trends identified in Botswana are echoed in other biomes. It is increasingly recognized that rates of disturbance vary with time and can depend on long-term climate trends, the influence of anthropogenic land-use practices (e.g., fire), wildlife population cycles, and other factors such as presence or introduction of invasive species (Wilson et al. 2019). As noted by Wilson et al. (2019), assessment of regional patterns and trends is needed, hence our approach that placed Botswana in the context of Southern Africa. Specifically, some crucial areas are mostly outside Botswana, but they have relevant spillover effects, especially for the Okavango Delta.

Specifically, when mammals in the region are differentiated by size and dietary requirements, some more telling climate risks emerge. Correlations are significant for annual temperature but only for large mammals, where 60–67% of the variability in species richness of large mammals is impacted versus <20% for small mammals (Andrews and O'Brien 2000). Small mammals are, however, strongly correlated with other either climatic or vegetation parameters. Plant richness, thermal seasonality, and frugivorous and insectivorous mammal richness are found to be correlated with thermal seasonality and minimum monthly PET (potential evapotranspiration). It is also found that arboreal and aerial species richness is associated with plant richness, thermal seasonality, and minimum monthly PET.

It is clear from Andrews and O'Brien's work (2000) that different classes of mammals respond to climatic and environmental factors in important ways. Earlier studies they contend did not identify these discrepancies, as the distinction between various sizes and guilds of mammal was not a common factor of analysis. With climate change, there will be issues across the diversity of mammalian species that should impact on their conservation in the future. This also points to the complexity of communities and the understanding of the potential importance of indicator species, whereby either a mammal's or other organisms' presence, absence, or abundance reflect on the environmental condition of either the ecosystem or biome. Such species can serve as critical indicators of tipping points in either an ecosystem or biome and act as a proxy for the health of that environment in the face of a changing climate.

Baseline Biodiversity in Botswana

Wide-ranging large carnivores are common in Botswana. They often range beyond the boundaries of protected areas into human-dominated areas. The mapping out on a country-wide scale and identifying areas with potentially high levels of threats to extensive carnivore survival is required when formulating national conservation

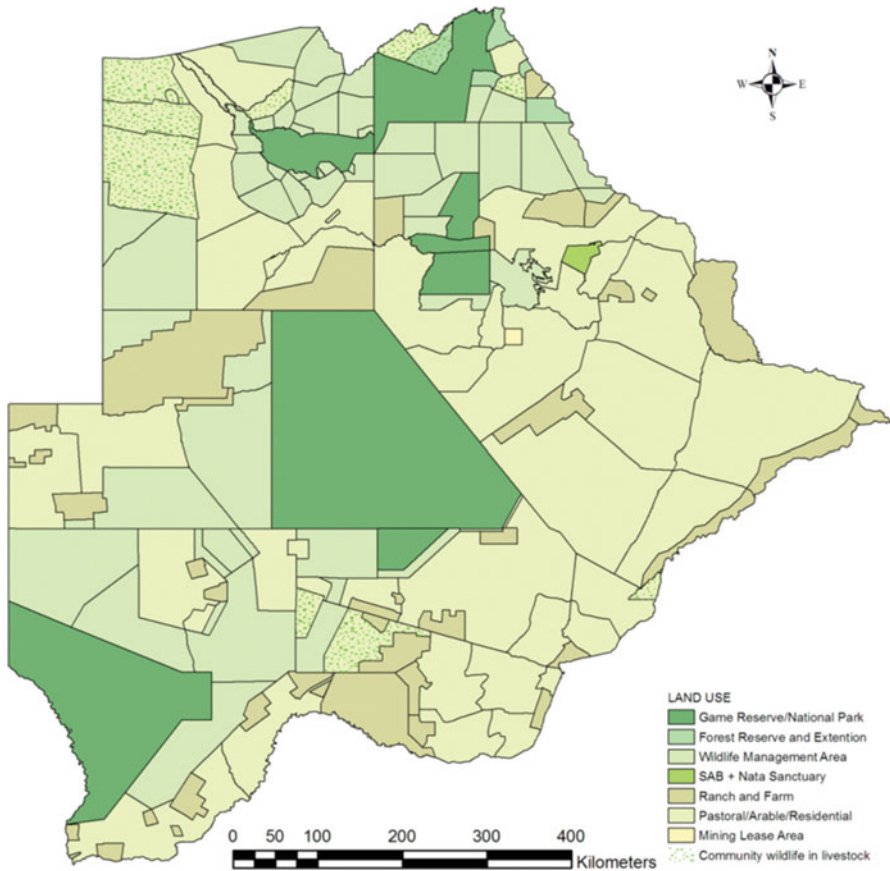


Fig. 4 Land-use zones in Botswana. (Courtesy of Winterbach et al. 2014)

action plans whether considering climate change or not. For this chapter, NPP (net primary production) in a historical context (and later in the context of climate change) has been linked with species biodiversity and richness.

This was done as the notion of NPP was linked with the country's large carnivore guild as part of a recent mapping project. In that project, Winterbach et al. (2014) identified and mapped areas consisting of leopard (*Panthera pardus*), lion (*Panthera leo*), cheetah (*Acinonyx jubatus*), brown hyena (*Hyaena brunnea*), spotted hyena (*Crocuta crocuta*), and African wild dog (*Lycaon pictus*) (Fig. 6). They discovered through this mapping project that habitat suitability for large carnivores depended primarily on prey availability but with secondary relationships with interspecific competition, plus conflict with humans. Winterbach et al. (2014) found that prey availability was a critical natural determinant. Wild ungulate species were preyed upon by the six large carnivores, and this helped to identify different management zones for large carnivore populations. The relationship with large ungulates and NPP



Fig. 5 Entrance to Moremi Reserve. (Source: authors)

in the country is strong. Therefore, small prey biomass was more evenly spread across large parts of the country, while high to medium biomass of large prey was primarily confined to conservation zones (Figs. 4 and 5).

As Botswana is central, both geographically and in terms of species biodiversity of the larger Southern African sub-Congo basin, its ecological system was deemed prudent to map changes in net primary production and species richness regionally. Changes historically and in the future in these factors will mean transboundary issues will ensue. It is evident in Fig. 6 that mammal species richness is linked with regional phenomena such as NPP, annual precipitation, and mean changes in temperature. The future will be different; hence, some biome shifts from areas currently outside the borders of Botswana could encroach into Botswana over time and as temperatures rise. Clearly, this could lead to critical transboundary implications for management of the subsequent changes in floral and faunal biodiversity.

Future changes in the three zones of species richness in Botswana (Fig. 7) across three key indicator groups, mammals, birds, and amphibians, show clear patterns from the southwest (low richness across all three groups nationally) to moderate richness in the east and high richness in the north. Importantly, these three zones are not national boundary bound but extend to neighboring countries as shown in Fig. 7.

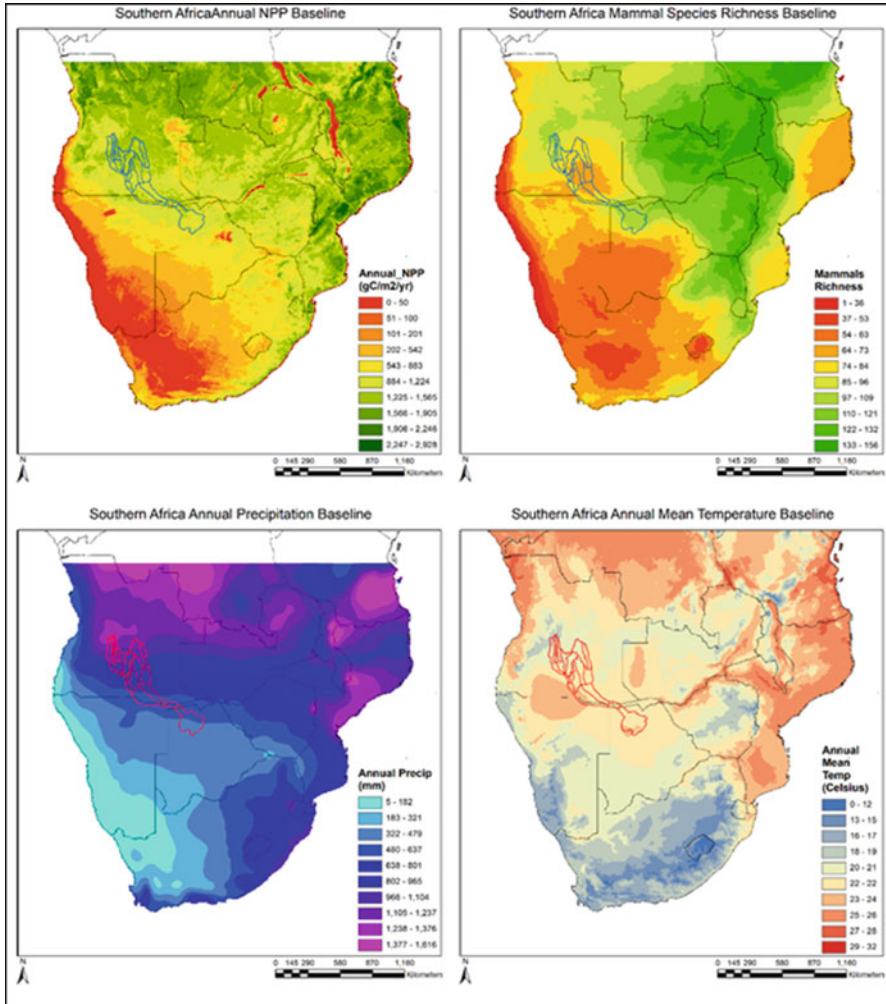


Fig. 6 Baseline NPP and the relationship between high values and mammal-specific richness, annual precipitation, and annual mean temperature. The Okavango River Basin that supports the Okavango Delta in Botswana is included as it is a key transboundary basin for Botswana species diversity and concomitant tourism and economic activities. (Source: authors)

Biodiversity, Ecosystem Services, and Tourism

Wildlife tourism in Botswana has provided strong economic incentives for conservation. With an abundance of wildlife and either the presence or absence of high-profile species, some zones are more suited to wildlife tourism. Winterbach et al. (2014) developed a set of parameters for assessing wildlife abundance and diversity.

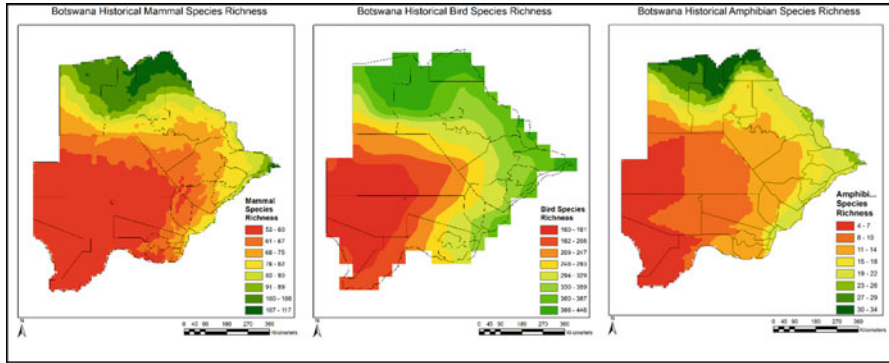


Fig. 7 Historical mammal. Bird and amphibian species richness highlight three key zones, the southwest (low), east (moderate), and north (high), and these three regions extend to neighboring countries. (Source: authors)

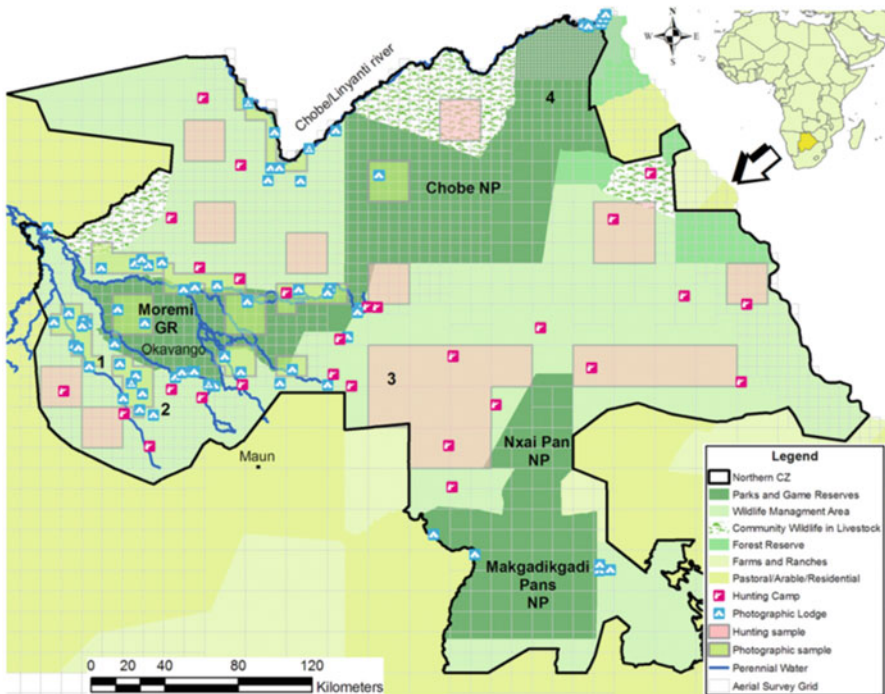


Fig. 8 Locations of photographic and hunting camps and land uses in northern Botswana in 2005. (Courtesy of Winterbach et al. 2015)

Their goal was to evaluate tourism potential in Botswana's Northern Conservation Zone. They also quantified and compared tourism experiences in areas with high and low tourism potential. Wildlife biomass is used as an indicator of NPP, and actual tourism experiences were included in their study to validate their mapping exercise.

Winterbach et al. (2014) found that areas used for high-paying/low-volume tourism had significantly higher mean wildlife biomass and diversity (Fig. 8). Only 22% of the Northern Conservation Zone against their framework had intermediate to high tourism potential. High tourism potential areas afforded tourists better wildlife sighting based on aerial survey data than low wildlife sights based on ground surveys. They also found that the economic viability of low-paying tourism may not even be met in zones with intermediate to high tourism potential. Much of the Northern Conservation Zone was found to have low tourism potential; however, this does not equate with a low conservation value.

Climate Change Impacts on the Biodiversity in Botswana

Africa is expected to be particularly severely impacted by climate change (IPBES 2018). Biggs et al. (2008) assessed the impacts on terrestrial biodiversity using the Biodiversity Intactness Index (BII). This index defines an average change in population size against a pre-modern state, across all terrestrial species of plants and vertebrates. In the next 100 years, they projected a decline in average population sizes of taxa that exceed by two to three times the decline that occurred since circa 1700. A reduction in this modeled declines of biodiversity loss in southern Africa posed considerable challenges. Better alignment is needed for integrated biodiversity conservation and development priorities in the region. Furthermore, what is thought to be required are context-sensitive conservation targets that account for the development of imperatives in different parts of the region.

The predominant climate signal from the climate models for southern African is for a hotter and drier future. This is having, and will likely continue to pose, serious consequences and challenges for policy development and management of environmental and related social change for the people of the region. Historical climate records, as indicated, fit reasonably well with future projections for the region, with the important caveat that temperature rises are trending faster than the global mean, especially in continental interiors such as Botswana. Rainfall, however, apparently has not changed significantly, as yet although the combination of higher temperatures and the potential for changes in the variability of rainfall (e.g., more intense) and also changes in seasonality has already shown changes in the trends in vegetation trajectories in the major biomes of southern Africa. Contrary to early projections for the Succulent Karoo biome, biomass and cover increased over time. This was mainly deemed in response to changes in land-use practices. MacPherson et al. (2019) also found that the fire-adapted fynbos biome either remained stable or increased over time with some expansion of forest species.

Meanwhile, and in the same study, it was found that the shrub-dominated Nama-Karoo biome increased in grass cover. Significantly, and in contrast with earlier

model predictions, the grassland biome has expanded westward into former Nama-Karoo biome sites. Regionally, the predominant savanna biome has experienced a relatively rapid increase in woody plants at rates initially unexpected by climate/vegetation models (MacPherson et al. 2019). The availability of new model parameters for biomes and net primary production also provide a useful context for evaluating future changes and for considering tipping points.

Climate change and adaptation have also become a significant issue in contemporary tourism development and policy discussions. This is particularly the case in Botswana and the broader geography of Southern Africa where wildlife in its natural environment dominate the sector. A study on perceptions of climate change (Saarinen et al. 2012) and adaptation strategies of tourism operators in Kgalegadi South District, of southwest Botswana, which also looked at their adaptation strategies, found a general awareness, but the research was conducted nearly 10 years ago. At that time, most operators did envisage challenges to future business growth and Botswana's tourism competitiveness. The perception is that climate change did not at that time have any impacts and that few adaptation strategies were in place. Anecdotal evidence from the consultant's time spent in the Okavango Delta (2019) with a tourism operator of considerable experience pointed to heightened concern regarding climate change. However, problems with earthquake impacts and climate change were signaled as underlying factors in reduced water flow into various parts of the Delta.

One Example: The Okavango Delta

The Government of Botswana has adopted a policy of economic diversification, which is reflected in the National Development Plan 8. There is a strong emphasis on the sustainable use of renewable resources such as veld products and wildlife. Tourism has been identified as a potential "engine for growth" (Jones 2017) and that tourism is based on wildlife and nature experiences. There is an increasing emphasis on the conservation and sustainable use of these resources with a strong geographic focus on the Okavango Delta.

There are significant variations in the size of the actual wetland seasonally as well as from year to year, depending on rainfall intensities in the watershed and other factors (McCarthy 2003). About half of the wetland is permanently inundated, whereas the other half is only seasonally flooded (Anderson et al. 2003); the two areas are referred to as the permanent swamp and the seasonal swamps, respectively.

The Okavango Delta is important ecologically as well as economically. The remoteness, spectacular landscape, and richness in wildlife make the Okavango Delta a magnet for tourists, and tourism has become the second most important sector of the Botswana economy.

Climate change and development-induced land-use change are explicit threats to sustaining biodiversity (Newbold 2018). Modeling and data limitations have hampered a better understanding of the underlying systemic risks. Also problematic are the quite different scales at which land-use and climate processes operate. Newbold



Fig. 9 Differentiation in water distribution within the Delta. (Source: authors)

(2018) predicted that climate change effects will become a significant pressure on biodiversity and could exceed the effects of land-use change by 2070. Both pressures were predicted to lead to an average cumulative loss of 37.9% of species from vertebrate communities under a “business as usual” scenario with an uncertainty range from 15.7% to 54.2%. The biomes to face the most significant pressures were tropical grasslands and savannahs (Fig. 9).

Tipping Points for Climate Change for the Biodiversity Sector

Results and Recommendations

Climate change is already well advanced in Botswana and has already created new challenges for biodiversity conservation. Evidence shows that two key elements that are driven by changes in climate are in a national-scale tipping point analysis: shifting biomes and changes in species composition that relates to net primary production of specific environments. Owing to the complexity of biodiversity and variability of species richness across the country, it was only possible to define broad relationships in terms of potential tipping points.

As mentioned, the dominant relationship between net primary production and biome shifts with the potential to support stable biodiversity mixes is complicated. Natural succession of species must be disentangled from a complex web of confounding factors including a plethora of human factors as well as a relatively rapid change in climate regimes. There appears to be emerging a maturing of the science related to shifts on biomes with changes in climate and signals are thus becoming more transparent that climate has a more dominant role to play in the transition of landscapes and hence biodiversity.

The mapping of mammalian, bird, and amphibian species in Botswana (Fig. 7) with modeled climate-induced changes in net primary production provides insights into possible future changes as temperatures continue to rise regionally. Of note, the temperature profiles of 1.5 °C, 2.0 °C, and 3.0 °C are presented in the introduction and are expected to be reached under current business as usual scenario (84th percentile) (RCP 8.5) in roughly 2028, about 2036, and around 2050,

respectively. There will, of course, be lag times in the response regarding average net primary production in the regions and subsequent potential shifts in biodiversity, barring any management interventions and other human dimensions of change that could ensue over the next 30 years.

The trend in net primary production, which is a driving factor in species richness, is for expansion from southwest to northeast of the lower productivity zone. Concurrently, across all three future temperature profiles, the higher NPP areas of the east and north also become progressively less productive. The same trends are then seen in Fig. 7 where the mammalian species richness diminishes nationwide, i.e., there are no parts of the country that with a temperature change should expect to see an expansion in species richness under natural conditions and changes in the net primary production. Again, these projections are made barring human dimensions of change and its management interventions. The same situation pertains to bird and amphibian species richness with a general overall reduction nationwide but with a general trend of a decline in net primary production from the southwest to northeast.

The change in NPP and species richness while following these trends also presents the opportunity to look contemporarily at areas with current NPP and species richness and consider how economic development strategies may intersect when the conditions found in one area expand into others and transition other biomes and communities. Therefore, there are current activities in the zones that will develop that may present insights for the future as these zones shift into new geographies. Given the relative homogeneity of the Botswanan topography, such transitions could expect to vary relatively little from current forms as they expand. Importantly, there is a change in NPP at the 3.0 °C tipping point that is different. In all the species richness projections (Fig. 7) at this degree of warming, a new low-end species richness category could exist in Botswana that is currently not represented. This is presented in the species richness maps as the 42–48 category for mammalian and bird species richness and the 2–4 range for amphibian species richness. Areas with these ranges of species richness could be found to the west and southwest of Botswana currently, but analysis would need to be done to see if these are, in fact, presently located in the broader region or this new low-end category is currently unknown in the area (Figs. 10, 11, 12, and 13).

Related to the shifts in NPP and species richness described above, the ranges and ecological dynamics of the country are changing, and current reserves will possibly struggle to support all species they were designated to sustain. Climate is, however, just one of the myriads of ISEET issues that impinge on the sustainability of Botswana's biodiversity. Action to mitigate the deterioration in biodiversity varies by spatial scale and the actors required. It is generally viewed that adaptation will require more and better regional institutional coordination, which broadens spatial and temporal perspectives with climate chance scenarios being considered as integral to the planning of actions. Local communities are critical to attaining conservation goals, as there are multiple threats to success. Regional planning, site-scale management, and the continued assessment and modification of conservation plans

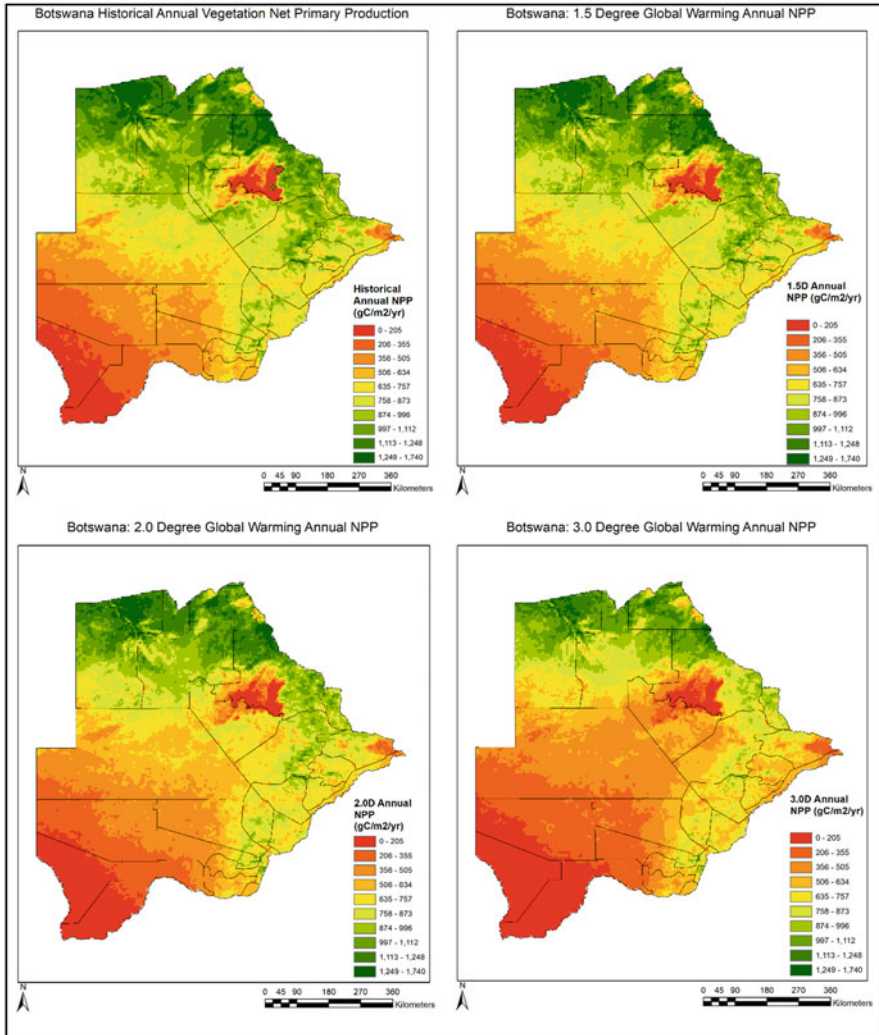


Fig. 10 Changes projected for net primary production (NPP) under the three tipping point scenarios of 1.5 °C, 2 °C, and 3 °C, from baseline (average of 2000–2016). (Source: authors)

will be required as the pace of climate-induced changes mirror those of society. The following needs have been identified:

- (1) more specific, operational examples of adaptation principles that are consistent with unavoidable uncertainty about the future;
- (2) a practical adaptation planning process to guide the selection and integration of recommendations into existing policies and programs; and,
- (3) greater integration of social science into an endeavor that, although dominated by ecology, increasingly recommends extension beyond reserves and into human-occupied landscapes. (Heller and Zavaleta 2009: 14)

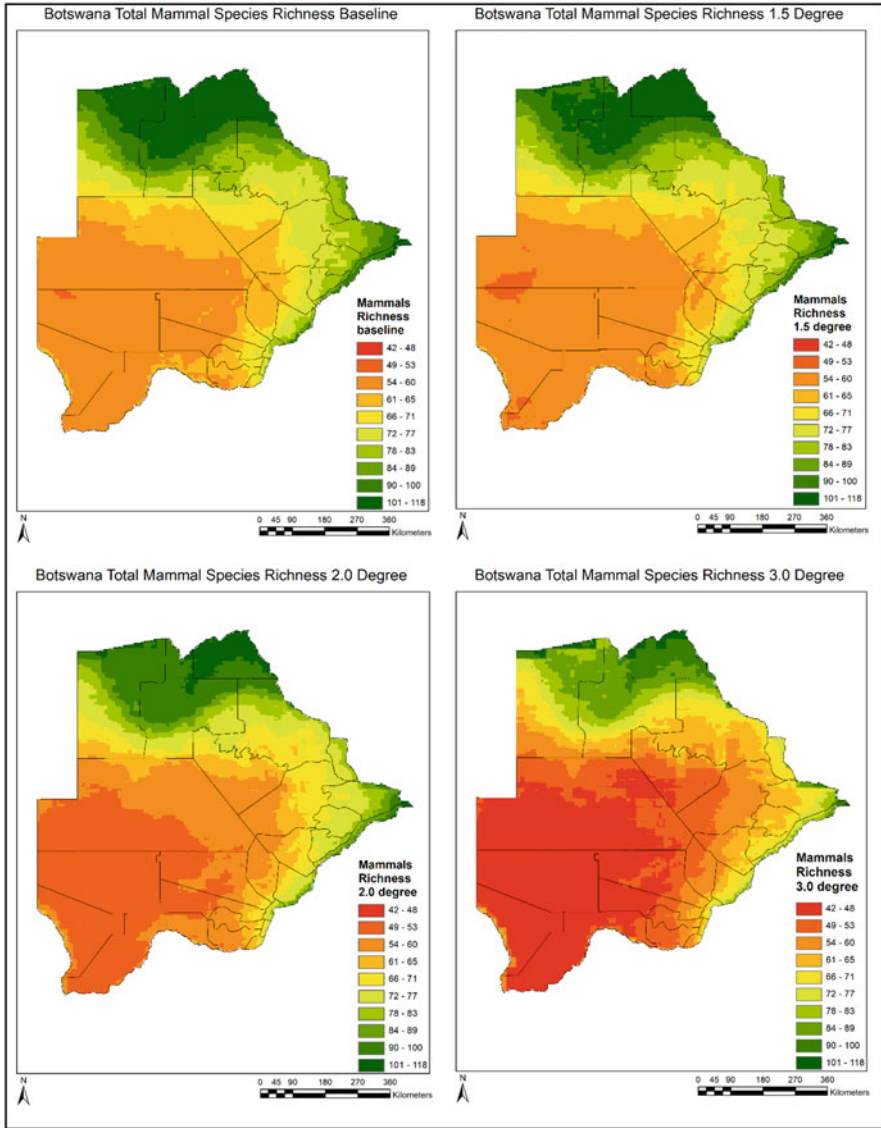


Fig. 11 Changes projected for mammalian species richness under the three tipping point scenarios of 1.5 °C, 2 °C, and 3 °C, from baseline. (Source: authors)

The Paris Agreement is deemed to be beneficial to the cause of species biodiversity conservation as it represents a template for a GDN by setting global targets, an evolving model for financial support, and recognizes the values obtained from bottom-up efforts. Nearly all nations have signed the agreement. Climate scientists have arrived at a single numerical target for maintaining Earth’s atmosphere at safe

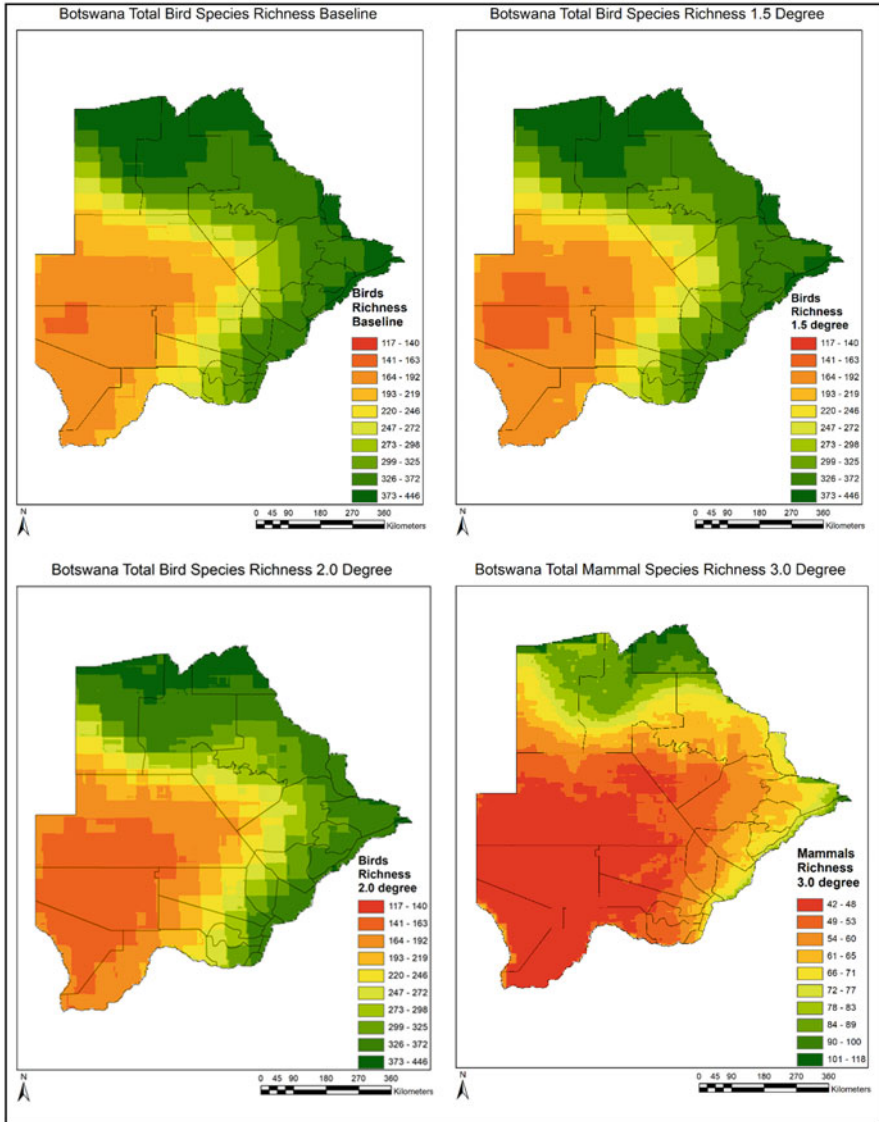


Fig. 12 Changes projected for bird species richness under the three tipping point scenarios of 1.5 °C, 2 °C, and 3 °C, from baseline (note: data source available is at a different resolution than mammalian and amphibian sources, hence the different map smoothness). (Source: authors)

limits (1.5 °C); however, biodiversity scientists work with multiple targets to conserve the rest of life on the planet given the diversity of life and ecosystems and range of resilience. The challenge clearly shown in the case of biodiversity in Botswana is the interconnectedness of the nation with the southern African region

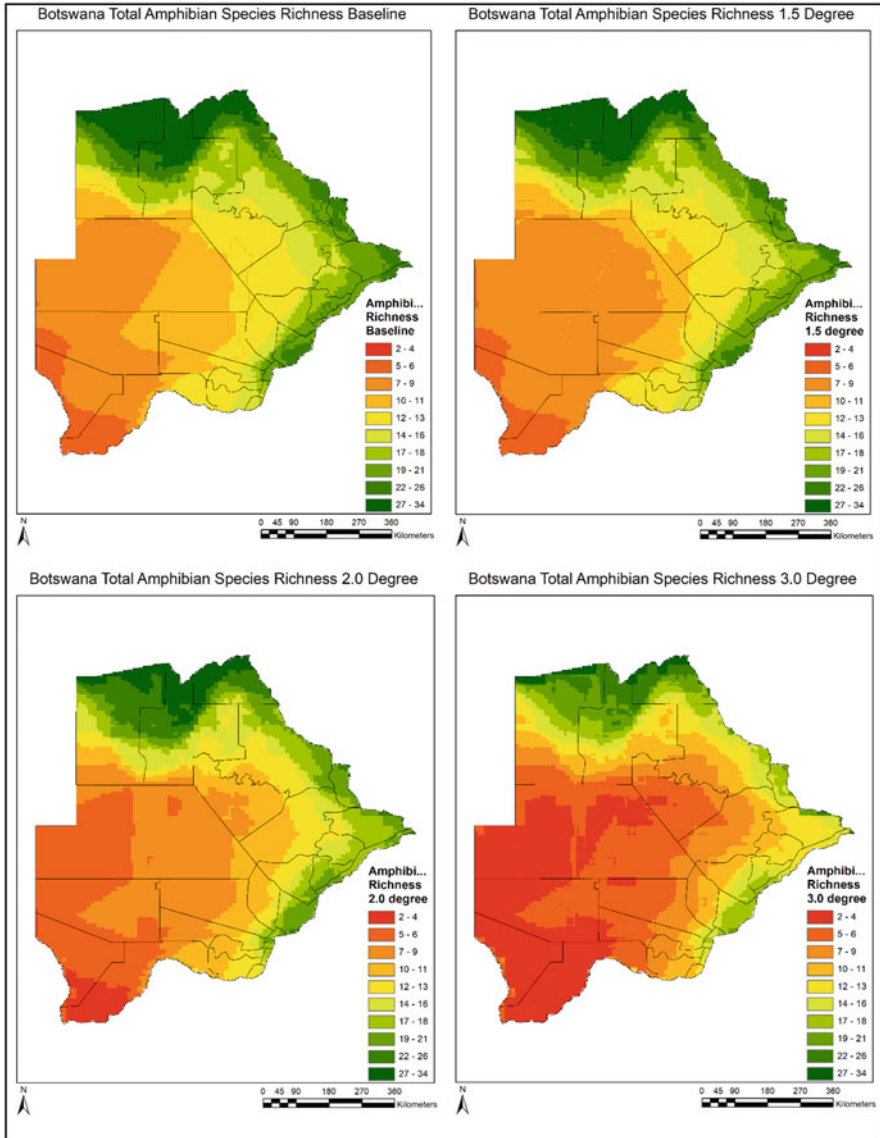


Fig. 13 Changes projected for amphibian species richness under the three tipping point scenarios of 1.5 °C, 2 °C, and 3 °C, from baseline. (Source: authors)

and the faster than global average rise in temperatures. The international climate science goal of limiting global temperatures to 1.5 °C by 2100 is not relevant for places such as Botswana that could reach that average rise in temperature as early as 2028. The GDN has expressed its own target like the Paris Agreement: protect at least half of Earth’s biodiversity by 2050 and ensure that these areas are connected

Table 4 Biodiversity sector tipping point analysis summary table

Impact factors	Slow processes	Variabilities	Extremes	Potential tipping points
Earth systems (climate change): Threshold risks	Biodiversity decrease vegetation primary production, land degradation, access to water, heat stress, diseases, tourism and agriculture land pressure, conflict	International variability increase, death rate increase, diseases, poaching	Extreme drought and diseases (foot and mouth) events Low water flows in Okavango Delta Wildlife movements/ encroachments to cropping areas	Continuous drought years could cause the wildlife high death rate and migration
Earth systems (climate change): Potential adaptation options	Recover and reserve natural habitats for natural earth systems	Provide alternative areas/substantial buffer zones for ecosystem change and succession	System integrity enhancement to support biodiversity resilience at times of climatic stress	Species migration pattern shifts Species decline and extinction Increased human/ biodiversity conflict
Social systems: Threshold risks	Tourism sector dependency, livestock number increase, rural labor force, and food relationship	Tourism natural conservation and human conflicts	Wildlife decrease during an extreme drought event	Dramatic changes in tourist sector behavior Loss of economic tourism opportunity without changes in location and interaction with species
Social systems: Potential adaptation options	Tourists and local people education and behavior regulation	Natural and human relationship education and behavior regulation	Reduce human impacts, support system natural recovery where is possible	Biodiversity and tourism sector in collaboration with other ISEET for systematic analysis and uplift social system support

(continued)

Table 4 (continued)

Impact factors	Slow processes	Variabilities	Extremes	Potential tipping points
Institutional system: Threshold risks	Deficiency and out of date in biodiversity protection legislation and policy, land-use and planning legislation and policy	Government policy and institutional implementation capacity	Institutional dramatic changes	Policy failure
Institutional system: Potential adaptation options	Balanced policy and regulation and implementation capacity for biodiversity protection and tourism development	Policy and regulations support the resiliency of the biodiversity conservation that allows natural system recovery	Reinforce and stabilize institutional system, prepared for emergencies	Work together with closely linked ISEET systems, to build the robust institutions for biodiversity conservation and tourism
Economic systems: Threshold risks	Tourism sector over development Irrational land-use and agriculture development	International tourism market variations. Changed habitats and protected area systems too rigid for continuous protection of biodiversity as biomes shift	Market collapse, financial crisis	International financial crisis Tourist air travel depressed by GHG accounting and social pressure to reduce flying
Economic systems: Potential adaptation options	Financial regulation for overdevelopment and land development	Economic measures for sustainable tourism and biodiversity protection subsidies and compensation incentives	Tourism sector support and alternative work development	Overarching economic and financial arrangement for biodiversity and tourism, in coordination with ISEET systems

(continued)

Table 4 (continued)

Impact factors	Slow processes	Variabilities	Extremes	Potential tipping points
Technological systems: Threshold risks	Wildlife and biodiversity conservation technology improvement Human intervention at a large scale to enhance biodiversity management regimes	Technology insufficiency Maladaptation in the management of biodiversity and conservation	Technology failure Species collapse from linked with wider environmental collapse from extreme heat and drop in net primary production	Huge biodiversity loss by technological system failure Disease outbreak and biome changes lead to mass extinction events and loss of keystone species
Technological systems: Potential adaptation options	Sustainable knowledge and technology applications development and introduction for biodiversity and tourism	Development and introduction of the knowledge and technologies for resilient biodiversity and tourism sectors	Technology improvement and backup mechanisms	Technology innovation and knowledge gaining for ISEET system stabilization

(Dinerstein et al. 2019). Over time the role of intact, diverse systems has been repeatedly demonstrated, and they are integral to carbon storage and hence the link to the Paris Agreement. For Botswana, intactness and linkages regionally will become increasingly relevant and urgent given the accelerating pace of temperature and other changes facing the country, which are well ahead of the global trends (Table 4).

Summary and Conclusion

The implications of climate change are a growing concern for biodiversity managers in Botswana. Even simple extrapolation of current trends in temperature makes clear that a warming climate can have negative impacts on many facets of Botswana's society and ecosystems. The sum of these troubling effects, although highly uncertain, motivates efforts to assess and manage potential climate change impacts.

Climate change may trigger major social transformations. As seen around the globe, both slow-onset climate change and extreme weather events can, for example, induce food and water insecurity. Subsequent riots, mass movements of people, and pressure on governance systems to respond to limit social anxiety and loss of national cohesion are being increasingly researched.

However, it is not a simple, one-to-one relationship. The relationship between climate and biodiversity and social change is not easy to identify. The scale of climate change that can induce significant and consequential change and related calls to action, including social transformations, may be minor or major. Often it is built-in

resiliency of Institutional-Socio-Economic-Ecological-Technological Systems (ISEETS) that determines if a drought, flood, fire, epidemic disease, or another extreme event will trigger a societal response.

Climate change experts such as Tim Lenton pioneered the use of the term tipping points to refer to “abrupt and irreversible changes in the climate system.” The concept has been taken further than climate knowledge to further our understanding of the consequences of climate change. What are often overlooked in climate change research are the social determinants of changes, for example, inequities in determining the social impacts of climate change. Also ignored are perceptions and (mis) representations of change in whatever form that might be, as well as governance systems and institutions, solidarity networks, and cultural values, and underlying technological condition and opportunities in their evaluation of the future social impacts of climate change.

The experience of those interested in biodiversity in Botswana forms a recent historical example of how ecological tipping points are identified and sometimes managed historically ineffectively but with increased local and specific cultural and environmental awareness, more effectively. What are, therefore, more challenging to determine are the social tipping points that would potentially lead to more accurate assessments of the future impacts of climate change. This then expands the thinking about climate change to more fully grasp the biological effects of a changing climate and our technological capacity to forecast them and respond more effectively.

News has emerged on the recognition of the cross-sectoral importance of a more resilient Okavango ecological system which is encouraging. The signing in 2019 of the three-country pact to work, titled “Transboundary cooperation for protecting the Cubango-Okavango River Basin and improving the integrity of the Okavango Delta World Heritage,” properly championing an integrated approach to the entire river basin management is an important step forward (Kari and Kaboza 2019). The actors and agents involved and their perspectives represent an ISEET-like approach. The follow-up activities of implementation of defining activities and their monitoring and evaluation will be critical. Time is running out as climate change and its impacts accelerate across Southern Africa.

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