Essay

Reflections on the Dynamics of Savanna Landscapes

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Abstract: Savanna landscapes are shaped by the interactions of disturbances with land use goals. Elephant hunting in a site in Botswana, and its consequences for wildlife, people, and landscapes, are described and discussed in order to make broader generalizations about the dynamics of savanna landscapes. Change comes from alterations in tree-grass interactions, fire regimes, predator-prey relations, livestock raising, and conservation goals. Some of these implications are specific to African landscapes, but others may be apt in global contexts.

Keywords: conservation; elephants; fire; hunting; hysteresis; lions; savanna ecology

1. Introduction

Savanna landscapes have mosaics of grasslands and woodlands. Thus, they have different vegetation types that maintain themselves on the same landscape, in a climate characterized by a rainy season that promotes plant growth, and a long dry season that facilitates fires becoming an important agent of change [1–3]. Explanations for this kind of landscape heterogeneity in land cover include slight differences in soils or topography that may favor microsites that create slight advantages for plant growth by woody plants in some specific areas and herbaceous plants in others. However, disturbances such as herbivore activities or burning from fires may shift which plant form dominates, creating a shifting mosaic through time.

The ways that multiple interactions and disturbances occur lead not only to landscape heterogeneity, but those spatial patterns may then themselves reinforce the shifting of the landscape mosaic with further alterations caused by herbivores, fires, people, or other agents of change (e.g., [4]). Crews and Young [5] called attention to interpretations of wild and humanized savanna landscapes in Botswana by referring to the contingencies of processes that in turn produce those spatial outcomes (e.g., [6,7]). We suggested in that article that the study and modeling of contingencies offer general approaches for understanding savannas. The processes identified included percolation through the spread and jump dispersal of the establishment of woody and herbaceous plants, fire-related effects as tempered by intensity and severity of the burns, and herbivore impacts, including consumption and trampling.

This essay serves to interpret further the ways that savanna landscapes change both spatially and temporally. It does so with an empirical basis in the author's research experiences in Botswana, but it aims to make possible more general insights into savanna dynamics, hence illustrating themes discussed in more detail in other articles appearing in this Special Issue entitled "Global Savanna Variation in Form and Function: Theory & Practice". I begin by considering the role of animals in those dynamics, starting from a personal experience with the consequences of legal elephant hunting, and then considering other agents of change, such as fires, and the overall importance of the degree and history of human management or intervention.

2. Positionality and Methods

An autobiographical approach to Land System Science, such as used here, allows for the utilization of emotions and memories to interrogate scientific questions, as shown recently by researchers examining the trophy hunting of a well-known lion [8] and by evaluations of the consequences of illicit behaviors and markets [9]. In this case, I utilize an essay style to share my reactions and perceptions as I consider how science can inform conservation and research efforts. I do this by reporting on an elephant slaughter I observed, and then place those observations into broader contexts of natural and human-caused alterations to landscape change, along with implications for interpreting savanna landscape mosaics. All photographs were taken by the author.

My positionality is as a white academic researcher interested in savanna dynamics, but feeling like my reactions to the elephant hunting described below moved me out of my comfort zone as an impartial researcher. I became located physically in a situation that felt uncomfortable and for a time, dangerous. Here, I first report on my emotional state and then situate it in relation to taking a landscape perspective on savanna dynamics. Note that I do not employ a sampling framework that would permit further quantitative evaluations of the elephant hunting, as my experiences may not be typical and my informants may not have been representative or even truthful. Nevertheless, other researchers have examined Botswana elephant hunting in more detail and I encourage interested readers to examine those publications for further information [10,11] acquired through quantitative and qualitative research.

3. From an Elephant Abattoir

It was a dark night, with no sign of the moon. The carcass of a dead elephant lay before the lights from the jeep. I was there to bear witness to one of the outcomes of legal hunting, from the perspective of an elephant abattoir. This was a site near the Botswanan village of Mababe that was used for the butchering of elephants killed by hunters who paid for the rights. The meat was meant for the local people, while the tusks were packed for export. I was left with mixed feelings, some of which later provoked thoughts about what processes animate savanna landscapes inhabited both by people and by wildlife. I utilize that experience to personalize my generalizations about the dynamics of savanna landscapes, the topic of this Special Issue.

In the daytime, it was clear that the abattoir contained the skeletal remains of more than a dozen elephants previously slaughtered: an elephant boneyard with the results of several years of hunting revealed by the skeletons (Figure 1). Some 15 local people were busy dismembering the latest corpse, separating meat from bone, and extracting the tusks from the skull with blows of an ax. The meat was carried away in buckets; there appeared to be little waste. The tusks, feet, ears, and tail were separated in a bundle to be delivered to the hunter, who appeared with part of his family while I was observing.

There were lions too that night when we went back, occupying their carnivorous niche but situated way too close to mine for comfort. A young male and larger female were on the elephant's corpse, claiming the remains for themselves in front of circling hyenas. They objected to our presence, only calming as we first dimmed our lights and then sat motionless, 30 m away in an open jeep. Later, those memories reinforced the need to think holistically about how wildlife acts as one source of contingent change among landscape elements such as patch and matrix. Nighttime in the abattoir belonged to nature. The lions seemed to consider themselves the top of the food chain, claiming first rights to the carcass. Later the hyenas doubtless helped to clean up, leaving behind bones and remnants of the skull.

Figure 1. Elephant boneyard in the abattoir near Mababe, Botswana. Shown are the remains of several years of legal hunting.

The hunting camp was located some distance from the abattoir. It had nicely furnished tents that served as housing for the hunter and party, along with other places meant for recreation and eating. Behind the scenes were workspaces for cooking and the preparation of animal hides, plus housing for about 20 workers. We were told by them that hunting camps represented good employment, especially as compared to other available options. Wage labor is uncommon in the area, limited to teachers, government workers, or helping out in a store. The hunting season attracts very different visitors than tourism focused on safari tours and the taking of photographs. The hunting requires much more local labor including scouts, drivers, skinners, cooks, cleaners, and others; and so, creates jobs in a place with few other options.

In fact, livelihood possibilities were even more limited than in other savanna areas, due to the nearness of Mababe to Moremi Game Reserve. In our study of human-wildlife interactions [12], our informants explained that they had had to give up on agriculture, with herds of elephants and buffalo entering the village, the former destroying fences and eating crops, and the latter attracting lions into the village itself. The women were afraid of harvesting firewood on their own. Only three village dogs were still alive, each marked with the scars of predators. The villagers reported that they no longer socialized outside their homes at night. In the day, they relied on outside visitors for income, either from hunters or tourists on safari.

Previously, we had noted that environmental governance in that part of Botswana was carried out through local actions except for certain issues where decision making was imposed from national and regional levels (see also [13]). In the case of flooding events in the Okavango Delta, we found [14,15] that the villages organized access to lands and building materials through land boards and inter-village agreements, with the exception that regulations requiring the free movement of waters meant that even quite modest use of

sandbags to limit flooding was technically illegal. Similarly, elephant hunting had become a national topic, affecting presidential campaigns but with local consequences [10,11,16]. When I witnessed in the abattoir, the year was 2012 (in the month of June), when elephant hunting was allowed, even encouraged as an effective tool for economic development and wildlife management. A national hunting ban took effect in 2014; people during the fieldwork knew that the ban was approaching and that their livelihoods would be altered.

The hunter also knew that a hunting prohibition was imminent, and that fact may have motivated the choice of location for the hunt that year. I ended up chatting with him both in the abattoir/boneyard itself and a few days later in the waiting room of the Maun airport. He wanted to make sure I understood his perspective, but his justifications echoed tropes of white hunter mythologies [17,18], at least to my ears. He said that he was interested in teaching his children how to hunt, and in this case, had chosen to only kill an older male elephant, presumably being an individual past his prime for mating but with desirable tusks. The ivory was meant for display in his house, along with the trophies of some 16 other elephants he had killed previously. He was using a black powder shotgun for hunting, which, he said, required much tracking in the bush so that the specific chosen elephant could be approached closely enough for a direct shot to the heart. He told me that the Bible says animals were put on Earth for our use. My memories of that encounter still reverberate with thoughts of centuries of European conquest [19], the global ivory trade (e.g., [20,21]), and the complications of elephant conservation [22,23], not to mention the intergenerational and gender dynamics his words revealed. I had thought we were waiting for the same plane flight, but no, he said, he had his own plane that he would be departing on soon.

There was a family drama at play in the abattoir in 2012, with the white hunter coaching his children on how to hunt and looking for the means to make "equal" the contestations between him and the elephant, searching for an old male to kill, of a similar social status to his own. He put himself at a disadvantage, with a large monetary value jeopardized if he was unsuccessful, as there are no refunds of fees to unsuccessful hunters. He was hunting on foot, with a gun shooting with black powder, reconstructing the perceived disadvantages of a historical white hunter. Ironically, in fact, elephant societies are matriarchal, with memories and decision making for the herd carried out by older females.

The advantages of elephant hunting include revenues in dry savanna areas that would be unattractive to most tourists. The hunting pressure and land use effects appear to be relatively minor, with only a couple dozen desired "trophy" animals killed each year and access limited to simple jeep tracks (Figure 2). This keeps large tracts of land under an economic use that in turn would tend to discourage poaching. In other parts of Africa, elephant populations in some situations have increased enough to damage vegetation [24], triggering efforts to control or limit their numbers. In others, civil unrest and ineffective policing have led to rampant poaching and defaunation.

Personally, in the abattoir I was troubled both by the ethics of killing large animals, especially elephants, and the implications for the local people, who seemed to be disadvantaged no matter which development strategy was utilized. Should the cognitive attributes of elephants put them in a different category, with conservation not only evaluated in terms of species survival and the needs of local people, but also considering the welfare of a species with complicated social needs and abilities? Should tales of an elephant boneyard be a distant historical memory, or utilized today as a tool for savanna management?

Studies done by other researchers on this topic [10,11] suggest that my experiences were not atypical, at least in the ways that local peoples manage their part of the legal elephant hunting going on at that time in Botswana. Obviously, my reactions are unique and a qualitative approach using memories and emotions will be limited in their generalizability. Mbaima [10] carefully summarized the economic and social consequences of the hunting ban, documenting loss of jobs and income sources in the villages, the forfeiture of game meat and the disruption of community-based development projects, and an increase in reports of poaching and in negative attitudes towards wildlife conservation. Previously,

we had shown [12] that wildlife offered both risks and opportunities for local people, so it is clear that there was disruption caused by the hunting ban.

Figure 2. Elephant along jeep track in Moremi Game Reserve. The savanna landscape shows few human influences except those caused by the dirt roads and the access they provide.

4. Animal Influences on Savannas

Elephants are unique ecosystem engineers [25,26], able and willing to knock over large trees. They can convert a woodland into a glade. In this manner, they may rival fire and humans as important agents of change in altering/controlling the tree-grass ratios that demarcate if a savanna is well treed, mosaicked with forest patches and corridors, or with a matrix dominated by turf and tussock grasses [1,2,27]. An African savanna with elephants will have disturbance processes caused by their actions.

Elephants create pathways among places used for drinking, foraging, and congregating; and they have memories that help them link steppingstones of habitat in order to trek long dispersal corridors as seasonal and irregular droughts alter conditions in their home ranges. The older females are living sources of history, with memories of past conditions decades earlier, and utilizing their ability to lead herds across inhospitable areas [28].

Elephants are browsers, consuming leaves and branches from trees and shrubs. They resemble other browsing species in that their abundances and movements are a function of the relative abundance of non-graminoid plants available as forage [29,30]. In turn, the grazing herbivores may move long distances as they pursue a particular height and forage value of the grass sward: famously, zebra eat coarse tall grasses, while wildebeest eat new sprouts, with the two species following the rains and each other across hundreds of kilometers [31]. Thus, all the herbivores involved need consideration in holistic studies of savannas, more so if those include animals whose presence and abundance are controlled directly by people.

In this context, the domesticated African herbivores—cattle, goats, and donkeys—are also important drivers of ecosystem change (Figure 3). Cattle and humans have millennial coevolutionary relations, meaning that their presence or co-presence in an African savanna is not a novel ecological situation, which is not to say, however, that land use with cattle is without environmental impacts. They consume forage that could have been used by wild

species, may trample around water holes that other species depend on, and their human caretakers may take actions that limit wild competitors or kill potential predators.

Figure 3. Donkeys in foreground and cattle in background of a landscape in northern Botswana. Along with goats, these are the primary livestock types raised here.

The Botswana context I experienced included vast tracts of land that are either designated as "wild" lands or those utilized by livestock [32]. The former category is kept separated from the latter by long game fences, designed to help Botswana produce beef declared free from hoof and mouth disease, while in practice acting to disrupt long-standing migration routes of wild ungulates [33]. I sensed that this division also metaphorically divided the African savannas into those with and without important contemporary human intervention in their dynamism [34]. Although most global classificatory schemes divide savannas by virtue of their locations along a precipitation gradient [3,35], I wonder if histories and more specifically, the human-related changes acting upon biota and ecosystem structure over centuries or millennia, would also be important variables to include in such representations. I propose that the human dimensions be made part of such global conceptual models. Essentially, instead of just tree cover vs. rainfall [1,3], those models could include one or more axes that represent the degree and antiquity of human impacts.

5. Human Goals for Savannas

No doubt humans are important ecosystem engineers, with planetary influences reaching to the outer atmosphere and into the deepest oceans [36]. Part of the evolutionary history of savannas in Africa is intertwined with the cladogenesis of *Homo* [37,38]. Perhaps unique is the ability of modern humans to plan, strategize, and then act together, sometimes through storytelling and writing, thus giving motivations that are carried through the generations [39]. In short, human goal setting, decision making, and the institutions that result are all important axes of the human dimensions involved, first at local scales, such as near the elephant abattoir of this essay, and then over regions defined by climate and interconnected by animal migrations (e.g., [40]).

The differing land uses around the abattoir included strictly protected conservation areas meant to prioritize wildlife populations (Figure 4), and large areas managed for livestock through community and village organizations (Figure 3). Conservation priorities would thus include (1) actions to foster population and genetic viability of the species of concern [41,42], and (2) activities to bolster local economies and human welfare [43,44]. The determined and destructive march of an elephant through fences and croplands in order to get to the waters of the Delta reminded me that those two goals may be incompatible, especially in places with multiple land uses.

Figure 4. Lion in a landscape with trees knocked down by elephants in Moremi Game Reserve. The actions of the elephants open up the woodland, allowing for grasses to sprout. In turn, this more open habitat changes conditions for predators and their prey.

Elsewhere in the world, this divide may be important to consider [45], in this instance between the various kinds of humanized savanna landscapes and those with little or no land use. In the former, ecological restoration might consist of restoring lost megafauna or predators, while the latter could potentially serve as baselines when conservation needs outweigh alternative uses. Elephants pose both challenge and opportunity as they cross the spatial divides from wild to managed landscapes [46].

Some human-nature interactions include the human-disease-wildlife interface [47,48], often modulated through domesticated animals, whether that be poultry and avian flu, or the various diseases originating from cattle. In colonial Africa, rinderpest, a disease affecting both wild and domesticated ungulates, was crucial in altering histories of development and land occupation before its eradication [49]. It is ambiguous which baseline for understanding African savanna dynamics should be used for comparisons: pre-colonial times, post-rinderpest, or something different.

6. Savanna Landscape Mosaics: Fires and Hysteresis

All savanna landscapes are shaped by fire; they are a result, at least in part, of past and present fire regimes [1–3,50]. There is a palpable resistance to switch from being a locale dominated by grassland, susceptible to frequent surface fires, followed by the eager regrowth of the culms, to a forest vegetation type with multiple strata, and accumulating leaf litter. The forest will tend to resist burning and shade out light-demanding plants, while the grassland will tend to burn frequently, with those fires excluding or limiting woody plants. This resistance to a state change is known as "hysteresis" [51] and can provide a powerful explanation as to why a given savanna climate can have two relatively stable vegetation types present [2,52]. The fire regime interacts with competitive and physiological processes resulting from the different rooting depths of trees and grasses, which in turn affect the soil moisture available to the different plant growth forms of neighboring plants.

Elephants can help push the hysteresis curve from woodland to grassland by knocking down trees, sometimes to feed on the bark and sometimes just because they can. Surface fires under relatively moist conditions remove the aboveground herbaceous biomass but leave behind standing the trees with bark resistant to heat (Figure 5). Often cattle will do the opposite, leading to bush encroachment. Fires under drought conditions can burn hot enough to kill woody plants, while the returning rains may then favor the sprouting or new establishment by seed of grasses.

Figure 5. Surface fire removing aboveground grasses but leaving behind surviving trees and shrubs in the Okavango Delta.

Fire is a chemical reaction, with characteristics shaped by fuel load, moisture, winds, and ignition sources [53]. In a savanna landscape with no or few human influences, soils and climate are major controls on the mosaic patterns that typically result [1,54]. Humans can provide new ignition sources and novel conditions [55–57], thus often inadvertently extending the length of the fire season and the number of places burning. Land use can change vegetation types, reduce indices of landscape heterogeneity, and increase the intensity of burning. In some situations, frequent fires are unwanted and suppression

activities tend to diminish fire frequency but increase severity when fires do eventually occur. All these regime variables can have an anthropogenic influence that in turn alters the tree-grass ratio, and then reciprocally changes conditions for herbivores and predators.

Even slight topographic relief or minor edaphic shifts can affect fires and post-disturbance recovery, adding to the stochastic elements that randomly alter seed dispersal and soil seedbanks, and hence the locations of plant establishment; the sprouting capabilities of burned plants in particular microsites, and hence what regrows; and whether an herbivore intervened during plant growth and succession. The mosaics that result include patches of differing composition that offer variable resources for fauna. Livestock may shift the balance towards woody plants [58] unless counteracted with landscape management by people [59]. The savannas of the world influenced by human land use are quite different in their disturbance regimes and the resulting dynamics of the landscape mosaics.

7. Conclusions

A localized disturbance that favors grass regrowth in a savanna landscape would in turn lead to a shift to grassland domination, while a localized disturbance that favored tree growth would increase woody vegetation. The contingent processes could reinforce or alter the respective state. Thus, in sites with uniform substrates, the result would be either forest or grassland, but with belowground heterogeneity, the expectation instead is a mosaic. The "bottom-up" processes would be topographic and edaphic, while the "top-down" processes would be human caused, climatically driven, or both. This approach was helpful for interpreting landscape change in Botswana [5]. It could be used to craft more sustainable livelihood approaches by knowing the resilience and dynamics of the different land covers. The ecologies of woodland and grassland differ, but so too does the economic value of those land covers for people. Such a perspective also potentially allows the means to connect global change phenomena to possible path dependencies acting at the scale of individual plants or microsites, in specific parts of savanna landscapes.

My experience in the elephant abattoir came with echoes of imperialism and colonialism in ways that imbue elephants with values that make their hunting and their ivory to have worth beyond the strictly monetary. The history of white peoples killing elephants in Africa continues, while black and brown peoples may be victimized or at least excluded from decision making, or they may under some circumstances take alternative actions so they will also be agents of change. None of these considerations would have been noted without the qualitative approach used here. Botswana ended its hunting ban in 2019, so once again the social and economic complexities are complicating conservation and development choices, as represented in recent empirical evaluations of those factors [10]. LaRocco [11] similarly documented the effects of the hunting ban, but took a research approach that stresses ethnic and cultural differences in the consequences observed. She showed that the national level decisions had negative effects for local people and savanna landscapes. Her focus was on the San people of that part of Botswana, who are particularly dependent on game and other natural resources that they harvest. She feels that the hunting ban applied to wildlife species essentially criminalized the game hunting crucial to San livelihoods and values. She joined other colleagues [60] in calling for research approaches that go beyond stating the positionality of the researcher, and that instead strive for a decolonialization agenda.

Elephants have self-awareness [61,62]. When we drove by them in northern Botswana, we saw them positioned within the lands of the wildlife reserve but facing into the hunting areas, apparently cognizant of the direction and spatial implications of where danger was located. They can distinguish tourists from hunters. They can sense other elephants through low frequency sounds and vibrations, so maybe they also can hear the results of hunting. Thus, sensory and cognitive abilities need consideration when researchers evaluate systems that include species like elephants. What should that mean for thinking about savannas where elephants are important agents of change? Does it trigger the need for approaches to animal rights recently codified by Nussbaum [63] or for morality as developed for the

investigation of wolf-human conflicts [64]? Should Land System Science more directly consider the ethics and morality of land use decisions? Is there a useful role for sentiments and values in a research setting? For that matter, hunting is yet another case of asymmetry in the power dynamics of southern Africa, with much money associated with the killing of a few trophy specimens, and with some concomitant advantages for conservation with presence and enforcement in bushlands that are not attractive for photographic safaris, but which allow for maintenance of intact and wild savanna lands. In Botswana, national economic development strategies may or may not help local people, but in either case, they may disempower them.

Top predators in Africa are intimidating. Landscapes in other latitudes have been evaluated in terms of "fear" [65], where the presence of predators alters the behavior of possible prey animals such as deer responding to wolves. In African savannas, a human is potential prey, altering perceptions, and reminding us of an evolutionary past when our species was often disadvantaged. The importance of fear could be built into assessments of human-influenced savannas. Wild savannas can be places where human influences are minimal while risks increase; humans do not set all the rules. Fires in African savannas co-evolved with humans, with fire use predating the speciation of *Homo sapiens* and probably intrinsically connected to the evolution of big brains and sociality in our species. As a result, I suggest that humans be considered an integral part of those savannas, and their removal need not necessarily be a primary goal of conservation. In turn, savannas without evolutionary histories with hominins may be managed to reduce or eliminate those effects, if the goal is strict conservation. Human land use history may be coequal to climate as explanations of savanna dynamics.

In this essay, I have strayed into memories and emotions while reflecting upon implications for the study of savanna dynamics. I did this through the lens of elephants and especially in relation to human interests, but I also point to ways to consider the perspectives of tree-grass interactions, fire regimes, predator-prey relations, and conservation goals. This more holistic way of thinking about savannas is not inappropriate given their importance globally, and their intimate connections to our own evolutionary history. Other researchers in this Special Issue include yet more drivers of change to consider in generalizing about the world's savanna landscapes.

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