Review Paper

Maasai Livelihood Strategies, Megafauna Biodiversity, and Ecosystem Services' Synergies and Tradeoffs in the Semiarids of Kenya: Scenarios and Implications of Climate Change in DPSIR model

Abstract:
Maasai rangelands of Kenya, epitomizes an ideal natural platform upon which the interactions of traditional and emerging livelihoods, economically important megafauna, and ecosystem services can be explored. The study integratively assesses and systematizes the structural elements driving ecoservice-interaction in a DPSIR model. The study reveals manifestation of more ecoservice-tradeoffs than ecoservice-synergies. Existing ecoservice-tradeoffs will intensify under changed climate scenario. The generated ecoservice-interaction is dictated by the way the relevant ecosystem is experienced, accessed, controlled, and managed by diverse stakeholders. This study reveals the cross-scale political, social, economic, ecological and climatic factors and processes, and interactions within which the Maasai's livelihoods-megafauna-ecoservices nexus is entrenched. The study provides an entry point for policies/practices concerning this nexus if effective mitigation of and adaptation to climate change amidst rapid permeation of sociopolitical and socioeconomic globalization is to be achieved.

Ecosystem services, ecoservice synergies & tradeoffs, Maasai, megafauna, wildlife, Driver-Pressure-State-Impact-Response model

1. INTRODUCTION

Livelihood vulnerabilities and threats to biodiversity and ecoservices are contemporary critical challenges facing most pastoral inhabited rangelands across Africa [1, 2, 3, 4], and Maasai-inhabited savannas of Kenya are not exceptional. Diverse livelihood types and intensification strategies have encroached vast areas of traditionally pastoral rangelands [1, 5, 6, 7]: these are core drivers and pressures impairing the integrity of biodiversity and ecoservices thereof; and by extension socioeconomic development of traditional inhabitants. A critical concern, therefore, arises of achieving sustainability of ecoservices and of linked livelihoods and biodiversity. There is no simple solution to this concern, and indeed regarding complex social-ecological systems that define these rangelands and Maasai livelihoods. However, unraveling the types and dynamics of social, ecological, and climatic factors, processes and their interactions can inform on the practical answer to this concern: this is the focus of this study.

As regards Maasai rangelands, the study premises that the changing climate, the state of livelihoods, ecoservices, megafauna-biodiversity, and associated governance institutions and structures are intricately linked. It must be pointed out that, apropos pastoral rangelands across Africa, concerns such as land/ecosystem-degradation (e.g., biodiversity loss, soil-fertility depletion), persistent food/nutrition-insecurity, and unsustainable production practices are well documented [8, 9, 10, 11, 12, 13, 14, 15] particularly for broader-scales. However, the interactions of these challenges through the buttressing *ecoservices' synergies and tradeoffs* (hereafter, ecoservice-synergy and ecoservice-tradeoff, and collectively ecoservice-interactions) need systematic documentation.

Traditional users of these rangelands, mainly Maasai pastoralists and wild-fauna, have high level of socioeconomic and/or ecological risk due to occurrence of frequent droughts, increased

rainfall-variability, and encroachment of other competing land uses [7, 16, 17, 18, 19, 20, 21]. In fact, a long-term and on-going project on livelihoods, environments, and development (LEDP) reveals that in 2005 alone, over 50% of Maasai households in these rangelands experienced severe food-shortage and malnutrition following an extreme drought that plagued the region. Among the Maasai, the emerging agropastoralists were the most affected: an interview conducted with Maasai people revealed that over 90% have adopted diverse agricultural intensification strategies [1, 5]. The reasons for vulnerability of emerging-agricultural systems are partly attributable to maladaptation/non-adoption of practical skills; and as one agropastoralists explained, "*... unlike livestock, crops cannot be migrated ... so you suffer loss*." Paradoxically, some household weathered drought by feeding their stocks on purchased (sometimes freely given) maize-stovers from non-Maasai agricultural farms in the same, and even drier, region.

Like the Maasai people, the wild fauna, particularly the large ungulates and carnivores inhabiting these rangelands have had to contend with the deleterious impacts of the changing climate, mainly recurrent droughts, and the encroachment of the aforementioned competing land-uses. More specifically, forage depletion and severe competition for critical rangeland resources (CRR) with other land-users (e.g., livestock, arable-farmers, and wild fauna) are common during periods of drought (*ibid*.).

Apropos climate change, the nexus of livelihood and megafauna-biodiversity via linked ecoservices-interactions, in the context of sustainability-vulnerability dichotomy, across the Maasai-inhabited rangelands of Kenya remain unexplored. Likewise, the cross-scale political, social, economic, ecological and climatic factors and processes, and interactions within which this nexus in entrenched remain undocumented. Sustainable extractions of natural resources, that is, without upsetting ecological integrity and food/nutrition-security across pastoral tropical rangelands, need to be informatively understood. Consequently, benchmarking potential of ecologically and/or socioeconomically desirable (best practices) livelihood strategies across these rangelands remain unknown. Similarly, the potential future of livelihood strategies, ecoservices, and megafauna-biodiversity under different climate change and/or sociopolitical and socioeconomic globalization projections and scenarios is unknown.

In this research an integrated approach is used, as afforded by DPSIR model, to highlight and unveil the interplay of diverse factors, processes, and their various interactions by exploring cross-scale ecoservice-interactions among Maasais' livelihood strategies and megafauna-biodiversity across savanna rangelands of Kenya in the context of sustainability/vulnerability dichotomy under various scenarios of climate change amidst sociopolitical and socioeconomic globalization. In addition to encapsulating relevant systems across scales, this study's approach enables the integration of interdisciplinary views, and therefore provides a theoretically grounded means of testing hypotheses about the dynamics/implications of ecoservice-interactions (tradeoff and synergies). In policy terms, the work further informs on the role of governance vis-à-vis the aforementioned dichotomy. The interactions of Maasai's indigenous and emerging livelihood strategies and critical ecoservices are explored; CRR extraction in Maasai-pastoralism and by socioeconomically-important megafaunas and the impact of the changing climate on these interactions explicated.

2. LOCATION OF THE STUDY AREA AND METHODOLOGY

The various data that inform this study captures the greater Maasai-inhabited savanna rangelands of Kenya, *viz*., Kajiado, Laikipia and Narok. The participatory data concerning Maasai's livelihood strategies draws from long-term studies covering Kajiado County (LEDP, *op. cit*.). This county lies at approximately 2°S and 37°, spans *ca.* 21903 km^2, much of area occurring at *ca*. 1000 meters above sea level (m a.s.l), but generally from 500 to 2500 m a.s.l [7, 22, 23, 24]. Kajiado County is characterized by several agroecological spaces, however, most area is predominantly semiarid; various land-use types under diverse holding are present [7, 16, 18, 19, 20, 21, 25].

The work predominantly draws and builds on my interdisciplinary work on sustainability, ecoservices, food security, climate change, agroecosystems, soil-fertility management, small-scale holdings, rural-livelihoods, and rangelands. Most importantly, the work strongly informs on the broader theme of climate change and its impact on ecoservices and biodiversity in arid and semi-arid zones. The research captures wide audience, and variously contributes to diverse topics including, but not limited to, ecoservices; climate change and dryland biodiversity vulnerability; situation of biodiversity and ecoservices in context of climate change. Other topics captured in this work include conceptual frameworks; approaches; climate change impact assessment, vulnerability, and ecosystem productivity; climate change, ecoservices and food security; impact of climate change on biodiversity and water; ecoservices and poverty reduction; climate change and land use, and ecoservices.

The methodology for this study is based on integrated and simultaneous assessment and systematization of structural elements driving ecoservice-interactions—cross-scale climatic, environmental, and socioeconomic/sociopolitical factors and processes factors, processes and their various interactions in *Driver-Pressure-State-Impact-Response* (DPSIR) model. Specific examples of indicators in DPSIR model for the current work is as follows: Driver (e.g., human population increase), Pressure (e.g., recurrent droughts), State (e.g., CRR access and availability), Impact (e.g., reduced CRR), and Response (e.g., conservation/ASALs policies). In DPSIR model, *Driver(D)* occasion *Pressure(P)*, which causes shifts in the *State(S)* consequently generating *Impact(I)*, and hence a need for *Response(R)* geared at adjusting (D) and/or (P).

One main advantage of the DPSIR model lies in its capacity to assess the current state and changes across scales (e.g., temporal), and to explore the interconnectedness of causes thereby revealing the most plausible keystone cause. The use of indicators via DPSIR model is widely engaged in assessment environmental/ecosystem integrity and society/human-environment/ecosystem interactions [e.g., 26, 27]. DPSIR is progressive causal model with diverse sections that allows simultaneous assessment and systematization of information. Although *Response(R)* in DPSIR mainly focuses on social facet e.g., conservation/ASALs policy and Maasai's drought-adaptations, for the purpose of the current work responses from specific characteristics of ecosystems are highlighted whenever applicable.

Review of literature, participatory surveys, and field observations provide data and information for the current study. The term *megafauna*, as employed for the purpose of this study encapsulates economically important large-ungulates (both mega-ungulates and meso-ungulates) and large/medium carnivores (collectively meso-carnivores) inhabiting the Maasai rangelands of Kenya. The use of the concept '*ecosystem service'* (hereafter ecoservice) draws from Millennium Ecosystem Assessment's definition: "*... the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits* [27]."

3. RESULTS AND DISCUSSIONS

3.1 Megafauna-Biodiversity and Cross-Scale Challenges: The Maasai Rangelands of Kenya

Several mega-/meso-ungulates (hereafter, mega-ungulates) disperse across Kajiado County (Table 1). Common megafauna ungulates include the African elephant (*Loxodonta africana*), Maasai giraffe (*Giraffa camelopardalis*), African/Cape buffalo (*Syncerus caffer*), and common eland (*Tragelaphus oryx*). Common water-dependent ungulates—often moving to reliable water-points between the rainy and dry seasons—include elephant (*L. africana*), wildebeest (*Connochaetes taurinus*), zebra (*Equus burchelli*), and African/Cape buffalo (*S. caffer*). Meso-carnivores include Maasai lion (*Panthera leo*), Leopard (*Panthera pardus*), Cheetah (*Acinonyx jubatus*), Spotted hyena (*Crocuta crocuta*), and Striped hyena (*Hyaena hyaena*). Dominant among meso-carnivores include Maasai lion (*P. leo*),

Spotted hyena (*C. crocuta*), Leopard (*P. pardus*), and Cheetah (*A. jubatus*)—and excepting the last one, these are the core nuisance predators preying on Maasai's livestock.

Table 1. Wild megafauna-biodiversity across Maasai savanna rangelands of Kenya. Source: LEDP, *op. cit*.

Wild megafauna biodiversity across savanna rangelands of Kajiado County, Kenya (N=1563)[€]	
Mega- & meso-ungulates	
African savanna/bush elephant (*Loxodonta africana*)[£12]	Thompsons gazelle (*Gazella thompsonii*)
Maasai giraffe (*Giraffa camelopardalis*)[#2]	Oryx (*Oryx beisa callotis*)
Wildebeest (*Connochaetes taurinus*)[#1]	Common waterbuck (*Kobus ellipsiprymnus*)
Plains/common zebra (*Equus burchelli*)[#1]	Bushbuck (*Tragephus massaicus*)
African/Cape buffalo (*Synerus caffer*)[£12]	Lesser kudu (*Tragelaphus imberbis*)
Common eland (*Taurotragus oryx/pattersonianus*)[#2]	Kirks dik dik (*Madoqua kirkii)*
Grants gazelle (*Gazella granti*)[#]	Topi (*Damaliscus lunatus korrigu/jimela*)
Hartebeest/Kongoni (*Alcelaphus buselaphus cokii*)	Gerenuk (*Litocranius walleri*)
Impala (*Aepyceros melaphus*)	Common duiker (*Sylvicapra grimmia*)
Meso-carnivores	
Maasai lion (*Panthera leo*)[3§]	Black-backed Jackal (*Canis mesomelas*)
Leopard (*Panthera pardus*)[3§]	Side striped jackal (*Canis adustus*)
Cheetah (*Acinonyx jubatus*)[3]	Golden jackal (*Canis aureus*)
Spotted hyena (*Crocuta crocuta*)[3§]	African hunting/wild dog (*Lycaon pictus*)
Striped hyena (*Hyaena hyaena*)	
[€]Large/medium wild animals also found in other Maasai rangelands of Laikipia & Narok. [£]Most dangerous to human. [#]Abundant. [3]Dominant big cats. [§]Nuisance predators. Examples of other wildlife (large/medium/small): African civet; African wild cat; Bat-eared fox; Marsh mongoose, Slender mongoose, Dwarf mongoose, Grey mongoose; Honey badger; Large-spotted genet, Small-spotted genet; Olive baboon; Warthog; Hippopotamus; Ostrich. 1=water-dependent, 2=common megafauna ungulate	

-Please arrange the table accordingly

From the studies with the Maasai people of Kajiado County (Table 2, LEDP, *op. cit.*), some of the common problems caused by wild-animals include livestock-predation, human-injuries and deaths, road-accidents, critical rangeland resource (CRR) competition, and spread diseases and pests. Other problems caused by wild-animals include stealing honey from beehives, beehives damage, crop-damage, attack/kill domestic-dogs, poultry-predation. As regards wild-animals pest/disease infested site, Maasai pastoralists cannot move away from problem site (e.g., diseased/pest-infested sites) because they have no alternatives.

In Table 2, diverse challenges occasion change in the population of wild megafauna across Maasai-inhabited savanna rangelands of Kenya. Examples of these challenges include encroachment of arable-farming, proliferation of unpalatable plants, occurrence of diseases and pests, and recurrent droughts.

Table 2. Challenges driving change in the population of wild megafauna across Maasai-inhabited savanna rangelands of Kenya. Source: LEDP, *op. cit.*

Challenges driving change in population of wild megafauna across Maasai rangelands of Kenya (N=1901)[λ£]
Encroachment of arable-farming (rainfed & irrigated)
Increase in human-settlements, roads, & other build-infrastructures
Proliferation of unpalatable & invasive plants
Habitat loss/fragmentation/modification/destruction; reduction in forest-/wood-/wet-/grass-land spaces
Ecosystem pollution
Uninformed extraction (e.g., hunting)
Poisoning (deliberate or accidental)
Diseases & pests
Critical rangeland resource (CRR) competition with livestock
Climate change/variability, recurrent droughts, increased rainfall-variability, extreme climatic-events
Other challenges[§]

[λ]Maasai-inhabited savanna rangelands in Kenya include Kajiado, Laikipia, & Narok. [£]Problems caused by wild-animals: livestock predation, human-injuries and deaths, road-accidents, critical rangeland resource (CRR) competition, and spread diseases and pests. [§]Other challenges include nature of the animal (e.g., physiological or genetic), its sensitivity to environmental or climatic changes, and location/space inhabited (e.g., inside vs. outside protected wildlife-sanctuaries).

3.2 Changing Maasais' Livelihood Strategies and Ecoservice Synergies and Tradeoffs

Maasai people of Kenya have predominantly subsisted on rainfall-dependent pastoralism in the savanna rangelands [1]; presently, however, they have gradually diversified into other forms of livelihood production systems [e.g. 1,5]. For example, practiced by over 80% households, the most common livelihood-diversification is individualized/private arable-farming [5]. Other widespread diversifications include tourism-based enterprises (e.g., CBOs, small-scale trade in curios), and extraction and sale of fuelwood (mainly charcoal and firewood) (*ibid*.). (Other examples of ecosystem services (ecoservices) linked Maasai livelihoods include the following: sale of medicinal concoctions (extracts from medicinal plants), cultural bomas, and educational tours.) Being land-based, the practice of these diverse livelihoods translates to, and reveals, diversity of ecoservices buttressing the same. Thus, in traditional nomadic Maasai-pastoralism, critical rangeland-resources (CRR), namely natural pastures, mainly grass, but also browse forage as livestock types are diversified, water, and salt-lick spaces [1] are the critical ecoservices. In arable-faming, the predominant livelihood-diversification among the Maasais of Kenya, water and soil-resources are used; in extraction and sale of fuelwood, woody-plant, often an entire tree/shrub, is extracted.

Here, similarity of some extracted ecosystem resource is evident: water in the former two livelihood-diversifications; and plants in the first and last modes of diversification. An intense demand is thus placed on such resources where diversifications co-exist than otherwise: consequently, conflict for such ecoservices is thus to be expected.

It must be pointed out that Maasai's arable-farms are relatively small, even opportunistic; that high population of non-Maasai arable-farmers are to be found in these rangelands; and irrigated agriculture, particularly in agri-firms (horticulture, floriculture), is common [5, 6, 7]. Suffice that, extraction of water in arable faming is widespread, and predominantly by non-Maasais. Although, water competition is to be expected, arable-farming offers fallback for the Maasai's livestock when natural pastures are inadequate: for example, maize-stovers and diverse post-harvest stubbles are used as animal feed. What's more, manure (livestock dung) is used to improve soil fertility in Maasai's small-scale farms; oftentimes, those with large herds sell the same to non-Maasais. Worth noting, in

nomadic Maasai-pastoralism, the inherent migrations of herds across the then vast savanna translate to dispersal of manure as such inadvertently fertilizing pasturelands that support their stocks and other animals: a symbiotic relationship is thus revealed. Logically the loss of pasture-space to arable-framing translates to loss of all the critical ecoservice (linked to livestock) therein and more so if the loss is to non-Maasais. Similarly the loss of forage in fuelwood extraction, since the entire tree/shrub is often taken, translates to loss of browse for livestock where such plant species are palatable, for example, the preferred species for fuelwood, especially charcoal is *Acacia tortilis* [5, 28]. This loss becomes profound as livestock-diversification to incorporate other browsers (e.g., camel in addition to goats) in Maasai-pastoralism is taken into account.

Nonetheless, amidst this loss, a surprise manifestation of a new ecoservice in charcoal-making spaces has been observed. The abandoned charcoal-kiln sites often transition to spaces upon where natural local palatable-to-man vegetables grow; Maasai women extract these vegetables, and are consumed with ugali (a popular Kenyan maize-meal) or with other accompaniments (Mwangi, *pers. comm.*). This *surprise new* ecoservice although minute, is noteworthy because it translate to improved household nutrition-security, and when sold, for some enterprising Maasai-women sell the same locally, additional income to the household. Clearly diverse livelihoods strategies and diversifications *contextually* interact across Maasai rangelands to reveal varying ecoservice-interactions.

Thus as regards Maasai rangelands, and in terms of ecoservice types, and the intensity and rapidity with which they are exploited, the following crucial questions necessarily emerge; and are the focus of the rest of this explication.

1). *How do these contextual ecoservice tradeoffs and synergies Maasai's livelihoods strategies and diversifications mean vis-à-vis shared ecoservices for the diverse wild-fauna inhabiting these rangelands?*
2). *As the climate continues to change, how will existing ecoservices' synergies and tradeoffs of Maasai's livelihoods, of wildlife biodiversity, or their diverse intersections unfold?*

It must be pointed out that Maasai pastoralists are excellently knowledgeable in sustainably managing livestock-linked ecoservices across the savanna rangelands of Kenya, which explains well why they have lived and thrived on pastoralism since time immemorial in these variable ecoclimatic zones [e.g., 1, 29, 30]. Having acknowledged that, a more important concern arises: presently, are they (Maasai) equally knowledgeable in managing ecoservices linked to their livelihoods strategies and diversifications, particularly as the climatic, environmental, and socioeconomic landscapes of these rangeland continues to change.

It must also be noted that as they diversify livelihood, the amount and the sophistication and fastness with which ecoservices are withdrawn/extracted is changing, even intensifying, and more so as other land use types, from non-Maasai, even international-catering agri-firms (e.g., floricultural and horticultural farms), are also involved. This land-use change (LUCs) have been occasioned by several factors, such as, agriculture expansion, rapid human-population increases, economic factors, changing land-tenure policies, politics, and sociocultural factors (poverty, education-levels, breakdown of traditional sociocultural values and norms) [e.g., 1,5, 14, 20, 25, 31, 32].

Except where the conservancies/sanctuaries are run by Maasais, most wildlife, including the nuisance wild-animals (e.g., lion, see Table 1), rarely, if at all, benefit Maasais or the locals, but the government and the elite. The practice of wildlife/tourism-based enterprises (e.g., CBO) translates to a formal mode of benefiting from local ecoservice, as opposed to traditional times when wildlife was extracted informally. Maasais have harmoniously lived with wildlife in these savannas since time immemorial. In fact, Maasais regarded the large ungulates (e.g., kongoni, see Table 1) as second-cattle, and even extracted some for food especially during periods of drought [5]. However, as CRR availability and space continuously diminish due to changes in land-use/tenure and non-participatory

implementation of various macro-econopolitical policies [e.g., 14, 25], Maasais' interactions with wild-fauna have gradually changed. Thus, where traditionally certain wild ungulates grazed side-by-side with Maasai's cattle, the former are presently seen a CRR-competitors, even pests, and reservoirs of diseases/pests from the perspective of these pastoralists.

As regards Maasai-pastoralists' livelihood strategies various interactions with the wild-animals in these savannas through the lens of CRR and diverse and shifting ecoservice-interactions are to be expected, and more so as emerging livelihood strategies intensify, and is the focus of the next section.

In order to informatively understand how the aforementioned *contextual* ecoservice-*tradeoffs and* ecoservice-*synergies*, evident in Maasai's livelihoods strategies and diversifications mean vis-à-vis the shared ecoservice for the diverse wild-fauna inhabiting these savanna rangelands, it is instructive to first grasp those ecoservice-interactions existing among these animals. It must be pointed out that, as regards Maasai-owned wildlife-based CBOs, the wild-fauna in such places/spaces are already beneficial as ecoservice for these pastoralist. The following explication looks at what ecoservice-interactions mean for the diverse wild-animals (and Maasai people) inhabiting these rangelands; *resource use-type/space* by the specific wild-fauna and/or gild is explored.

3.3 Megafauna-Biodiversity and Maasai Livelihoods Interactions: Ecoservice Synergies and Tradeoffs

As aforementioned, Maasai people predominately subsist on pastoralism; they also engage in other diverse livelihood types and intensification strategies [see 5]. A recent study reveals that over 80% livelihood-diversifications, dominant among which include arable farming, tourism-based enterprises, and extraction/sales fuelwood (charcoal and firewood), among the Maasais are hinged on natural resources' extraction (*ibid*.) entailing various ecoservices that are also (as revealed in the following explication) used by diverse wild-fauna inhabiting these rangelands. Suffice that, the various ecoservices buttressing the proper operation of Maasais' dominant livelihood types, also buttress the survival of wild-fauna dispersed across these rangelands. The following explication focuses on the interactions of Maasai-pastoralists' livelihood strategies and wild-fauna biodiversity through linked ecoservice-interactions.

From the current evidence, diverse wild-ungulates, including browsers, grazers, and mixed, foragers, and carnivores inhabit Maasai rangelands of Kenya (Table 1). As aforementioned in the previous section, although a rich diversity of wild-animals inhabit these rangelands, the current study focuses on the economically megafauna, mainly ungulates and nuisance carnivores for these are closely linked to Maasais' livelihood strategies. A rich mix of ungulate browsers and grazers is evident (Table 1). The most common wild-ungulates include African elephant (*L. africana*), Zebra (*E. burchelli*), African/Cape buffalo (*S. caffer*) Maasai giraffe (*G. camelopardalis*), and wildebeest (*C. taurinus*) (Table 1).

In the system of Maasai-pastoralism, the most nuisance livestock-predators include lion, leopard, and hyena (Table 1). Thus, it should be clear: Maasai rangelands of Kenya, epitomizes an ideal natural platform upon which the interactions of traditional/local and emerging livelihood strategies, economically important wild-fauna biodiversity via ecoservice-interaction can be explored.

As regards Maasai interactions with the wild-fauna in these rangelands, presently, plausibly of greatest public concern is Maasai's killing of lions [e.g., 33], which killings are retaliatory; the nuisance carnivore(s) preying on Maasai's livestock is tracked and speared to death by the *Il-Moran* (e.g., *ibid*.) other times they are simply poisoned (LEDP, *op. cit*). Traditionally this was never the case. Maasai pastoralists harmoniously lived with the diverse wild-fauna that disperse across the savanna rangelands of Kenya (and Tanzania), and judiciously extracted the same for food or ritual purposes. Apropos this last point, the harmonious co-existence is excellently captured in a recent

study:

> "Concerning the rarely done extraction of wild fauna, the Maasai only kill animals on an as-needed basis. For example, they might consume wild animals, such as the eland, particularly in times of drought or other famine-causing catastrophes. In fact, they consider wild herbivores that resemble cattle (e.g., kudu, kongoni, and the like) as their second cattle that are provided by the land and used as appropriate given fluctuations in environmental or social conditions. The *Il-Moran* would hunt a kudu, which is consumed by a number of households during times of drought; sharing is an unspoken and strongly held virtuous norm among the Maasai. The kudu's skin and horns would be conserved for other uses—for example, the latter is blown during e*unoto* ceremony to call the attention of the *Il-Moran;* the former is used to make ropes for tying a bundle of firewood that is ferried on one's (female) back, restraining cow's legs when milking, and other uses. Among the Maasai, "*... you don't kill a wild animal unless it is perilously crucial* ...," a Maasai-elder informs during one of the participatory interviews [5]."

Implicit in this last point is the innate *sharing of provided* ecoservices in the traditional Maasai system, which sharing is eroded with emergence of individuated livelihoods and entry of non-Maasais in these rangelands.

3.4 The Changing Geography of Maasai-Wildlife Interactions: Inconvenient Resources, Precious Resources

Although Maasai's decimation of the nuisance predators serves to 'send a definite warning' to would-be livestock-predators, and indeed to the existing plausibly 'insensitive-to-Maasai-livelihood' policies, decimation of lions (*P. leo*), an already vulnerable keystone species and a top-predator, has far-reaching implications on the nature, availability, and quality of ecoservices across these rangelands. Lion is already classified as vulnerable (IUCN), and therefore continued decimation of this big cat, alongside persistent climatic and socioeconomically induced habitat loss, serve to further threaten it. Lion is a common predator on Maasai's livestock, particularly during periods of drought when resources are limited (LEDP, *op. cit.*).

In addition to contending with the nuisance predators, Maasai have had to deal with CRR and habitat competition and resource degradation (*ibid.*), with other socioeconomically important wild-fauna (e.g., Table 1), most of which are dispersed outside the sanctuaries in Maasai ecosystems. For example, both grazers and browses among the Maasai's livestock and wild-ungulates use and access CRR in the now reduced land-spaces under Maasai's control. For example, buffalo, with diet mirroring that of cattle, is a major reservoir and transmitter of several diseases and pests to livestock (e.g., [34]; LEDP, *op. cit.*). Maasais often avoid areas inhabited by buffaloes for this latter reason; and also because they are dangerous human-attackers (LEDP, *op. cit.*). As regards diet, a CRR competition is to be expected between Maasai's cattle and the buffaloes, and indeed other ungulates, especially the large populations of wildebeest and zebra found in these rangelands (Table 1) Among Maasai pastoralists it is acknowledged that buffalo's calving sites are often plagued with fatal diseases, and are thus avoided [35]. Maasais also acknowledge that wild-dog is associated with transmittance of rabies, and as such, the herder's often kills these dogs (*ibid.*). Maasai's avoidance of potentially disease/pest-infested buffalo space translates to denial of CRR located therein: an ecoservice-tradeoff. Since Maasai practice disease/pest-control measure on their livestock, then, an ecoservice-synergy can also be seen in these spaces. For example, where pest-control measures (e.g., dipping or race-spraying with acaricide) of livestock, eradicate ticks in such spaces, or disinfect areas where the livestock were herded immediately after such measures thereby benefiting wild-fauna (e.g., buffalo in this case).

Thus far, it should be clear: an indirect ecoservice-tradeoffs (and/or ecoservice-synergy) in the use CRR is evident for the case of game-sanctuaries vs. outside parks CRR. Apropos this last point,

indirect because it's an *inadvertent, even synthetic, "trading off*"; the seeming tradeoffs is a concealed power inequalities among stakeholders. Authentic ecoservice-tradeoffs is evident, for example, between livelihoods and Maasai run wildlife-CBO initiatives within Maasai spaces. In policy terms therefore, the focus on the an *inadvertent/synthetic, "trading off*" common in broader-scale policies leads to inadvertent denying the locals of CRR, and even misinforming the general public of the benefits of such efforts. Apropos this last stance, the retaliatory killings explain well, in part, the affected-locals' disdain toward these tourism-assets: it must be noted that Kenya's tourism sector is a key revenue-earner, and thus economically important at the national-scale (even international scale), but so is pastoralism at the household-scale.

Thus far, it should be clear that in ecological terms, wild or domestic fauna under similar ecological-gild and/or trophic-level display ecoservice-tradeoffs e.g., buffalo and cattle, cheetah and leopard, and camel and goats. It should also be clear that, to a lesser extent, retaliatory killings are plausible signatures of upset in trophic-levels in the wild, for example shortage of preys in the wild for the lions, especially during periods of drought when most move to wherever pastures may be found, forcing this cat to prey on livestock. However, it must be pointed out that some of these *nuisance* lions are "strays" from sanctuaries, and given the existing human-encroachments into much of wilderness, these cats are trapped within these human-settled spaces, which also harbor easy prey, viz., Maasai's livestock. The impacts of human-wildlife conflicts, particularly due to LUC (e.g., Table 2; [36, 37, 38]); wild-and domestic-ungulates' competitions and co-existence via CRR [e.g., 39, 40] are well documented. As regards LUC, in addition to increased human-wildlife conflicts, other common effects on wildlife include displacement of wildlife by livestock, declined number of wild-animals, habitat destruction, and land-degradation [e.g., 36, 38, 41, 42]. Apropos these last points, and in equity terms vis-à-vis sharing of land-space, it should be clear: the very decimation of lions can thus be seem as a decimation of the very victim of cross-scale anthropogenic resource change.

Collectively, ecoservice tradeoffs and synergies' emanations among and between Maasai livelihood strategies and megafauna occurs directly via CRR, and indirectly via inhabited spaces, stakeholders' relations, or management of either livestock or wild-fauna. As changes in livelihoods, land-use/cover/tenure, and climate intensify, shifts in these interactions are to be expected. A critical concern, therefore, arises of achieving sustainability of ecoservices and of linked livelihoods and megafauna-biodiversity. There is no simple solution to this concern, and indeed regarding complex social-ecological systems that characterize these rangelands. However, unraveling the types and dynamics of social, ecological, and climatic factors, processes and their interactions can inform on the practical answer to this concern: this is the focus of the following section.

3.5 Changing Climate, Changing Ecoservice-Interactions: Ecoservice Tradeoffs and Synergies among Maasai-Livelihoods and Megafauna

In this section, scenarios of ecoservice-Interactions under specific projections of changed climate are explicated; existing ecoservice tradeoffs and synergies among Maasai-livelihoods and megafauna (see above section) is the baseline. As regards Africa, and rangelands (ASALs) in particular, studies have documented existing and potential effects of the changing climate on environments, ecosystems, and livelihoods. Examples of these effects include increased rainfall variability, evaporation, intense droughts, extreme climate events, aridity, water stress, desertification [see 43, 44, 45, 46]; and altered growing seasons and species' range of both domesticated and wild plants [43, 44, 45].

The IPCC [43, 44, 45] projections indicate manifestation of an admixture of drier and wetter spaces, with consequent lowered ecosystems' stability across Africa. Overall, heightened, predominantly deleterious, effects of climate change for ASALs across Africa are projected (*ibid*.). As regards Africa, and on concern related to ASALs, a recent study covering Maasai rangelands of Kenya reports the following. "Existing studies generally confirm that Africa will experience these deleterious

effects of climate change in an intensified manner, primarily because her key production systems and economic sectors are sensitive and are already vulnerable to changes in climatic conditions; due to its inadequate adaptive capacity; and because her core livelihood production systems are coupled social-ecological systems [43, 44, 45, 46]. In addition to being triggered and/or aggravated by drought, the prevalent inadequate adaptive capacity across Africa has multiple drivers, for example poverty, degradation of the natural resource-base, and unfavorable economic and political conditions [1]; *ibid*.)." The foregoing raises salient concerns: w*hat does the effect of the changing climate mean for the existing ecoservice tradeoffs and synergies among Maasai-livelihoods and megafauna-biodiversity; what are the potential outcomes on these ecoservice-interactions?*

Presently, drought is the most deleterious climatic effect devastating Maasai rangeland of Kenya, and indeed the GHA [see 35, 47]. Thus far, it should be clear that a scenario of intensified occurrences of droughts in Maasai rangelands of Kenya will manifest, or is manifesting, against a backdrop of multiple pressures from human-systems, namely, social, cultural, political, and economic factors and process and their diverse interactions, and biophysical factors. Therefore, frequent occurrences of drought, alongside these pressures are legitimate platform upon which to informatively address the integrity of social-ecological systems that define these rangelands including the livelihoods, biodiversity, and ecoservices thereof. This concern becomes more crucial because much of the region is characterized of variable critical resources (as is expected of drylands), recurrent prolonged droughts, and highly variable rainfall [1, 47, 48, 49]: thus higher odds exist of disrupting rainfall-dependent livelihoods, economically important megafauna, and critical ecoservices as the climate continues to change. Clearly, an informed understanding of the aforementioned nexus becomes important if effective mitigation of and adaptation to its deleterious impacts of climate change is to be achieved. It must be pointed out that, coarse-scale projections indicate that, as the climate changes, the frequency with which drought occurrences manifest, their duration, and their spatial extent will increase relative to the present conditions [see 43, 44, 45]. Moreover, it should be noted that a slight change in climate could trigger significant intensity and frequency with which extreme climatic events (e.g., extreme droughts) manifest across the ASALs of Africa [50].

As regards Maasai rangelands, recent studies documents spatiotemporal high rainfall-variability; and occurrence of widespread, recurrent, cyclic, occasionally clustered droughts [1, 47]. In fact, over the past 30 years, Kajiado County recorded over 85% major-droughts [47]. As regards the broader region's rainfall amount received, Nicholson [49] documents a total decline of 50–75% below average within the last decade. It must be pointed out that the persistently declining snow cover on Mount Kilimanjaro is a plausible signature of increased temperature in the region [e.g., 51]. Apropos the GHA, the entire suite of impacts of the changing climate projected for ASALs already devastates much of the region. Thus it would be informative to explore some of the implication of drought on the existing ecoservice-interactions.

Under recurrent drought conditions, and *ceteris paribus*, the following scenarios will plausibly unfold: (*i*) the existing ecoservice-tradeoff between water needs for arable-faming and livestock, and for domesticate and wild water-dependent ungulates e.g., cattle vs. buffalo, will intensify. (*ii*) lion's predation on Maasai's livestock, is likely to become more frequent, since most wild ungulates migrates therefore more preying on resident ungulates, both domestic and wild. (*iii*) Intensified ecoservice-tradeoff should be expected among wild or domestic fauna under similar ecological-gild and/or trophic-level e.g., buffalo and cattle, cheetah and leopard, and camel and goats. Increased evaporation, extreme droughts events, aridity, and desertification [e.g., 43, 44, 45, 46] would also unfold any of these three ways.

Altered growing-seasons and species range of both domesticated and wild plants for example due to change in climatic conditions [e.g., 43, 44, 45] in terms of these rangelands translates to reduced availability and/or loss of natural pastures: this is because existing varieties/cultivars, mainly tropical graminoids have plausibly already reached their optimal phenological levels [43].

Consequently, like the aforementioned scenario, an intensified ecoservice-tradeoff should be expected among wild or domestic fauna under similar ecological-gild and/or trophic-level.

In addition to the challenges posed by the changing change, the broader region (the GHA) have had to contend with diverse and scalar non-climatic factors: ranging from unfavorable permeation of socioeconomic and sociopolitical factors and processes [e.g., 52, 53, 54 55, 56]. Presently, as agriculture encroachment persists, especially irrigated forms, competitions of water should be expected, and more so during periods of drought. Thus, for example, the water-extraction, particularly through irrigated-agriculture in the environs neighboring swamps and other wetlands across these rangelands (e.g., [1]; LEDP, *op*. *cit*.), affects the integrity such CRR, and hence the fauna relying on the same. Apropos this last point, a tradeoff is generated at different place and time. Suffice that, the land-use/tenure and conservation policies have inadvertently created ecoservice-tradeoffs as regards the wellbeing of Maasai-livelihoods and megafauna. As climate continues to change, and hence increased occurrences of recurrent and intense drought or more variable rainfall, the starkness of impaired ecoservices and dominance of ecoservice-tradeoffs becomes clear. In Maasai rangelands, some of factors and processes driving ecoservice-interactions are diverse and closely interlinked and include governance, land-use, ecological/environmental changes, the way ecoservice is used, and types of stakeholder. Collectively the findings of this research reveal that increased occurrences of drought under a changed climate, amidst rapid permeation of sociopolitical and socioeconomic globalization across Maasai's landscapes, will alter CRR and megafauna-biodiversity and trigger shifts in ecoservice-interactions in ways yet unknown. Therefore, the need for informed realization of sustainability of ecoservices and of linked livelihoods and megafauna-biodiversity cannot be overemphasized.

4. Conclusions, Emerging Themes, and Recommendations

The current study used the *Driver-Pressure-State-Impact-Response* (DPSIR) model to integratively and simultaneously assess and systematize the structural elements driving ecoservice-interactions: namely, cross-scale climatic, environmental, and socioeconomic and sociopolitical factors and processes factors, processes and their various interactions using the case of Maasai savanna rangelands of Kenya. Potential policy/practice responses that would ensure informed and practical achievement of sustainability of ecoservices and of linked livelihoods and biodiversity were presented. As regards Maasai rangelands, the changing climate, the state of livelihoods, ecoservices, biodiversity, and associated governance institutions and structures are intricately linked. Diverse livelihoods strategies and diversifications *contextually* interact across Maasai rangelands to reveal varying ecoservice-interactions.

Most shifts in ecoservice-interactions, particularly synergies, are occasioned by challenges associated with land-use/tenure change. Land-use change has widespread, even cascading, deleterious effects on the provision of ecoservices across these rangelands. Encroachments of other land-use types in these rangelands have occasioned severance of some ecoservice-synergies between Maasai-livelihoods and wild megafauna. In these rangelands common ecoservice affected include water quality, forage quality, soil/site, and habitat-space; CRR are the critical ecoservice, and have the strongest tradeoff. The study reveals manifestation of more ecoservice-tradeoffs than ecoservice-synergies. The generated ecoservice-interaction is dictated by the way the relevant ecosystem is experienced, accessed, controlled, managed, and changed by diverse stakeholders. The evident indirect *inadvertent, even synthetic*, tradeoffs in the use CRR is evident reflects concealed power inequalities among stakeholders.

Presently, wild or domestic fauna under similar ecological-gild and/or trophic-level reveal predominance of ecoservice-tradeoffs. Under recurrent droughts occasioned by changed climate, and *ceteris paribus*, the existing ecoservice-tradeoff between water needs for arable-faming and livestock, and for domesticate and wild water-dependent ungulates, will intensify. Similarly, an intensified

ecoservice-tradeoff should be expected among wild or domestic fauna under similar ecological-gild and/or trophic-level under such scenario. Under the same scenario, lion's predation on Maasai's livestock and on resident ungulates is likely to become more frequent.

The incorporation of response component, as availed via DPSIR model, into concern of the changing climate change and rapid permeation of socioeconomic and sociopolitical globalization help inform on practical adaptation and/or mitigation strategies to cushion megafauna and Maasai-livelihoods from the deleterious emanations from the same, or conversely, take advantage of favorable outcomes from the same. The advantages of DPSIR model for this study is clear: it simultaneously captures cross-scale drivers and pressures; it helps identify priorities; and it reveals practical responses toward achieving sustainability of ecoservices and of linked livelihoods and megafauna-biodiversity.

The study reveals the nexus of Maasai-livelihoods and megafauna-biodiversity across savanna rangelands of Kenya via ecoservice-interactions: in the context of sustainability/vulnerability dichotomy, and amidst the changing climatic and non-climatic factors and processes, and their interactions. Persistence of the existing challenges on Maasai's livelihood strategies, ecoservices, and megafauna under different climate change projections and scenarios is to be expected. The current study provides an entry point for practical policies/practices vis-à-vis this nexus if effective mitigation of and adaptation to deleterious impacts of climate change amidst rapid permeation of sociopolitical and socioeconomic globalization is to be achieved. Therefore policies/practices that anticipate achieving sustainability of ecoservices and of linked livelihoods and biodiversity for these rangelands, should account for this nexus and the cross-scale linkages thereof.

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