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Source: Tropical Conservation Science, 16(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/19400829231166832

Research Article

Tropical Conservation Science
Volume 16: 1–15
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Reconstructing Historical Distribution of Large Mammals and their Habitat to Inform Rewilding and Restoration in Central Tanzania

Paulo C. Athumani[1], Linus K. Munishi[1], and Issakwisa B. Ngondya[1]

Abstract

Backgroundand research aim: In the anthropogenic landscapes where historically wildlife existed, there can be a potential for rewilding to reverse extinction. However, there is limited literature providing approaches to achieve successful rewilding. The current study aimed at providing empirical based methodological procedures for successful rewilding of the University of Dodoma (UDOM) and nearby degraded landscape by assessing past and current vegetation and large mammal species' occurrence.

Methodology: The past occurrence of mega-herbivores and their habitat was assessed using systematic literature survey, past vegetation maps and key informant interviews. EBSCOhost database and Google Scholar search engine were used for literature searching. A survey was conducted at UDOM area which is one of the remaining habitat patches in central Tanzania to examine present plant diversity.

Results: The baseline vegetation map of 1960 indicated that the study area was mainly Savanna woodland. Literature suggested that anthropogenic activities resulted into Land-Use Land-Cover Changes (LULCC) leading into wild animals' extirpation leaving remnant populations in the surrounding protected areas. While the key informant interviews verified local loss of mega-herbivores, field data collected at UDOM campus in 2022 indicated the vegetation transformation to bushland dominated by *Dichrostachys cinerea*. The area's past vegetation composition was 33% grasses, 29% herbs, 21% shrubs and 17% trees while the current was 18% grasses, 42% herbs, 30% shrubs and 10% trees.

Conclusion: The study revealed that central Tanzania hosted spectacular large mammal populations that interacted with the savanna which has recently been transformed to bushland. However, observed evidence on past existence of large mammals and recent elephants' sightings at UDOM area indicate great potential for rewilding.

Implication for conservation: Reconstructing historical information of ecosystems is crucial for successful rewilding. Such information can guide conservation efforts aiming at reversing extinction and reestablishing connectivity of large herbivore population across ecosystems.

Keywords

restoration, rewilding, UDOM campus, central tanzania, habitat fragmentation, bush encroachment, savanna woodland

Introduction

Ecosystems across the globe have been altered by faunal declines and extirpations, mainly due to anthropogenic activities and these have accelerated sharply over the past century (Mendiratta et al., 2021; Stalmans et al., 2019). While changes in response to novel ecological interactions may be unpredictable, catastrophic decline of large mammal

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Received: 7 October 2022; accepted: 14 March 2023

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populations has significant impacts to the landscape; including for example, invasion of grasslands by woodlands in savanna ecosystems (O'Connor et al., 2014). Surveys of large mammals between 2000 and 2002 revealed a significant decline of diverse populations of species while some (e.g., leopard, wild dog, spotted hyena) had been extirpated with significant changes in plant and animal biomass (Bouley et al., 2021). Evidence further shows that effects of mega herbivore removal on vegetation, e.g., vegetation changes to more dense and uniform formations may be influenced by the extent of their decline, species' traits, habitat requirements, among other factors (Bakker et al., 2016).

Anthropogenic pressure (e.g., land use change) that is being exacerbated by man has led to habitat loss and degradation, contributing significantly to global biodiversity loss and eventually towards the sixth mass extinction (Pearse & Altermatt, 2013; Pimm & Raven, 2000; Wagler, 2011). Megaherbivores such as elephant, rhinoceros and giraffe among others are at the highest risk of extinction due to overhunting and habitat loss compared to birds and reptiles due to their position in trophic level and their body sizes (Tomiya, 2013; Atwood et al., 2020). The highest risk of extinction is attributed to loss of forage (Pearse & Altermatt, 2013), isolation and loss of connectivity and interactions between populations (Miyazono & Taylor, 2013).

Increased habitat loss and degradation due to land-use and land cover change (LULCC) is the main threat to terrestrial ecosystems (Makwinja et al., 2021). Together with climate change, LULCC are potential drivers of species extinction (Jantz et al., 2015). Land cover dynamics might be influenced not only by land use and climate change but also the proportion of herbivore (grazers and browsers) species in a given ecosystem (Soininen et al., 2021). More grazers without browsers will promote wood encroachment while inclusion of relatively many browsers will reduce higher plants in favour of grassland (Maron & Crone, 2006; Soininen et al., 2018; Staver et al., 2021). Thus, understanding these dynamics is crucial for successful rewilding of degraded rangelands.

Rewilding is the term that is used in different contexts depending on practices but with the main goal of maintaining or increasing biodiversity while reducing the impact of intervention of human beings through reintroduction of species and ecological processes (Lorimer et al., 2015). It involves different practices such as species restoration, assisted migration and natural recolonization (Corlett, 2016). Rewilding is considered central for overcoming the global crisis of biodiversity loss and key for restoration efforts (Svenning, 2020). This concurs with the UN decade of ecosystem restoration 2021-2030 with the main focus on recovering damaged, destroyed and degraded ecosystems to make them ecologically functional so that people can accrue benefits from them (Fischer et al., 2021). Furthermore, trophic rewilding is of great importance to ensure that vegetation cover is utilized efficiently to maintain vegetation stability over a long period of time and reduce the impact of climate change (Cromsigt et al., 2018).

Nevertheless, rewilding faces a number of limitations which delay and/or render a number of projects unsuccessful (Torres et al., 2018). In Europe, uncooperative policies and persecution of restored key stone species has limited progress of several rewilding projects (Segar et al., 2022). This is coupled by lack of innovative sources of finance, political and professional interest of deploying and experimenting rewilding as a new approach adding up to competing socio-economic interests (Jepson et al., 2018; Segar et al., 2022). Moreover, challenges in establishing quantitative information about the impacts of landscape changes led to poor progress of rewilding projects in Netherland and Argentina (Torres et al., 2018). Likewise, inadequate quantitative information, technical capacity, lack of baseline information (Cortina-Segarra et al., 2021; Wells & Winowiecki, 2017) and shifting of baselines due to climate change have hindered effective and large scale implementation of restoration efforts (Hirsch, 2020). The researcher may have current composition and abundance of species but lack the historical information which is the key for successful restoration (Humphries & Winemiller, 2009).

Environmental degradation is a matter of global concern that is attributed to many factors. In Turkey, industrialization and urbanization are known to be the sources of environmental degradation leading to habitat loss and ecosystem disturbance and thus threating biodiversity (Kavzoğlu, 2008). The increase in population in Nigeria, for example, has contributed significantly to environmental degradation as a result of high concentration of people in urban areas who are involved in economic activities that increases Carbon dioxide (CO_2) emission (Yahaya et al., 2020). Similarly, in India, population growth and urbanization have remarkably negatively impacted the environment due to air pollution and increased solid waste deposition (Azam & Khan, 2016; Maiti & Agrawal, 2005).

Dodoma region in the central area of mainland Tanzania is not far from the fact that population increase has resulted into LULCC, habitat loss and fragmentation leading to significant loss in biodiversity (Kangalawe & Lyimo, 2010). Due to increased anthropogenic activities such as overgrazing and crop cultivation coupled with climate change, some areas in the region have changed into bushed grassland (Komba et al., 2021). This has resulted into tremendous loss of biodiversity including decline and/or local extirpation of large mammal populations (Prakash & Verma, 2022).

Given the UN declaration of 2021-2030 as the decade of restoration (Fischer et al., 2021) and the relatively higher current rate of habitat loss (Kerr & Deguise, 2004) as well as local and global wildlife extinction (Pimm et al., 2014), there is a need to reconnect and restore areas often needed to conserve metapopulations. Reconnecting and restoring such areas are important as a solution to mitigate further extinction by improving the population viability and persistence of species. Yet, there is limited literatures which provide clearly the methodological procedures to achieve successful rewilding.

This study aimed at providing stepwise evidence based methodological procedures to perform rewilding by linking the past with the current information. The study seeks to put research into action and form the basis for adaptive management strategies for the future rewilding projects. We summarized existing knowledge of the past (using the 1960 as the base year for the recent past) and present (2022) vegetation cover and composition and wildlife occurrences, as a way of reconstructing habitat relevant for reintroducing the herbivores on the University of Dodoma (UDOM) campus proposed rewilding area. We also used the current vegetation survey data to inform the changes in the UDOM vegetation and how shifts in habitats can be used to advise the best evidence for any future reintroduction in the area.

Materials and Methods

Study Area Description

Central Tanzania is a semi-arid area historically characterized by savanna vegetation defined by wooded grassland occupied by different species of wild animals including mega and mesoherbivores. The area is found in the Central Plateau of Eastern Africa extending from Ethiopia in the North to the Transvaal in the South and elevated from 1200 m to 1500 m above sea level (Msabi & Makonyo, 2021). It receives 300 mm to 800 mm of rainfall from November to April and only 15 mm to 1 mm from May to October. The temperature varies between 15°C in July and 30°C in October (Msabi & Makonyo, 2021). The area is surrounded by several protected areas including Swagaswaga, Muhesi, Kizigo and Rungwa game reserves and Ruaha, Mikumi and Udzungwa national parks (Figure 1) making massive movement of wild animals across the region.

Where Rewilding/Reintroduction is Anticipated

Rewilding is anticipated to be done at UDOM area situated at its main campus (Figure 1(c)). The UDOM area is located at 6°10’32” S and 35°49’19”E (Rao & Murthy, 2017). The campus, covers an area of approximately 6,000 ha which was once occupied by savanna woodland but now bush encroached (Vats & Safari, 2014). The area was then inhabited by humans for more than 100 years. People who were inhabiting the area performed different activities including crop cultivation and cattle grazing until 2007 when they were evicted from the area. After eviction, most of the area was left intact excluding the area where the buildings were erected. Due to anthropogenic activities the vegetation that was once dry miombo and acacia-commiphora woodland is now transformed to bush-encroached land.

Historical Vegetation and wild-Fauna Data Collection

We assembled past vegetation information for the region by using historical vegetation maps created in ArcMap software version 10.5 (ESRI 2005) and conducted an extensive systematic literature search from January to April 2022 to understand the historical changes in vegetation and wild fauna species in and around the study area over a span of sixty-two (62) years (1960-2022). The originality of the literature was randomly selected based on the search responses; therefore, the coverage was worldwide. The search based on relevance and not by period range. Relevant documents that were in English and/or Swahili were selected for this review. Searches were focused mainly on EBSCOhost database and Google Scholar search engine but sometimes involved consulting some governmental, non-governmental organizations and wildlife research institutions. The EBSCOhost database and Google Scholar search engine contained the most important and relevant literature, but sometimes failed to provide a direct link to a journal’s webpage of the target literature. In such instances, the search was extended to a specific journal. The key words used to search the literature included “vegetation and central Tanzania or Dodoma, wild-fauna and central Tanzania or Dodoma, vegetation history and central Tanzania or Dodoma, wild-fauna history and central Tanzania or Dodoma”.

Furthermore, the scanned topographical maps of 1960 with the scale of 1:50,000 obtained from the Department of Survey of Tanzania were used to generate the 1960 land use/cover types. Additionally, AFRICOVER map shape files with the scale of 1:2,000,000 based on the data (Land Use Systems) was deployed in this study. Moreover, ArcMap (ESRI 2005) software was used to derive and analyze land use/cover classification and changes in all the data set.

To begin with, scanned topographical map sheets of 1960 were displayed and rectified using a coordinate system which is an area-specific standard UTM projection system for Tanzania with the ArcMap software version 10.5. The map was digitized, edited, and leveled by using the same software. The AFRICOVER map of Tanzania was then clipped by using the same software to obtain the map of the study area. Afterwards, the map of the study area was reclassified into simplified AFRICOVER map with six classes (savannah woodland, natural forest, bushland, urban areas and rural settlements, crops land and bare land) as done by Dewan and Yamaguchi (2009). Finally, vector land cover data from the topographical and AFRICOVER maps were used to generate the heat map (Figure 2) for each vegetation type category by using the default settings of the Kernel density tool in ArcMap (DeBoer, 2015) in order to determine the most dominant vegetation layer. Eighty (80) reference point data that were collected in the field using a handheld GPS were used for evaluation of the result by cross checking the land cover change through field validation. This information was then applied into ArcMap and overlayed with the heat map generated using data obtained from the topographical and AFRICOVER map shape files for ground truthing and classification accuracy. The wildlife corridors across the study region adopted from Riggio and Caro (2017) and supported by Debonnet and Nindi (2017) were overlaid on the same map.

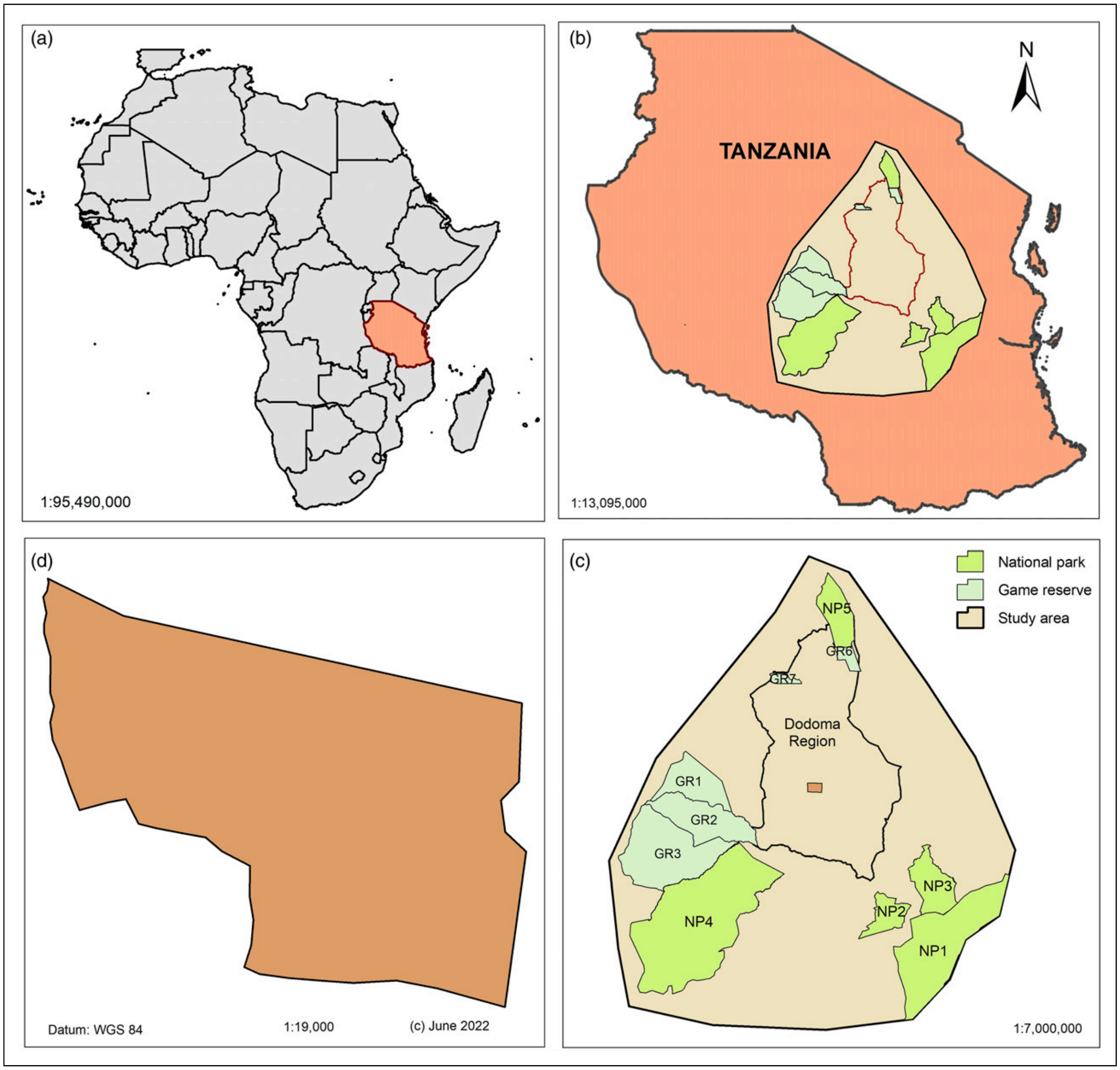

Figure 1. A map of the University of Dodoma showing the area proposed for restoration and rewilding. **(**NP1=Nyerere National Park; NP2=Udzungwa National Park; NP3=Mikumi National Park; NP4=Ruaha National Park; NP5=Tarangire National Park; GR1=Muhesi Game Reserve; GR2=Kizigo Game Reserve, GR3=Rungwa Game Reserve; GR4=Swagaswaga Game Reserve; GR5=Mkungunero Game Reserve).

Additionally, key informant interviews were randomly conducted and subsequent focused group discussion for 10 elders who inhabited the proposed and nearby rewilding (UDOM) area in the past, one (1) Tanzania wildlife management officer at UDOM station (to obtain information about the past vegetation and wild fauna in and around the area and one (1) pioneer of the university of Dodoma (to capture the status of the area when the university was established). The key informants were obtained from the UDOM surrounding villages of Makulu, Nghonghona and Ihumwa. The VEO (village executive officers) suggested the names of the qualified key informants (those inhabited the rewilding proposed area for the period of over 20 years and aged 50-70 years old). The number of key informants was determined by their availability as most of the past inhabitants of the rewilding proposed area had shifted to other remote areas. The data were summarized in excel and analyzed thematically in NVIVO 11 software.

Vegetation Data Collection from the Field

Following assemblage of historical wildlife and vegetation data, this study further assessed the recent species composition, abundance and diversity of vascular plants (tree, shrubs, forbs and grass) for two seasons; dry (November, 2021) and wet

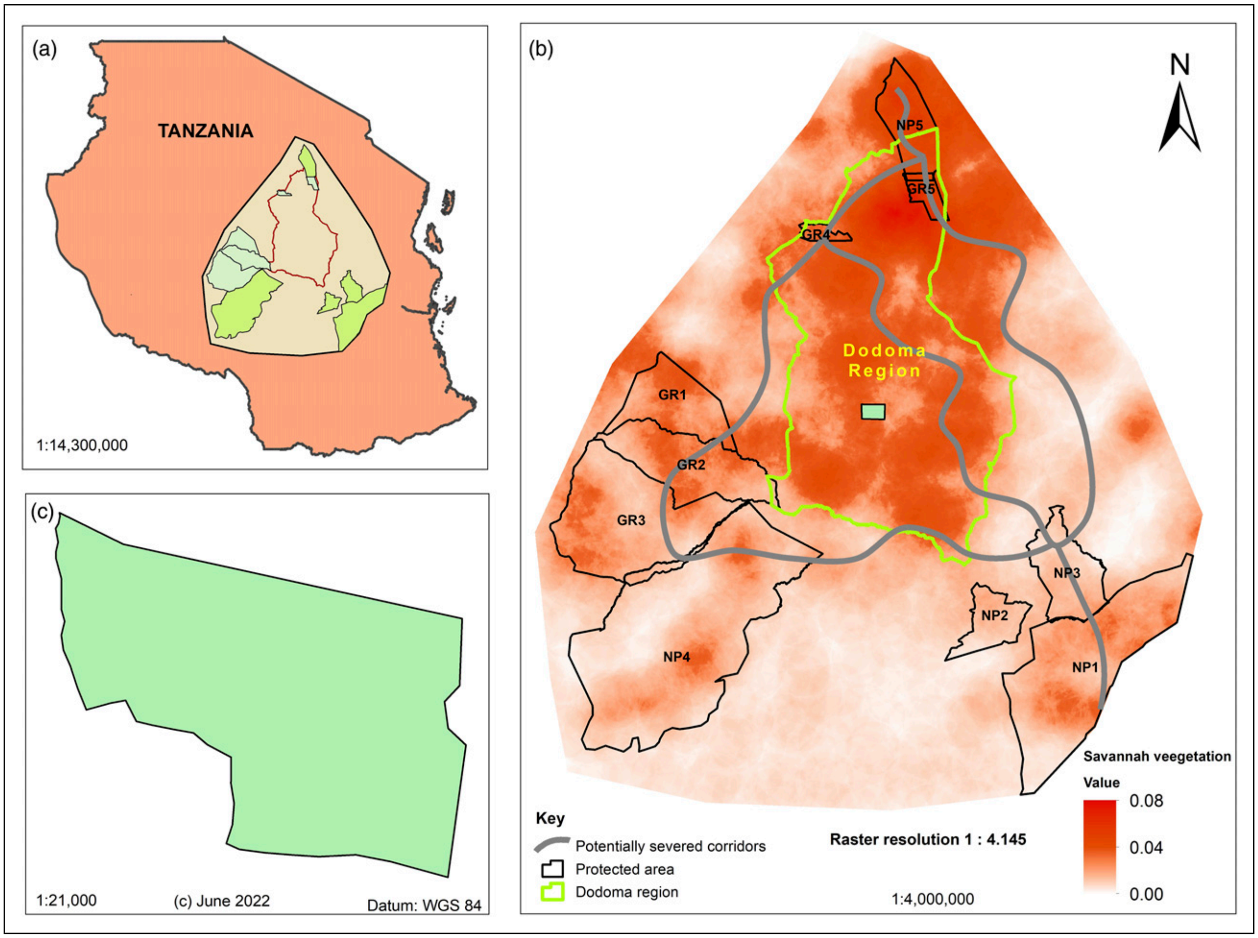

Figure 2. A map of the Dodoma region and surrounding protected areas showing past vegetation and corridors those were once present but now are severed due to LULCC. **(**NP1=Nyerere National Park; NP2=Udzungwa National Park; NP3=Mikumi National Park; NP4=Ruaha National Park; NP5=Tarangire National Park; GR1=Muhesi Game Reserve; GR2=Kizigo Game Reserve, GR3=Rungwa Game Reserve; GR4=Swagaswaga Game Reserve; GR5=Mkungunero Game Reserve).

(April, 2022) to compare extent of change from the historical plants and large mammal species. For the assessment of current plant diversity status, the study area was divided into 155 grids of 50x50 m (of which 30% (47) were randomly selected for inclusion in the study. 50x50 m grids ensured maximum sampling and less influenced by spatial autocorrelations (Goslee, 2006; Bonham, 2013). In every selected grid of 50x50 m, three quadrats of 10x10 m, 5x5 m and 1x1 m were nested and laid diagonally across the grid for trees, shrubs and grasses/ forbs identification respectively. While sampling the vegetation, the vegetation cover was visually estimated after consensus by a team of three experts. Past vegetation will be used as a blueprint for restoration in relation to present vegetation cover and species composition.

Statistical Analysis

Shapiro-Wilk test was used to test for data normality; for normally and non-normally distributed data, one-way analysis of variance (ANOVA) and the Kruskal–Wallis H tests respectively were used. Paired sample Student's t-test was performed to compare plant species diversity between two seasons (dry and wet) while Kruskal-Wallis H test was used to compare plant species richness between the two seasons. The statistical software used was R-statistical software version 3.6.3 with the level of significance set at $p < 0.05$.

Permission to conduct research

The permission to collect data at the University of Dodoma campus was given in writing by the University of Dodoma.

Results

Historical Information

Past Vegetation Classification. The vegetation map of 1960 created in ArcMap suggested that the study area was dominated by Savanna woodland vegetation (Figure 2). The southern and eastern blocks which are occupied by the

Rungwa-Ruaha ecosystem were covered by Miombo woodland (Backéus, 1994; Gillman, 1949; White, 1983). The northern block occupied by the Tarangire-Manyara ecosystem was covered by Acacia-commiphora woodland (Ludwig et al., 2008; White, 1983) while the western block that was occupied by Itigi and surrounding areas was covered by thickets.

Information from literature and the interviews indicated that anthropogenic activities such as settlement and smallholder agriculture expansion resulted into LULCC which eventually led to extirpation of key large mammals in the area. While some populations were locally extirpated, leaving remnant population in the surrounding protected areas (Hariohay et al., 2019; Prakash & Verma, 2022), respondents from interview indicated that some species such as elephants have been observed to cross in the area from and to nearby protected areas. The vegetation map of 1960 showed the vegetation cover but could not be able to reveal the floristic composition. However, based on the past studies in the area; from 1933, (Greenway, 1933; Gillman, 1949; Backéus et al., 1994; Ludwig et al., 2008; Kayombo et al., 2020;); the area proposed for rewilding (Figure 1(c)) in the past comprised a mixture of 19 species of grasses (33%), 17 species of herbs (29%), 12 species of shrubs (21%) and 10 species of trees (17%) (Table 1 and Figure 3).

Results from the Interview Responses. Savanna vegetation (grasses and scattered trees) with several wildlife species were reported to dominate the rewilding proposed site in the past (100%, n = 10). The wildlife species included elephants (100%, n = 10), buffalo (100%, n = 10), hippopotamus (100%, n = 10), zebra (100% n = 10), giraffe (100%, n = 10), impala (100%, n = 10), grant gazelle (70%, n = 10), bush pig (100%, n = 10), warthog (100%, n = 10), lion (100%, n = 10), hyena (100%, n = 10), bushbuck (100%, n = 10), wildebeest (80%, n = 10), eland (80%, n = 10), kudu (80%, n = 10), civet cat (80%, n = 10) and genet (60%, n = 10). Wild animals that are seen occasionally to date are red duiker (100%, n = 10), elephants (100%, n = 10), civet cat (60%, n = 10) and genet (60%, n = 10). It was further reported that the area was put under anthropogenic pressure through cattle grazing and crop cultivation which involved clearing of the vast areas (100%, n =10).

Historical Occurrence of Large Mammal Species. The herbivores that inhabited the proposed rewilding area in the past included *Loxodonta africana, Taurotragus oryx, Giraffa camelopardalis*, *Syncerus caffer, Aepyceros melampus, Equus quagga, Alcelaphus buselaphus, Phacochoerus africana, Hippopotamus amphibius, Tragelaphus strepsiceros, Tragelaphus imberbis* and *Hippotragus niger* (Riggio & Caro, 2017; Foley et al., 2014; Barnes & Douglas-Hamilton, 1982; East, 1981; Lamprey, 1963). Common carnivores that dominated the area included *Panthera leo, Panthera pardus, Lycaon pictus* and *Acinonyx jubatus* (Caro et al., 1998). These results are supported by the responses from the key informants who confirmed the notable populations of most of the large mammal species such as greater kudu, buffalo, zebra, and of ecosystem engineers such as elephants and hippos especially between the 1970s and 1990s.

Table 1. Past Floristic Composition of the Study Area as Reported by (Backéus et al., 1994; Gillman, 1949; Greenway, 1933; Kayombo et al., 2020; Ludwig et al., 2008).

Common floristic types			
Grasses	Herbs	Shrubs	Trees
Digitaria milanjiana	*Bidens Pilosa*	*Indigofera rhynchocarpa*	*Brachystegia microphylla*
Setaria sphacelate	*Ruellia tuberosa*	*Solanum incanum*	*Brachystegia spiciformis*
Dichanthium annulatum	*Thunbergia sp*	*Markhamia obtusifolia*	*Albizia petersiana*
Hvparrhenia filipendula	*Tridax procumbens*	*Maerua angolensis*	*Clerodendrum myricoides*
Sporobolus festivus	*Vernonia glabra*	*Vangueria infausta*	*Euphorbia candelabrum*
Chloris virgata	*Stylosanthes fruticose,*	*Grewia bicolor*	*Cassia abbreviata*
Eragrostis patens	*Waltheria indica*	*Lippia javanica*	*Combretum mole*
Pennisetumn polystachyon	*Acanthospermum hispidum*	*Agave sisalana*	*Terminalia sericea*
Cynodon dactylon	*Tephrosia pumila*	*Caturanegam spinosa*	*Acacia tortilis*
Tragus berteronianus	*Triumfetta rhomboidea*	*Dodonaea viscosa*	*Acacia Senegal*
Setaria homonyma	*Commelina spp.*	*Conyza pyrrhopappa*	
Panicum maximum	*Crabbea velutina*	*Rhus natalensis,*	
Heteropogon contortus	*Triumfetta macrophylla*		
Eragrostis cylindriflora	*Hibiscus calyphyllus*		
Dactyloctenium aegypticum	*Acalypha sp.*		
Pogonarthria squarrosa	*Leucas deflexa*		
Rhynchelytrum repens	*Achyranthes aspera*		
Aristida congesta			
Harpachne schimper			

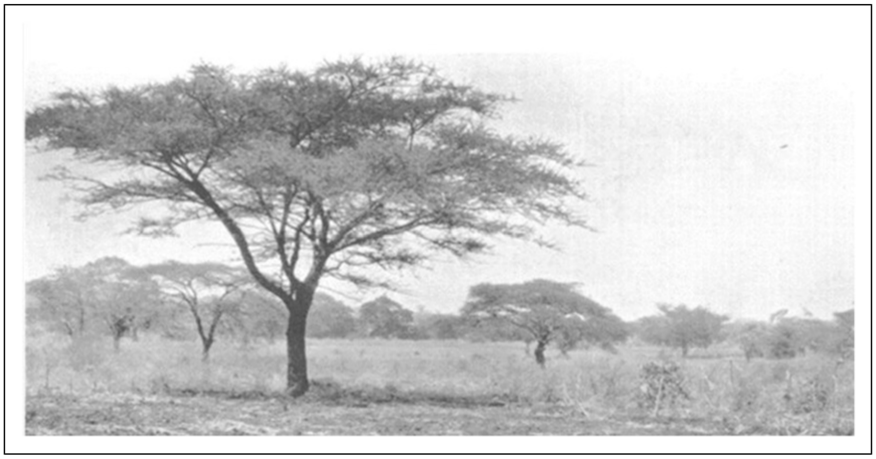

Figure 3. Vegetation cover of the study area as observed by Greenway in 1933 (Greenway, 1933).

Current Vegetation Status

Current Vegetation Structure. Approximately 50% of the study area vegetation was a bush land that was dominated by *Dichrostachys cinerea* as estimated during vegetation sampling. The remaining 50% was observed to be occupied by grasses, forbs and relatively few and scattered trees (Figure 4). The dominant trees were *Acacia tortilis*. Most grasses were annual and more abundant and diverse during the wet season than during the dry season.

Plant Species Composition and Abundance. During the wet season, there were a total of 158 plant species (40 families) at the UDOM rewilding area, compared to 86 species (29 families) in the dry season. The top ten common plant families during both seasons were as per Figure 5.

During the (wet and dry) seasons, the area comprised a mixture of grasses (18% and 9%), forbs (42% and 27%), shrubs (30% and 45%), trees (10% and 19%) respectively (Table 2 and 3). The family *Poaceae* dominated in both seasons with *Setaria pumila* (4,218) and *Eragrostis cylindiflora* (725) being the most abundant grass species during wet and dry seasons respectively (Table 2).

Plant Species Diversity. There was a significant difference in plant species diversity between the wet and dry seasons ($t_{140} = 67.8$, $p < 0.001$). Similarly, plant species diversity differed significantly within both the wet and dry seasons ($t_{140} = 34.2$, $p < 0.001$ and $t_{140} = 14$, $p < 0.001$ respectively) (Figure 6).

Discussion

Populations of the world's largest mammals are declining while others are going extinct in their historical ranges with consequences on ecosystem and landscape changes. Evidence shows that when mega herbivores decline in an area, bush encroachment can be widespread especially in areas where there is a single soil layer and where grazing is infrequent and light (Prins & van der Jeugd, 1993; Ward, 2005). In working with partners and stakeholders towards restoration programmes in such altered ecosystems, there is a need to investigate and quantify the impacts of megaherbivore and other large mammal removal; the results of which are useful in informing the ongoing and future restoration and conservation efforts. This information is timely and will contribute to recent science base information that is supporting restoration programmes including those promoting trophic rewilding as a means to mitigate climate (e.g., Cromsigt et al., 2018) as well as those that established how rewilding revives biotic resistance to shrub invasion (e.g., Guyton et al., 2020) among others. Restoration and conservation efforts need such information which can remarkably provide us with guidance needed to effectively implement evidence-based restoration and conservation programmes.

Humanity is facing a massive anthropogenic driven environmental emergency that constitutes the dual biodiversity and climate crises with around a quarter of extant species being at risk from extinction, while wildlife populations are widely declining and extinction rates are several orders of magnitude higher than the natural norm (Svenning, 2020). The ongoing destruction and fragmentation of natural vegetation cover is mainly caused by agriculture, urbanization, and other unsustainable land use conversions (Broughton et al., 2021; IPBES, 2019; Yannelli et al., 2022). Similarly, the loss and extinction of megafaunas and other biodiversity has been historically driven by overkill and climate change (Surovell et al., 2005). Given these threats, both rewilding and targeted ecosystem restoration are being regarded as effective approaches to mitigate the loss of natural ecosystems and their biodiversity (Bastin et al., 2019; IPBES, 2019). The effectiveness of these approaches will require among others solid background knowledge of the flora and fauna native to an area to ensure that rewilding and restoration efforts are carried out with care, and that the right species mix is selected considering reference vegetation types, in addition to suitability to the current biophysical conditions.

Figure 4. Photo showing the current (2022) vegetation structure in the study area (Source: Own field photo).

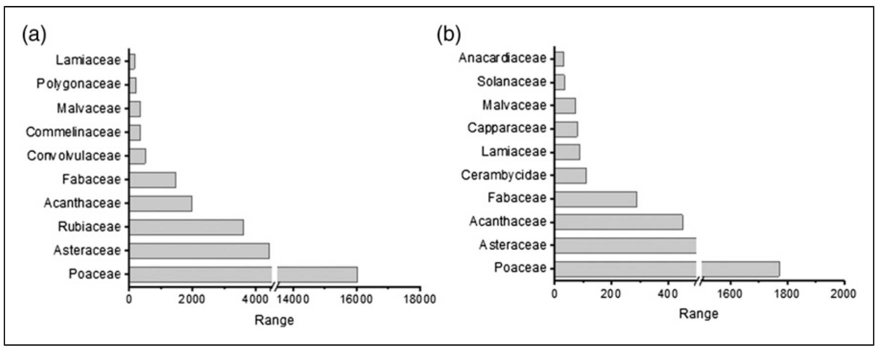

Figure 5. Ten dominant plant families that are found in the proposed rewilding site during (a) wet and (b) dry season as of the year 2021-2022.

While passive rewilding is of paramount in restoring complex ecosystems and is regarded as cheapest method of restoration (Morel et al., 2020), the practice needs to be backed up with a good understanding of the past and present conditions of a site. This can also be explained well by the concept of ecological memory. The concept explains how biotic and abiotic materials and the past information legacy of ecosystem such as remnants of population of locally extirpated species can influence the current reintroduced species (Khalighi et al., 2022; Schweiger et al., 2019). The recently sightings of African elephants (*Loxodonta africana*) and other herbivores such as common duikers (*Sylvicapra grimmia*) at UDOM proposed rewilding site prove that there some elements of the past information for the survival of herbivores and ultimately high possibilities of returning ecosystem to its past prime condition.

Climate and LULCC are the main drivers of environmental degradation leading to loss of vegetation and eventually local extinction of animal communities (He et al., 2019). Furthermore, environmental degradation is associated with the relatively higher costs that cannot be matched by the benefits accrued from economic development (Ma et al., 2020). The costs are the consequence of air, land and water pollution which in turn affect human health, water shortage, crop yields and materials loss (Ali et al., 2020). The world loses about US$ 231 billion annually due to land degradation and LULCC (Nkonya et al., 2016). It is projected that, West Africa coastal areas of Ghana, Ivory Coast, Togo and Benin would incur environmental degradation cost of approximately US$ 3 billion by the year 2100 due to flooding and erosion (Bolle et al., 2021). In Tanzania, environmental cost associated by deaths caused by air pollution, unsafe water and sanitation was US$ 28.7 billion in the year 2013 (World Bank, 2019) while the cost of land degradation due to LULCC is approximately US$ 18.47 billion yearly (Kirui, 2016). Basically, the reverse of these costs is the economic value of the rewilding which can be obtained directly or indirectly through ecosystem services and economic activities (e.g., ecotourism) associated by restored biodiversity (Hall, 2019; Moorhouse & Sandom, 2015).

Passive rewilding can be deployed to counteract the impacts of environmental degradation which are anthropogenic by nature by allowing natural succession (Broughton et al., 2021). This is a very important tool to support the UN Decade on ecosystem restoration ambition for preventing, halting and reversing the degradation of ecosystems worldwide. Additionally, rewilding is vital for creating microhabitats for ecosystem engineer species (species that modify, maintain and or create habitat to others) in order to save them from the impact of climate change while in turn they serve other

Table 2. Current Floristic Composition of the Study Area as Observed During Field Survey 2021–2022.

Common floristic types			
Grasses	Herbs	Shrubs	Trees
Digitaria milanjiana	*Bidens Pilosa*	*Boscia mossambicensis*	*Lannea triphylla*
Digitaria macroblephara	*Cyathula orthocantha*	*Solanum incanum*	*Trichelia emetica*
Dactyloctenium aegyptium	*Cucumis aculeatus*	*Markhamia obtusifolia*	*Vitex sp*
Cyperus amabilis	*Tridax procumbens*	*Sida ovata*	*Croton macrostachyus*
Cynodon dactylon	*Vernonia glabra*	*Steganotaenea araliacea*	*Euphorbia candelabrum*
Panicum maximum	*Stylosanthes fruticose*	*Stereospermum kunthianum*	*Cassia abbreviata*
Heteropogon contortus	*Waltheria indica*	*Strophanthus eminii*	*Combretum apiculatum*
Eragrostis cylindriflora	*Cynanchum dregea*	*Trumfetta rhomboidea*	*Acacia sp*
Dactyloctenium aegypticum	*Tephrosia pumila*	*Waltheria indica*	*Acacia tortilis*
Digitaria ganzensis	*Triumfetta rhomboidea*	*Zanthoxylum chalybeum*	*Acacia Senegal*
Rhynchelytrum repens	*Crotalaria retusa*	*Ipomoea mombassana*	*Acacia nilotica*
Chloris gayana	*Crotalaria cylindrical*	*Dalbergia acariiantha*	*Albizia harveyi*
Cenchrus ciliarias	*Commicarpus plumbagineus*	*Acalypha fruticose*	*Balanites aegyptiaca*
Aristida keniensis	*Commelina benghalensis*	*Combretum aculeatum*	*Commiphora swynnertonii*
Bachiaria deflexa	*Cleome hirta*	*Commiphora schimperi*	*Delonix elata*
Digitaria milanjiana	*Chamaecrista mimosoides*	*Commiphora sp*	*Delonix regia*
Diheteropogon filifolius	*Chamaecrista hildebrandtii*	*Cordia sinensis*	
Eragrostis cylindiflora	*Acanthospermum hispidum*	*Dalbergia nitidula*	
Eragrostis tenuifolia	*Alysicarpus glumaceus*	*Dichrostachys cinerea*	
Tragus racemosus	*Asparagus africanus*	*Ehretia obtusifolia*	
Heteropogon contortus	*Bidens schimperi*	*Entada stuhlmannii*	
Urochloa trichopus	*Blepharis sp*	*Grewia bicolor*	
Rottboellia sp	*Desmodium sp*	*Grewia flavescens*	
Schimidtia sp	*Dicoma tomentosa*	*Indigofera arrecta*	
Setaria pumila	*Dyschoriste hildebrantii*	*Hibiscus micranthus*	
Sporobolus ioclados	*Euphorbia hirta*	*Senna singueana*	
Sporobolus pellucidus	*Dyschoriste trichocalyx*	*Indigofera garckeana*	
Themeda triandra	*Euphorbia crotonoides*	*Indigofera trita*	
	Euphorbia inaequilatera	*Ipomoea polymorpha*	
	Glossocardia bidens	*Jasmimum fluminense*	
	Glycine wightii	*Lagenaria sp*	
	Gutenbergia cordifolia	*Lannea humilis*	
	Hirpicium diffusum	*Lannea schweinfurthii*	
	Indigofera indica	*Lantana trifolia*	
	Justicia debilis	*Maerua decumbens*	
	Justicia matammensis	*Maytenus senegalensis*	
	Launaea cornuta	*Melhania velutina*	
	Leonotis nepetifolia	*Momordica boivinii*	
	Leucas grandis	*Mundulea sericea*	
	Ocimum sp	*Olax sp*	
	Oxygonum sinuatum	*Opilia campestris*	
	Sesamum angustifolia	*Opilia celtidifolia*	
	Spermacoce princeae	*Polygala sphenoptera*	
	Stylosanthes fruticose	*Rhoicissus tridentata*	
	Tephrosia alata	*Senna absus*	
	Tephrosia purpurea		
	Tribulus terrestris		
	Trichodesma zeylanicum		
	Tridax procumbens		
	Vernonia glabra		

Table 3. Summary of the Species Abundance and Composition as Observed During Field Survey 2021–2022.

	Dry Season		Wet Season	
Life Form	Species	Genus	Species	Genus
Grasses	06	02	26	02
Forbs	21	02	62	04
Shrubs	36	03	45	03
Trees	14	02	14	02
Total	77	09	147	11

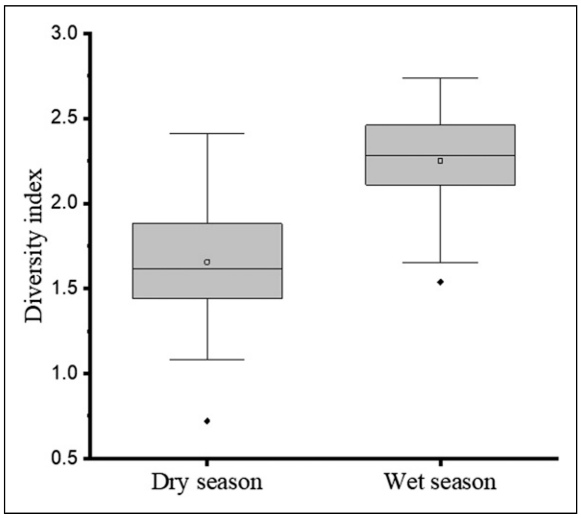

Figure 6. Plant species diversity variation between 2021-2022 dry and wet seasons at UDOM site.

species (Thakur et al., 2020). As it is well known that, environmental degradation and its associated impacts has significant cost implication globally (Ma et al., 2020), successful rewilding and restoration can help to avoid these costs.

Semi-arid rangelands are known for their potential to provide ecosystem services and supporting lives of wild fauna (Koch et al., 2022). Yet, in last decades, rangelands have succumbed into bush encroachment which led to reduced species diversity and richness of the vegetation essential for survival of herbivores (Liao et al., 2018). The main driver of bush encroachment being anthropogenic activities (i.e., overgrazing) backed up by climate change (Kgosikoma & Mogotsi, 2013). Bush encroachment have been linked to extinction of wild fauna from herbivores to apex predators in a cascading way with example of the Australian predator, the dingo *(Canis dingo)* which went extinct for the same reason (Gordon et al., 2017). Therefore, trophic rewilding is very important for shaping vegetation and in due course ensure survival of wildlife species which are constantly threatened by loss of habitat due to human induced bush encroachment.

The data and information generated from this work has provided evidence that guide our understanding of the historical background of UDOM area and its surrounding ecosystems in terms of both fauna and flora which is crucial for a successful rewilding and restoration of this area. Therefore, for effective rewilding and restoration, ecologists need to synthesize and generate sufficient past information that can be used as baseline information during the process of implementing restoration actions. Given the survey results from the historical data and vegetation inventory, the future direction in restoring natural vegetation of the UDOM area should be towards rehabilitating encroached bush land mainly being dominated by a number of species including *Dichrostachys cinerea.* The species now covers approximately 50% of the area and may continue to dominate in the future, thus calling for reversing this encroachment through restoration of appropriate megaherbivores (browsers and grazers) to shape the vegetation.

Recent publications aiming to identify areas with the biggest possible benefits and cost-effective consequences to optimize tropical vegetation restoration (Brancalion et al., 2019), have led to a narrow emphasis on just planting trees to mitigate climate change. Such studies have been criticized for incentivizing large-scale tree plantations in the wrong places (e.g., in savannas) or with the wrong species (e.g., using nonnative species). Indeed, massive tree plantations can increase fire risk, lead to plant invasions, further land degradation, endanger sustainable development (Bond et al., 2019; Nuñez et al., 2021) and native species extinctions (Veldman et al., 2019). Efforts of just planting trees or vegetation restoration as the only way to mitigate anthropogenic and global change-driven impacts should not be the sole effort since this disregards the value of other threatened fauna biodiversity and their ecosystems (e.g., grasslands and wetlands), which through their interactions perform important ecosystem processes and functions. For a successful rewilding of the area, efforts need to be directed to ensure that the area is restored to almost its near past vegetation and large mammal diversity and composition (i.e., Savanna grassland). This should be done through trophic rewilding and restoration of past native plant species with examples in Neotropics, Europe and other parts of the world (Egoh et al., 2021; Svenning & Faurby, 2017). Likewise, Fernandez et al. (2017) put emphasize on restoring the interaction within an ecosystem rather than focusing on single component while planning for a successful rewilding. This showed promising results in rewilding of Atlantic Forest as both defaunation and restoration of ecological interaction were executed. Furthermore, restoration success can only be warranted by active knowledge transfer between all stakeholders including scientists, local communities, and policy makers (Baker & Eckerberg, 2016), to ensure this effort is carried out with care.

The overall goal of rewilding and restoration in the UDOM area should be to enhance native biodiversity, benefiting local communities, as well as protecting and connecting to other valuable non-savanna ecosystems. This involves the reintroduction of different guilds of herbivores (grazers and browsers) which were formally part of the native fauna biodiversity and these will shape the vegetation while facilitating the natural vegetation succession. For instance, reintroduction of Giraffe (*Giraffa camelopardalis*) and greater kudu (*Tragelaphus strepsiceros*) which are known as non-specialist browsers, browsing on different species (Mandinyenya et al., 2019). The two animals browse on similar species but at different heights (Makhabu, 2005) and are both known to prefer *Dichrostachys cinerea* (Levi et al., 2022). The two can therefore be reintroduced in the area to open up the bush and allow more forbs and grasses to grow.

The area can similarly support specialist grazers such as zebra and wildebeest which were historically present in the area (Foley et al., 2014). This can help to reduce understory competition and therefore allow for a diverse regrowth of palatable forbs and or grasses. The presence of grasses such as *Setaria spp, Digitaria macroblephara, Cynodon dactylon, Themeda triandra* and *Aristida spp* which are foraged by zebra and wildebeest (Owaga, 1975) is an indication that they can survive in the area. Likewise, medium-sized antelopes such as Impala (*Aepyceros melampus*) can also be reintroduced in UDOM rewilding area to further rewild the site. Impala are intermediate feeders; grazers-browsers that graze during the wet season and shift to browsing during the dry season (Mramba, 2021). They graze on a variety of species including *Cynodon dactylon, Panicum maximum, Urochloa spp., Eragrostis spp., Themeda triandra and Digitaria eriantha* (Mandinyenya et al., 2018; Pieterse, 2018). Moreover, they browse on *Acacia spp.* (leaves and pods), *Combretum spp., Boscia spp., Grewia spp., Commiphora spp., Terminalia spp.* and *Dichrostachys spp.* (Mandinyenya et al., 2018; Pieterse, 2018). In so doing such species will not only aid in further dispersing the tree species that have been observed to decrease in the study site compared to past years but will also improve ground cover of the area. An important activity to complement rewilding in the area is to set up the monitoring plan that can inform the restoration and conservation efforts about responses of large mammal population recovery on the vegetation structure and composition over spatial and temporal scale.

Our study highlighted on the important information about the historical and present vegetation and mammal distribution in central Tanzania firstly by providing a novel synthesis of the various vegetation cover and composition that existed in the region and how large herbivores interacted with these, and the way anthropogenic drivers, including LULCC have driven these to local extinction. Additionally, it explored the role of reintroduction and rewilding as extinction reversal strategies by highlighting potential large mammal species that can be reintroduced in the UDOM area as socio-ecological opportunity not only for UDOM campus but also at regional scale. These results can further guide both the current and near-future restoration and large herbivore rewilding opportunities elsewhere.

Implication for Conservation

Reconstructing historical information of ecosystems is crucial in ensuring successful rewilding and restoration. Such information aids in reversing wildlife species extinction and reestablishing connectivity of large herbivore population across ecosystems. Most wildlife species have disappeared from man dominated landscapes due to loss of habitats attributed by anthropogenic activities. In order to restore them there is a need to have an informed history of an ecosystem to be restored or rewild. Rewilding has potential to reverse species extinction by creating suitable habitats. These habitats are important patches in connecting different metapopulations. Furthermore, rewilding assists in reversing the environmental degradation costs by returning the lost ecosystem processes, functions and services. Besides, the money which would have been used for the degraded landscape restoration would be applied to foster other conservation efforts. On top of that, in this era where climate change is the undisputable threat to biodiversity and ecosystems, successful rewilding is important to regulate the impact of climate change and serve ecosystem engineer species which are vital in any ecosystem.

Declaration of Conflicting Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the University of Dodoma.

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