Addressing landscape connectivity in biodiversity conservation strategies in the African Sahel

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Todas as correções determinadas pelo júri, e só essas, foram efetuadas.

O Presidente do Júri,

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MSc

“... deserts are superb evolutionary laboratories of nature. For that alone, they merit conservation.”

David Ward, in The Biology of Deserts

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Resumo

Atualmente a biodiversidade enfrenta a sexta extinção em massa, onde fatores antropogénicos, tais como a perda e fragmentação do habitat e as alterações climáticas, são os principais impulsionadores. A eco-região do Sael é uma zona de transição entre a região do Paleártico e Afro-tropical que exibe uma grande diversidade de espécies. No entanto, são várias as ameaças que atualmente afetam a biodiversidade, tais como o aumento da população humana e de infra-estruturas, as alterações no coberto vegetal e no uso do terreno e as alterações climáticas. As alterações nos habitats favoráveis para as espécies podem conduzir ao seu isolamento populacional e a um aumento do risco de extinção. A conectividade da paisagem pode mitigar os efeitos negativos promovidos pela fragmentação dos habitats, possibilitando a dispersão de indivíduos e a persistência de metapopulações. Esta tese foca-se em dois casos de estudo que têm como intuito aperfeiçoar metodologias para a conservação em regiões áridas e encontrar as melhores abordagens para alcançar os objetivos de conservação para a biodiversidade no Sael. No primeiro estudo, as grandes alterações no coberto vegetal e no uso do terreno devido à Iniciativa da Grande Muralha Verde do Saara e do Sael (Muralha) foram mapeadas tendo em conta a distribuição dos vertebrados de forma a perceber quais as espécies que serão mais afetadas pelas mudanças na conectividade regional. A fragmentação do habitat criada pela Muralha irá promover um efeito barreira para as espécies adaptadas às regiões áridas e desérticas e a elevada atividade antropogénica na região poderá vir a criar impactos a curto prazo em várias outras espécies. É necessário garantir corredores de dispersão providos de habitats favoráveis ao longo da Muralha para mitigar os seus efeitos. No segundo estudo, múltiplos cenários foram testados para entender a localização de áreas prioritárias à conservação de vertebrados de água doce na Mauritânia. Diferentes regras de conectividade foram aplicadas para entender o seu impacto na seleção de áreas prioritárias e um novo método foi desenvolvido para realçar a importância das zonas a montante na rede hidrográfica. As áreas prioritárias para a conservação de espécies dependentes de água foram selecionadas levando em consideração a conectividade através da rede hidrográfica. O novo método realça a importância de considerar as zonas a montante para assegurar a proteção das conexões entre as unidades de gestão, articulando a proteção de ecossistemas terrestres e de água doce. Os dois estudos desenvolvidos mostram por um lado que a falta de conectividade numa iniciativa à escala internacional poderá gerar impactos negativos para espécies que não estão adaptadas a um habitat particular, aumentando o seu risco de extinção. Por outro lado, considerar a conectividade na definição de novas áreas prioritárias para a conservação à escala local poderá atenuar os efeitos do isolamento de espécies. A atual fragmentação dos habitats requere a implementação da conectividade como uma estratégia central para a conservação da biodiversidade no Sael. Ambos os estudos realçam a importância de preservar a conectividade para garantir, a longo prazo, a conservação de espécies e populações adaptadas a regiões áridas.

Palavras-chave: corredores, fragmentação, *hotspots* de biodiversidade, persistência, planeamento de conservação, regiões áridas

Abstract

Global biodiversity is currently facing the sixth mass extinction, where human-related factors, such as habitat loss and fragmentation and climate change, act as the main drivers. The Sahel ecoregion is a transition zone between the Palearctic and Afro-tropical realms exhibiting high diversity of species. However, it is undergoing many threats that affect local biodiversity, such as increasing human population and infrastructures, land-cover and land-use changes, and climate change. The changes in suitable habitats for species may lead to their isolation and increased extinction risk. Landscape connectivity could mitigate the negative effects promoted by habitat fragmentation, by allowing the dispersal of individuals and the persistence of metapopulation structures. The present research focuses on two case studies that aim to improve conservation methodologies in arid regions and to find the best approaches to achieve conservation goals for biodiversity conservation in the Sahel. In the first study, the massive land-use and land-cover changes created by the Great Green Wall for the Sahara and the Sahel Initiative (Wall) were mapped against terrestrial vertebrate distribution to understand which species are going to be mostly affected by the regional connectivity changes. The habitat fragmentation created by the Wall will promote a barrier effect for desert-adapted species and the strong anthropogenic activities in the area can have short-term impacts in many others. Ensuring dispersal corridors with suitable habitats along the Wall are needed to mitigate its effects. In the second study, the location of priority areas for conservation of freshwater vertebrates was tested for multiple scenarios in Mauritania. Different connectivity rules were addressed to understand their impact in the priority areas selected and a new framework was presented to emphasise the importance of hydrologic upstream areas. Priority areas for conservation for water-dependent species were selected taking into account freshwater connectivity. The new framework highlights the importance of considering upstream areas to ensure the protection of connections between management units within their hydrological context, linking freshwater and terrestrial ecosystem protection. The two studies developed show that on the one hand, the lack of connectivity in a large international scale can negatively impact species not adapted to a particular habitat, increasing its extinction risk. On the other hand, addressing connectivity in the definition of new priority areas for conservation in local scale can help to mitigate the effects of species isolation. The current habitat fragmentation demands connectivity as a core strategy for biodiversity conservation in the Sahel. Both studies emphasise the importance of preserving connectivity to ensure long-term conservation of species and populations adapted to arid regions.

Keywords: arid region, biodiversity hotspots, conservation planning, corridors, fragmentation, persistence

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List of abbreviations

BLM	Boundary length modifier
CBD	Convention on Biological Diversity
CP	Connectivity penalty
DEM	Digital elevation model
DNA	Deoxyribonucleic acid
eDNA	Environmental DNA
GPS	Global Positioning System
ha	Hectare
IUCN	International Union for Conservation of Nature
Km	Kilometre
m	Meter
mm	Millimetre
Mya	Million years ago
N	Number
NDWI	Normalised difference water index
NW	Northwest
PU	Planning unit
S	South
SAV	Savannah
SDGs	United Nations Sustainable Development Goals
SHL	Sahel
SHR	Sahara
SPF	Species penalty factor
UNCCD	United Nations Convention to Combat Desertification
USD	United States Dollars
UTM	Universal Transverse Mercator
W	Weighting factor
WCP	Water Residency Time – Hydrologic Connectivity
WGS	World Geodetic System
WWF	World Wildlife Fund
ZSL	Zoological Society of London

Chapter I: General introduction

1.1. Global biodiversity crisis

Global biodiversity is facing an unprecedented loss, currently considered the sixth mass extinction (Dirzo and Raven, 2003; Ceballos *et al*., 2010). Recently, the World Wildlife Fund (WWF) together with the Zoological Society of London (ZSL) published an indicator of the state of the global biological diversity, presented in the Living Planet Index (WWF, 2018; Fig. 1.1), showing the average rate of vertebrate species population changes over time. Between 1970 and 2014, there was an overall decline in 60% of population sizes of vertebrates from all species across the globe (WWF, 2018).

Habitat fragmentation and degradation is one of the main drivers of biodiversity loss (Dirzo and Raven, 2003; Secretariat of the Convention on Biological Diversity, 2010, 2014; Joppa *et al*., 2016), responsible for creating a matrix of small isolated habitat patches and increasing the edge effects (Haddad *et al*., 2015; Fig. 1.2). Moreover, isolation plays a crucial role in decreasing populations' viability by reducing genetic diversity due to genetic drift and contributing to inbreeding depression, decrease the fitness of individuals and loss of evolutionary and adaptive potential (Tanaka, 2000; Frankham, 2005; Allentoft *et al*., 2009). Climate change is a global concern of this century, impacting from individuals to biomes and is known to alter natural systems, changing interspecific relations and testing physiological tolerances (Griffis-Kyle *et al*., 2018; Li *et al*., 2018). Species are expected to shift their ranges to more favourable habitats or adjust to the new conditions by phenotypic plasticity (Sinervo *et al*., 2010; Davies *et al*., 2012). In addition, extinction is expected when a species has low dispersal abilities and fails to adjust or adapt (Thomas *et al*., 2004). Both habitat fragmentation and climate change are human-related factors leading to populations declines and species extinction, which will affect ecosystem functioning and, in its turn, human welfare (Dirzo and Raven, 2003; Pimm, 2008; Dirzo *et al*., 2014; Haddad *et al*., 2015).

Biodiversity, apart from the aesthetic value, provides direct economic benefits essential to humankind (Singh, 2002). Therefore, there are growing concerns about its protection and preservation. The Convention on Biological Diversity (CBD) adopted the Strategic Plan for Biodiversity 2011-2020 to reverse global biodiversity loss and enhance its benefits for people (CBD, 2010). Among the Strategic Plan, the Aichi Biodiversity Targets encompasses twenty ambitious targets, including the expansion of the global protected area network to 17% of the world's land cover by 2020 (Aichi Target 11), aiming to protect ecologically representative and well-connected terrestrial and freshwater areas. An effective management of protected areas and corridors between them will allow to achieve different goals proposed by CBD, namely the reduction of biodiversity pressures and the improvement of biodiversity status, from genes to ecosystems (CBD, 2010).

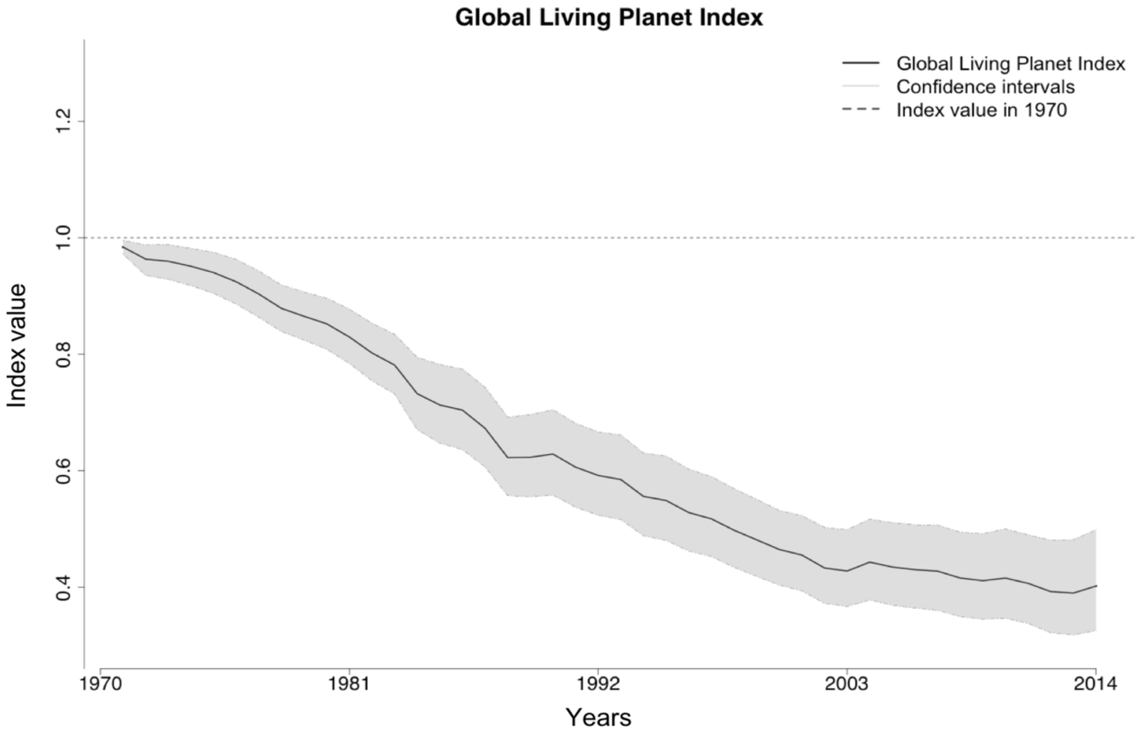

Figure 1.1 | The Global Living Planet Index from 1970 to 2014. Average abundance of 16,704 vertebrate populations representing 4,005 species monitored across the globe declined by 60%. The black line represents the index values and the shaded areas represent the statistical certainty surrounding the trend, ranging from -50% to -67%. Adapted from WWF (2018).

1.2. Landscape connectivity: a key point to persistence

The negative impacts that habitat loss and fragmentation have on biodiversity led to the recognition of the importance of spatial conservation prioritisation studies (Margules and Sarkar, 2007; Moilanen *et al*., 2009). Identifying new sites for biodiversity protection should follow a systematic conservation planning approach and fulfil two main objectives: representation and persistence (Margules and Pressey, 2000). Representation ensures that protected areas include all levels of organisation, representing the full variety of biodiversity of a defined region. Persistence ensures the long-term survival of conservation features, either taxa, habitats or climate regions, and the preservation of viable populations and the natural processes (Margules and Pressey, 2000). Protected areas have been used as a core strategy for many years and, if well-managed, they can reduce the rate of habitat loss (Geldmann *et al*., 2013; Watson *et al*., 2014) and maintain species population levels over time, including threatened species (Taylor *et al*., 2011;

Butchart *et al.*, 2012; Spooner *et al.*, 2018). Incorporating connectivity in the protected area design helps to maximise its effectiveness and efficiency (Shafer, 1999). By combining protected areas with landscape corridors for species dispersal, the effects of habitat fragmentation and climate change over biodiversity can be mitigated.

Landscape connectivity was defined by Taylor *et al.* (1993) as “the degree to which the landscape facilitates or impedes movements among resource patches”. Structural connectivity focus on the spatial configuration of the landscape, evaluating the physical continuity of the habitat, such as corridors (Tischendorf and Fahrig, 2000). However, it is independent from biological responses to the landscape (Tischendorf and Fahrig, 2000; Dehaghi *et al.*, 2018). Differently, functional corridors take into account species behaviour to the landscape, assessing the migration pathways that species would take between suitable habitat patches (Taylor *et al.*, 2006; Dehaghi *et al.*, 2018). Connectivity can differ depending on the type of landscape that dispersal processes takes place (Baguette *et al.*, 2013). Terrestrial landscapes are usually patchy as a result of natural barriers to habitat continuity or anthropogenic habitat fragmentation (Haddad *et al.*, 2015), creating a resistance matrix with an associated cost to species dispersal. Each individual with different habitat requirements will disperse through layers with lower cost to reach suitable habitats. On the other hand, in freshwater and marine systems, riverscape and seascape respectively, connectivity is mostly made through water, where non-aquatic environments represent the resistance landscape (Pringle, 2003). In riverscape connectivity, individuals can passively disperse downstream due to water currents, creating a source-sink metapopulation dynamics, where the upstream populations act as a source and the downstream act as a sink (Baguette *et al.*, 2013). Generally, single individuals, with enough time and dispersal capacity, can move through the landscape to reach a favourable area or even a different population. A strong network of habitat corridors promoted by landscape connectivity will allow species shifts and the recolonization of new habitats creating a metapopulation dynamics (Hanski, 1998). The extinction risk is expected to decrease as periodical inputs of new genes from adjacent populations contribute to increased genetic variability and potentially to genetic adaptation to environmental changes (Massot *et al.*, 2008; Fig. 1.2). Although, promoting artificial connectivity may emerge as a threat to biodiversity due to the attenuation of natural physical barriers for species (Jackson and Pringle, 2010). Increasing artificial connectivity can easily enhance the propagation of invasive species and pollutants. In arid regions, increasing hydrological connectivity through irrigation, mobilized toxic elements such as contaminants and pesticides used in agriculture (Jackson and Pringle, 2010). At population level, species may disperse across a homogenized landscape, decreasing the differentiation between populations of the same species. This process will potentially lead to loss of genetic diversity and evolutionary units (Dowell *et al*., 2016). Globally, there is a progressive increase of well-connected protected areas network, although additional efforts are needed to achieve the Aichi Target 11 (Saura *et al*., 2019). For their importance in biodiversity conservation and for their susceptibility on the propagation of threats, such as fire, invasive species and pathogens (Slimberloff and Cox, 1987), the protection of corridors is crucial to mitigate the effects of species isolation and maintain local diversity (Damschen and Brudvig, 2012).

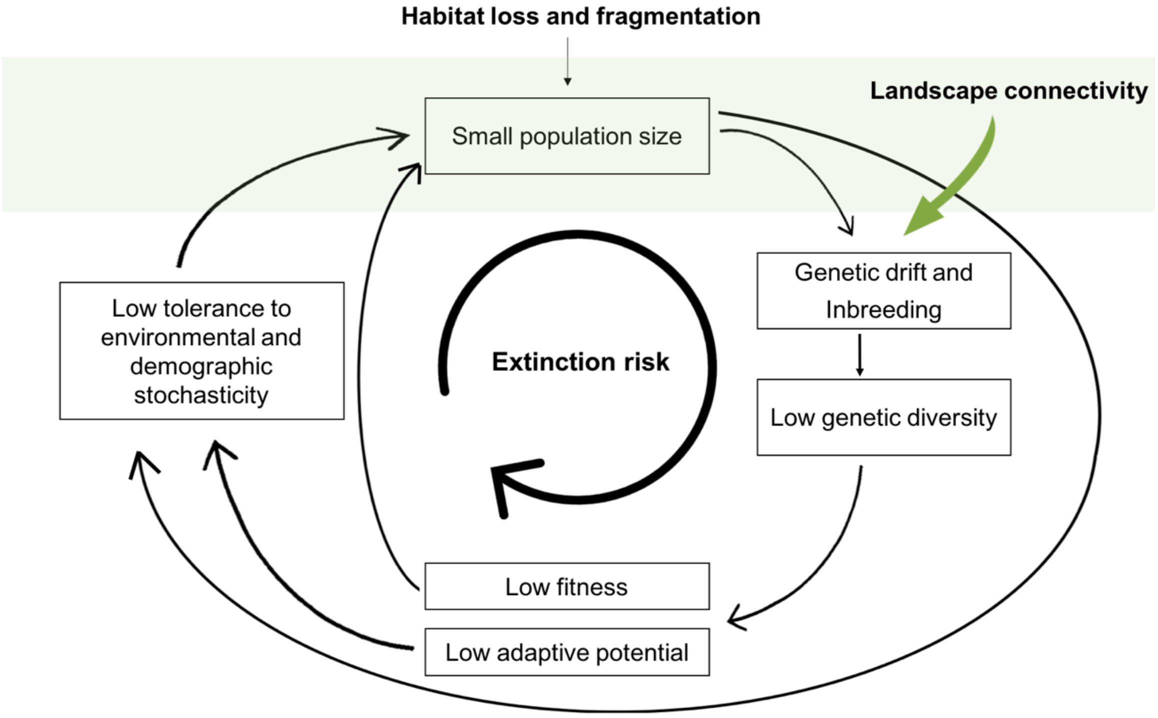

Figure 1.2 | Scheme depicting the different effects of habitat loss and fragmentation in species and populations, which leads to an increase in extinction risk. Landscape connectivity as a measure to mitigate the negative effects of habitat loss and fragmentation, represented by the green arrow. Adapted from van Andel and Aronson (2012).

Different strategies in conservation planning have been developed to incorporate connectivity in order to design more connected reserve systems (Daigle *et al*., 2018):

i) Connectivity as conservation features establishes connectivity pathways in the landscape as a target for the spatial prioritisation. Hence, a minimum amount of that habitat needs to be select as priority area for conservation;

ii) Connectivity as spatial dependencies incorporates a penalty cost for protecting one site and not adjacent areas to which it is connected. This will reduce isolated areas selected, trying to increase the aggregation of the priority areas selected;

iii) Connectivity as a cost uses an inverse distance cost to define more desirable areas (*e.g*. areas suitable for connectivity) as cheaper to protected compared to less desirable areas, increasing its probability of being selected as priority for conservation.

For instance, when considering priority areas for aquatic species, it is desirable to decrease the cost of water layers that connect important wetlands for species;

iv) Connectivity-based objective function includes a persistence metric into an objective function that will run the optimisation processes. Metapopulation information, such as fecundity and mortality, can inform about the probability of persistence in an area and influence the result of priority areas selected.

Spatial conservation prioritisation has been drawn in response to global biodiversity crisis, which is particularly alarming in largely intact areas, such as deserts (Durant *et al.*, 2014; Iknayan and Beissinger, 2018). Habitat connectivity is essential for arid-adapted populations, since connectivity is highly limited due to the instability and the temporal variation of natural resources, such as water, primary production and shelter (Shkedy and Saltz, 2000). Therefore, there is an urgent need to identify areas predicted to be severely affected by climate change (Loarie *et al.*, 2009; Murphy *et al.*, 2015; Li *et al.*, 2018), which harbour unique threatened species, by allowing migration movements between populations, thus avoiding population fragmentation and isolation.

1.3. Biodiversity in deserts and arid regions

Deserts and arid regions cover 17% of the world's land mass (Fig. 1.3) and are often perceived as homogeneous, bare areas with low biodiversity (Durant *et al.*, 2012). The temperature can reach extreme values during the day, and fall below freezing point during the night, however it is the aridity and the lack of precipitation that define deserts (Ward, 2016). Average precipitation is low, unpredictable and highly variable in space and time (Zeng, 2003). Despite the small amount of primary productivity (Durant *et al.*, 2014), desert areas harbour high biodiversity, comprising threatened and endemic species (Brito and Pleguezuelos, 2019) crucial to provide ecosystem services in those regions (Safriel *et al.*, 2005). The extreme abiotic factors promote highly evolutionary distinct species that exhibit adaptations to current harsh conditions (Brito and Pleguezuelos, 2019), although as they are already experiencing their physiological limits, are more susceptible to climate change (Vale and Brito, 2015; Iknayan and Beissinger, 2018; Li *et al.*, 2018). Climate change is the major threat affecting deserts and arid ecosystems (Loarie *et al.*, 2009), although other human induced factors are emerging. In Africa, livestock grazing and the increase of greenhouse gases are considered the most important causes of desertification (Hutchinson *et al.*, 2018). Although desertification may be perceived as a natural process, nowadays have a strong influence from human activities (Giannini, 2010). Increase in desertification affected millions of people around the world (Hutchinson *et al.*, 2018), creating a negative perspective that deserts and arid regions are a spreading disease, instead of a natural ecosystem which contribute to the Earth's biological, landscape and cultural diversity. The highlight given to biodiversity hotspots (Myers *et al.*, 2000) has neglected desert and arid ecosystems, consequently, attracting less financial support to these areas (Durant *et al.*, 2014). Although, its biodiversity have a unique evolutionary history (Brito and Pleguezuelos, 2019) and are currently threatened by many anthropogenic factors. Therefore, these ecosystems should also be under conservation focus.

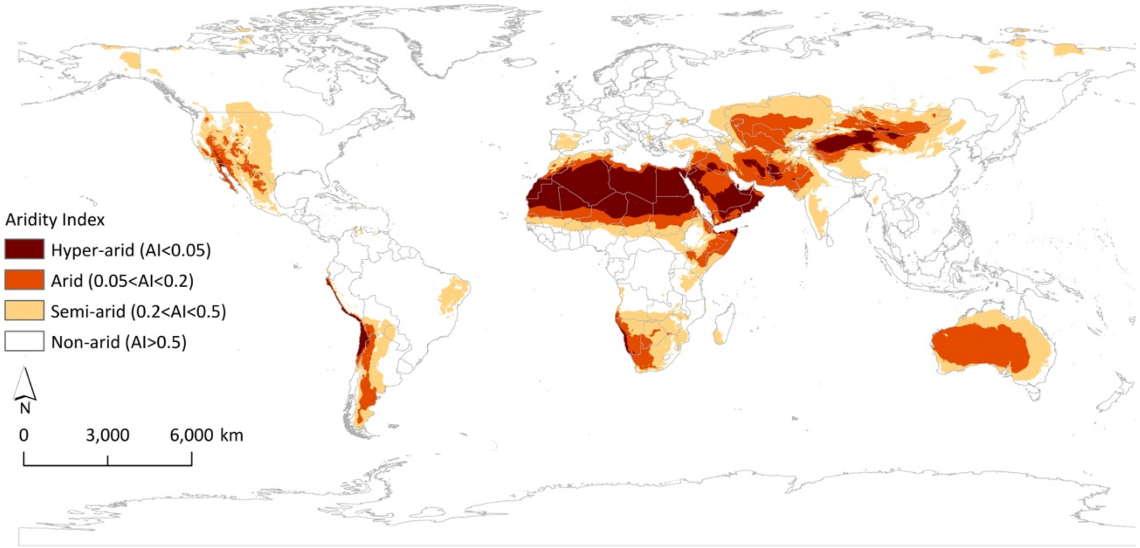

Figure 1.3 | Global distribution of deserts (hyper-arid) and arid regions, following the aridity index (average annual precipitation/potential evapo-transpiration). Adapted from Ward (2016).

1.4. The African Sahel as a case study

The arid Sahel (Arabic for "shore") is a transition zone between the Palearctic and Afrotropical realms, which extends for 3,000,000 km^2 between the Sahara Desert to the north and the sub-humid savannahs to the south (Le Houérou, 1980), and together with the Sahara, they represent the two major ecoregions in Africa (Dinerstein *et al.*, 2017). The age of the Sahara-Sahel is still debatable, ranging from at about 7 million years ago (Mya) (Schuster *et al.*, 2006) to about 2 - 3 Mya in western areas (Zhang *et al.*, 2014). Nonetheless, it is known that this region experienced strong climatic and land-cover oscillations along the history, characterised by dry-wet cycles, since the Pliocene, which allowed successive expansions and contractions, where the Sahara-Sahel limit suffered different shifts (Le Houérou, 1997; Foley *et al.*, 2003; Gasse, 2006). In the last humid period, grasslands, scrublands and mega-lakes covered the majority of North Africa (Prentice *et al.*, 2000; Giannini *et al.*, 2008; Holmes, 2008; Kröpelin *et al.*, 2008). At the Mid-Holocene, a gradual decline in precipitation levels contributed to the aridification of the Sahara-Sahel and to the turnover between humid and desert-adapted species (Holmes, 2008; Kröpelin *et al.*, 2008). Currently, the Sahel climate is characterised by a long dry season and a short humid season. Similar to other arid regions, precipitation is the most important factor controlling the Sahel ecosystem and its scarcity and unpredictability increases northwards. The landscape is characterised by sparse vegetation with shrubs and annual and perennial grasses, closely related with the seasonality in precipitation (Le Houérou, 1980).

The climatic oscillations and geographic shifts that shaped Sahel into what it is today, had consequences on biodiversity patterns (Le Houérou, 1997). Moreover, the distribution of biodiversity appears to be linked to environmental changes (Brito *et al.*, 2016), inducing allopatric diversification and speciation events (Brito *et al.*, 2014). The steep climatic gradients within short distances, as precipitation and habitat types, favours high species richness (Da *et al.*, 2018), particularly in southern regions, and harbours endemic and threatened species (Brito *et al.*, 2016; Vale *et al.*, 2019). Humid-adapted species still persist in isolated unchanged environments, known as climatic refugia (Anthelme *et al.*, 2008; Trape, 2009; Vale *et al.*, 2015; Velo-Antón *et al.*, 2018). Mountains gather favourable conditions for species persistence due to the high geodiversity (Da *et al.*, 2018) and often retain water during the dry season, allowing suitable conditions for species survival (Vale *et al.*, 2015). Although, the unique biodiversity present in the Sahel transition zone is facing threats that can affect its viability. The Sahel has undergone severe droughts since the late 1960s (Zeng, 2003) leading to low productivity, soil erosion and increase of aridification (Foley *et al.*, 2003; Ahmed *et al.*, 2008; Schwalm *et al.*, 2017). The effects of low precipitation can have enormous consequences in the future, as its positively correlated with a decrease in primary productivity and consequently, decrease in local food sources (*e.g.* Barros *et al.*, 2018), as this region is identified one of the global hotspots for climate change effects (Diffenbaugh and Giorgi, 2012). Moreover, increases in human activities, such as over-hunting, livestock grazing, wood collection and exploitation of natural resources, and the predicted increase of human African population (Hutchinson *et al.*, 2018) are expected to become a serious threat to its biodiversity (Brito *et al.*, 2014, 2016; Duncan *et al.*, 2014). Long-term conflicts, socio-economic instability and the remoteness of certain regions (Brito *et al.*, 2014, 2018) along with the scarce scientific attention (Durant *et al.*, 2014), contributes to the lack of information available for species diversity and distribution in Sahara-Sahel. All these factors together with increasing effects of climate change (Loarie *et al.*, 2009) are threatening this low resilience region.

1.5. Objectives

Landscape connectivity is an important parameter in biodiversity conservation strategies and can be applied in local and broader scales. Specifically, the present thesis focuses on two case studies:

i) Manuscript I: the ongoing Great Green Wall for the Sahara and the Sahel Initiative (www.greatgreenwall.org) is an international collaboration initiative that aims to change the habitats in arid regions through afforestation. This large-scale program can have massive effects in the landscape and consequently, in species adapted to arid environments. Currently, with a global growing interest for afforestation programs to mitigate the effects of climate change (Bastin *et al.*, 2019) is it time to evaluate its impacts on overlooked biodiversity, particularly how it affects landscape connectivity disruption for arid species and to understand how they can be reversed.

ii) Manuscript II: *Gueltas* are mountain rock pools that harbour endemic and threatened species and are essential for the survival of species in arid regions (Vale *et al.*, 2015). Incorporating connectivity as spatial dependencies (Daigle *et al.*, 2018) between these priority freshwater sites in local conservation strategies is important to account for species dispersal and consequent its persistence, allowing the maintenance of a metapopulation dynamics and mitigate extinction risks.

Accomplishing these two different works will help to improve conservation methodologies and advise policymakers with the best approaches to achieve conservation goals for biodiversity in this arid region.

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Chapter II: Manuscript I

The Dark Side of the Green Wall: biodiversity impacts should be minimised in the African Sahel[1]

Abstract

The severe droughts that affected the arid African Sahel during the 1970s – 1980s caused a widespread food crisis, with hundreds of thousands of human deaths and migration waves. The world was so utterly shocked with the images of human starvation that global initiatives were developed to relieve the food crisis (*e.g.* Live Aid). This crisis prompted the United Nations to establish the Convention to Combat Desertification (UNCCD) in 1994, and eleven years later the African Union put forward the “Great Green Wall for the Sahara and the Sahel Initiative” (hereafter “Wall”). The aim was to stop desertification, ensure food security, halt conflicts over dwindling natural resources and mass migration to Europe, and above all, improve human living conditions in this low resilience region. Currently, a continuous line of trees stretching from the Atlantic to the Indian Ocean is being planted. This Wall will become the largest living structure on Earth and allegedly provide a vital contribution to the United Nations Sustainable Development Goals (SDGs). However, such massive land-cover and hydrological changes will likely lead to irrevocable losses in biodiversity, such as decimating, fragmenting, and isolating endemic and threatened dryland species, that have largely been overlooked. To lessen these impacts, the Wall should be designed to avoid biologically important localities and to provide natural north-south corridors that maintain population connectivity and ecologically representative ecosystems.

Keywords: afforestation, barrier effect, connectivity, desertification, fragmentation, habitat change

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2.1. Introduction

2.1.1. A colossal Wall

The Wall was envisaged along the Sahel-range (Fig. 2.1A) to prevent further desertification and promote drought resilience, food security, and human well-being (Zeng, 2003; Hutchinson *et al*., 2018; www.unccd.int). This gigantic investment may reach up to $10 billion USD, with contributions from national and international partners including the African Union, The World Bank, European Union, and the Food and Agriculture Organization. Scheduled to be completed by 2030, the Wall will span the African continent – ranging 7,775 km from the Atlantic to the Indian Ocean – and comprise an average of 15 km wide band of arid-resistant tree species (www.greatgreenwall.org; Fig. 2.2A). Additionally, the overall planned intervention zone target areas with average rainfall between 100 - 400 mm (Fig. 2.1B), and thus will reach up to more than 200 km wide and include multiple land-uses, such as agroforestry and pastoral activities (Dia and Duponnois, 2010). It will cross eleven countries: Senegal, Mauritania, Mali, Burkina-Faso, Niger, Nigeria, Chad, Sudan, Eritrea, Ethiopia, and Djibouti. Each of these countries has developed a national implementation plan (Pan-African Agency of the Great Green Wall, 2018) specifying the places allocated for the initiative. As of 2019, these Wall countries are primarily undertaking afforestation activities and improving agriculture and water harvesting (Pan-African Agency of the Great Green Wall, 2018).

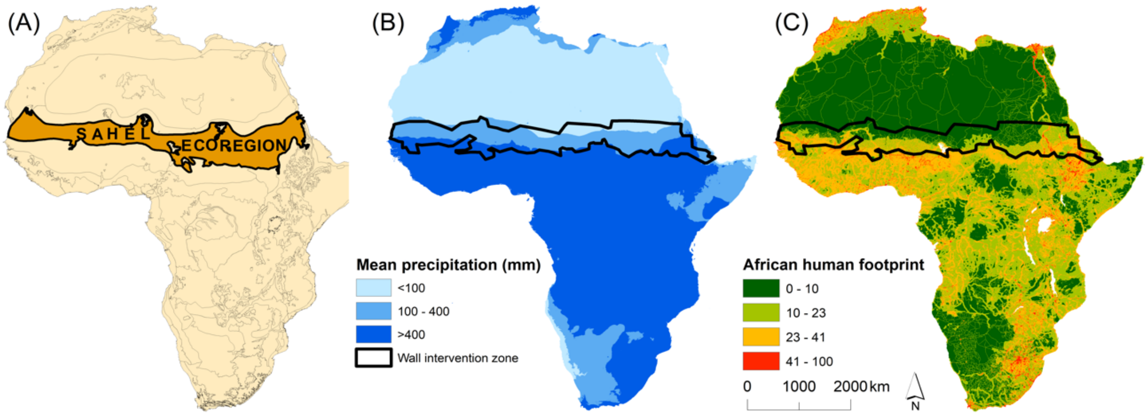

Figure 2.1 | (A) Location of the Sahel among all African ecoregions; (B) mean precipitation in Africa, depicting the location of the Wall, and (C) the human footprint index in the African continent and within the Wall intervention zone, expressed as a percentage of the relative human influence (high values and red colour stand for higher human footprint (Venter *et al*., 2018).

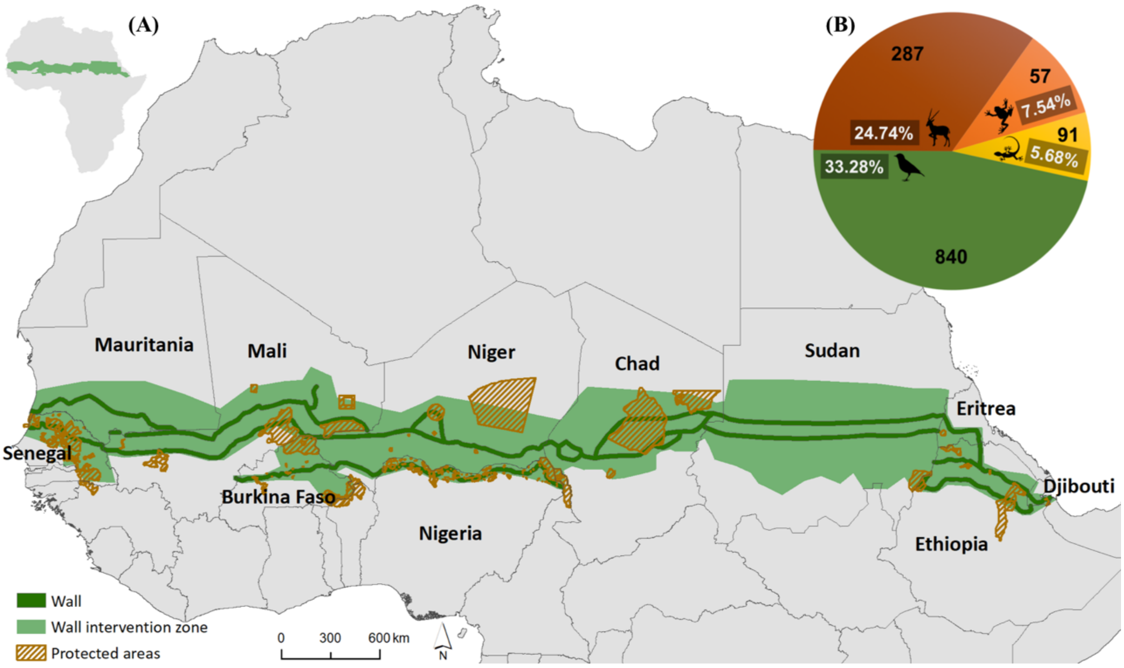

Figure 2.2 | (A) Location of the Great Green Wall (Wall) and respective intervention zone. (B) Number of terrestrial vertebrate species in each taxonomic group (amphibians, reptiles, birds and mammals) occurring in the Wall intervention zone (N = 1,275) and percentage in relation to the terrestrial vertebrates present in Africa (N = 6,041).

This study presents a critical view on the implementation of the Wall by addressing the potential impacts to biodiversity. Specifically, it aims to: i) identify which species have its distribution range within the Wall intervention zone; ii) identify its biogeographic affinity and conservation status; iii) discuss the potential lack of connectivity created by the Wall for arid-adapted species; and iv) present recommendations to enhanced the Wall initiative by taking into account biodiversity conservation.

2.2. Material and methods

2.2.1. Definition of the Wall location

The Wall location and intervention zone were digitized to spatial polygons from the most recent national reports (Pan-African Agency of the Great Green Wall, 2018) and georeferenced to the WGS84 coordinate system. Protected areas were extracted from the World Database of Protected Areas (UNEP-WCMC and IUCN, 2018) and manually cleaned, eliminating the areas not yet implemented, marine, not related to biodiversity conservation (hunting, cinegetic interest, and sylvo-pastoral reserves), and non-managed (forest reserves and classified forests). All processes and projection to the Africa Lambert Conformal Conic Projection were conducted in ArcGIS v.10.5 (ESRI, 2016).

2.2.2. Species list

Species range data for African amphibians, reptiles, birds and mammals were obtained from the Red List by the International Union for Conservation of Nature (IUCN) and BirdLife International (BirdLife International and Handbook of the Birds of the World, 2018; IUCN, 2019), with the exception of *Eudorcas rufifrons*, for which an updated polygon was used (Brito *et al*., 2018). Marine, introduced, and extinct species were excluded from the analysis. Species distribution polygons intersecting the Wall intervention zone were selected for analysis, resulting in a total of 1,275 species, including 57 amphibians, 91 reptiles, 840 birds (wintering and/or breeding), and 287 mammals (Table S1). This species list is an underestimate of the real number of species that are potentially affected by the Wall because not all African vertebrates have been assessed by IUCN Red List (Not Evaluated status), and thus range polygons are unavailable. For instance, in the Sahara-Sahel only, 88 reptiles known in the area have not been evaluated and thus range polygons are unavailable (Brito *et al*., 2016). All data were projected to the Africa Lambert Conformal Conic Projection.

2.2.3. Species biogeographic affinity and conservation status

From the 1,275 species potentially affected by the Wall intervention zone, 110 are endemic to the region (≥ 75% of the range occurs in the area) and display distinct biogeographic affinities: Sahara, Sahel, Savannah, or Wall endemics (Fig. 2.3). The Sahara, Sahel and Savannah categories were defined from the percentage of the range (≥ 75%) intersecting the respective ecoregion (Dinerstein *et al*., 2017). The Wall endemics include the species in which the percentage of the range (≥ 75%) intersects the Wall intervention zone. The current conservation status of each species was extracted from IUCN Red List (IUCN, 2019). Incorporating biogeographic affinity helps to identify species adapted to live in a particular region, exhibiting particular habitat requirements, where land-cover and land-use change can have higher impacts.

The area (km^2) of the African distribution of each species and the area of the African range intersected by the Wall intervention zone were both calculated with ArcGIS. These values allowed calculating the percentage of the African range that will be affected by the Wall intervention zone.

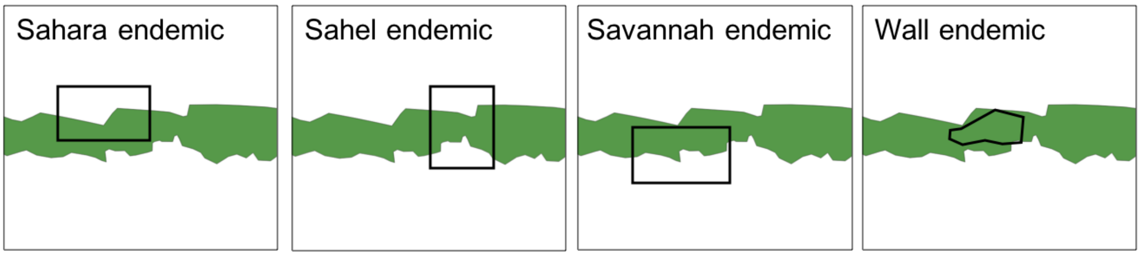

Figure 2.3 | Geographical representation of biogeographic affinities. Sahara endemic includes species whose distribution reaches the northern part of the Wall intervention zone, Sahel endemic includes species whose distribution transverses latitudinally the Wall, Savannah endemic includes species whose distribution reaches the southern part of the Wall, and Wall endemic includes species whose distribution occurs ≥ 75% within the Wall. The black polygons illustrate hypothetical species distributions.

2.2.4. Species richness

Species richness was calculated using R v.3.3.3 (R Core Team, 2016) through Rstudio 1.1.456 (RStudio Team, 2015). A square grid containing cells with 50 km^2 resolution was created over the Wall intervention zone using “raster” (Hijmans, 2017) R package. Species range data were overlaid with this grid using “rgdal” (Bivand *et al.*, 2017), “letsR” (Vilela and Villalobos, 2015) and “sp” (Pebesma and Bivand, 2005) R packages. A species was considered to occur in a cell if any portion of the species’ range overlapped the cell. The final maps of species richness were obtained in ArcGIS by summing the number of species occurring in each cell. Species richness was calculated for every taxon in the present study and for the subset of species endemic to the Wall intervention zone.

2.3. Results and discussion

2.3.1. Overlooked biodiversity impacts

The Wall has been announced as a strategy to enhance biodiversity conservation. Supposedly, the Wall will improve landscape connectivity, habitat protection, species diversity (including agrobiodiversity), and critical ecosystem services (*e.g.* water supply, pollination, and carbon sequestration; Davies, 2017) and claims to be aligned with the SDGs (specifically Goal 15 – “Life on Land”). However, its implementation will potentially cause multiple impacts on local biodiversity that, to date, have not been adequately addressed in reports by the initiative (Davies, 2017; Pan-African Agency of the Great Green Wall, 2018).

Firstly, the Wall will significantly alter the habitats of 1,275 terrestrial vertebrates occurring within intervention zone representing at least 21% of all African terrestrial vertebrates (Fig. 2.2B, Table S1). Approximately 6% of the affected species (N = 77) have more than half of their African range inside the Wall intervention zone (Fig. 2.4).

The Wall intervention zone contains many endemic and threatened species with distinctive evolutionary histories that are adapted to live in extreme environments (Vale and Brito, 2015; Brito *et al*., 2016). For instance, six globally threatened Sahara endemic species occur within this zone (Critically endangered, Endangered, or Vulnerable status on the Red List by the IUCN; Fig. 2.5). Additionally, three threatened species and eleven Data Deficient species with unknown population trends or extinction risks occur entirely within this zone. From the total species affected, 103 species are classified as threatened or Near Threatened and correspond mostly to birds and mammals (Fig. 2.6). Furthermore, the viability of the reintroduction program of the Extinct in the Wild scimitar oryx (*Oryx dammah*) in Chad could be affected since it is completely covered by the Wall intervention zone (Fig. 2.7). When finished, the Wall will likely affect many more species, including biocrusts, invertebrates, and vertebrates for which precise spatial distribution data are currently unavailable. Afforestation of previously open areas will likely result in species replacement, decreasing the number of arid-adapted species and increasing generalist species, and in turn alter food web structure and ecosystem function. Perversely, in Chad and Nigeria, a shelterbelt is being planted using alien tree species (Pan-African Agency of the Great Green Wall, 2018) with reported invasive potential (*e.g*. Davies, 2017), such as neem (*Azadirachta indica*), the Mexican palo verde (*Parkinsonia aculeata*), and two mesquite species (*Prosopis chilensis* and *Prosopis juliflora). P. juliflora* enhances the capacity of *Anopheles* mosquitoes to transmit malaria (Muller, 2017). Similarly, in Nigeria, *Eucalyptus* species are being planted to build the Wall (Pan-African Agency of the Great Green Wall, 2018), despite the fact that their long roots increase desertification risks by desiccating wetlands. Such landscape changes could increase extinction risks, via inbreeding depression and loss of genetic diversity (Frankham, 2005), in two Wall endemics – Heuglin’s gazelle (*Eudorcas tilonura*) and dama gazelle (*Nanger dama*) – which persist in small and fragmented populations experiencing continuous decline (Fig. 2.7). These species have been extirpated from most of its African historical range due to human disturbance through habitat conversion to agroforestry and pastoral units; the latter are precisely a part of the Wall objectives. Additional overhunting and habitat loss driven by natural system modifications in the Wall could potentially drive these species towards extinction.

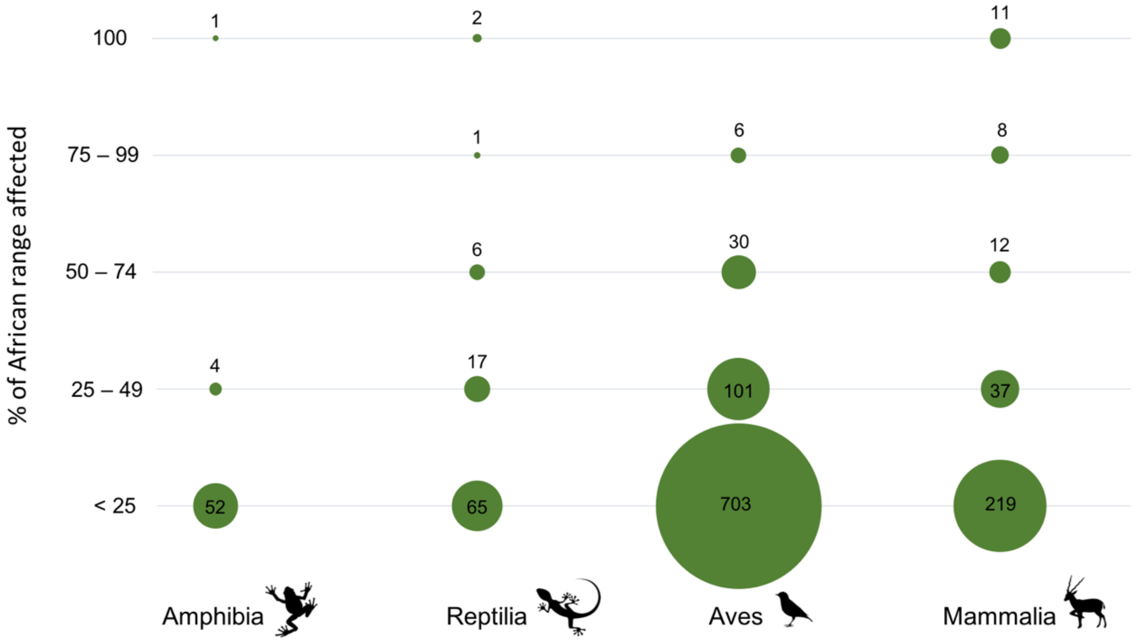

Figure 2.4 | Percentage of the African range of species that are within the Wall intervention zone (N = 1,275). Representation by taxonomic group, where the size of each circle represents the amount of species in each range category. A total of 236 species have their range affected by ≥ 25% and 77 species have their range affected by ≥ 50% (18.0% and 6.0% of the total species, respectively), while 14 of them have their distribution 100% affected by the Wall intervention zone.

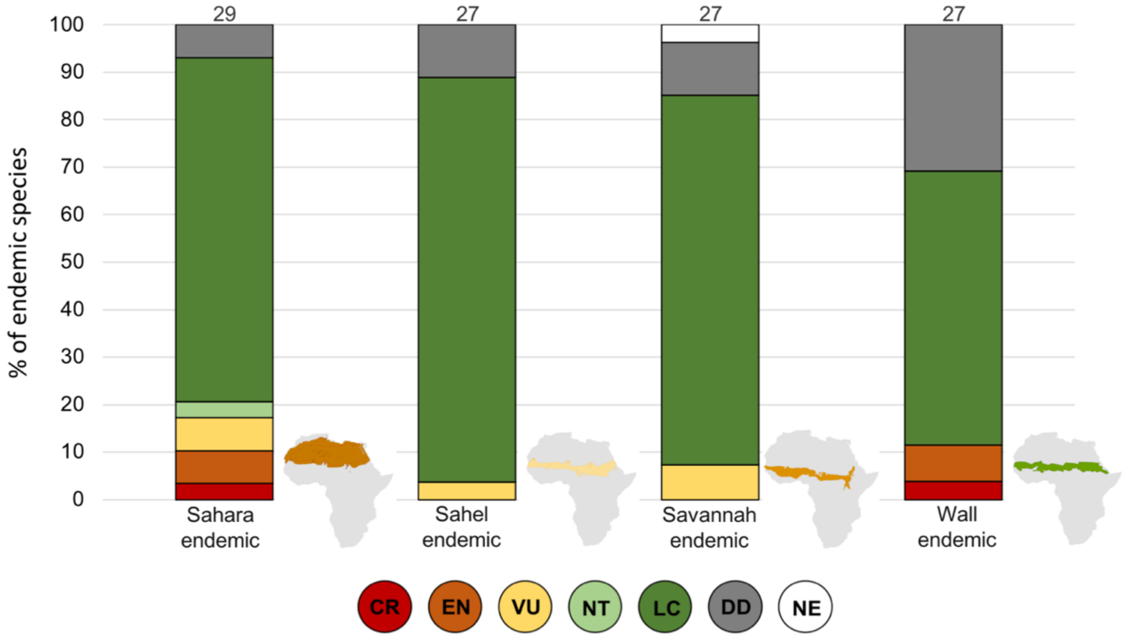

Figure 2.5 | Percentage of endemic species by conservation status and biogeographic affinity. From the total 1,275 species, 8.6% of them (N = 110) are endemic and categorise in one of the four biogeographic groups. The number of species in each biogeographic group is given above bars.

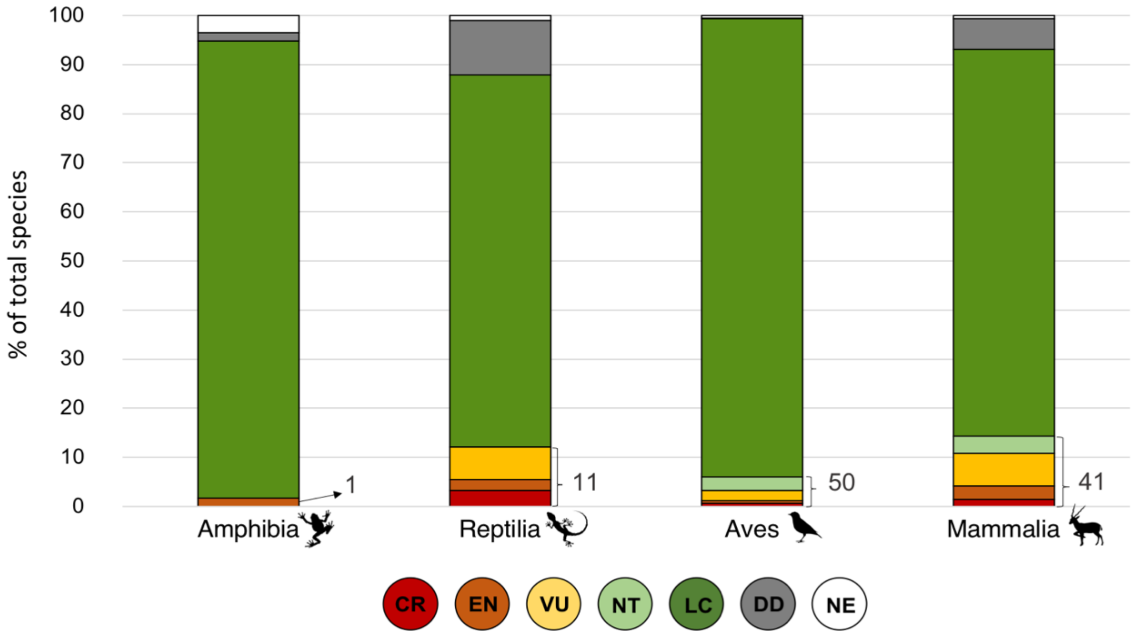

Figure 2.6 | Percentage of species by conservation status and taxonomic group (N = 1,275), whose distributions occur within the Wall intervention zone. The conservation status nomenclature follows the IUCN Red List categories (IUCN, 2019): NE (Not Evaluated), DD (Data Deficient), LC (Least Concern), NT (Near Threatened), VU (Vulnerable), EN (Endangered) and CR (Critical Endangered). Numbers to the right of the bar depict the number of species near threatened or within a threatened IUCN category.

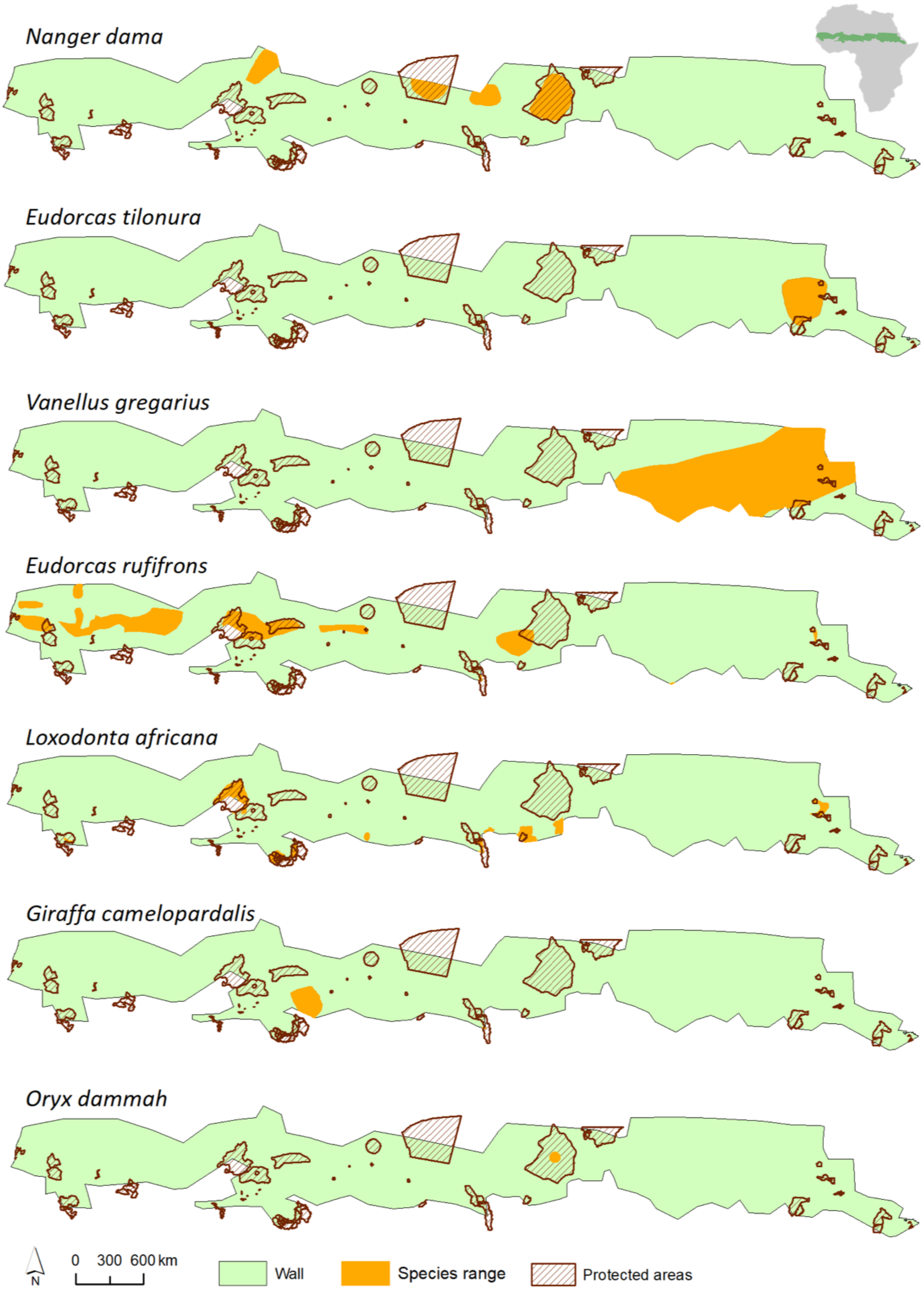

Figure 2.7 | Distribution of threatened fauna within the Wall intervention zone. Representation of species range of six threatened species and the reintroduction site of the Extinct in the Wild *Oryx dammah*.

Secondly, the Wall will decrease landscape connectivity and species movement along the north-south axis by creating a barrier across the intervention zone (Fig. 2.2A).

Currently, trees are being planted close together (2.5 m apart; Dia and Duponnois, 2010), and such narrow spacing will substantially increase the amount of shaded areas in the near future. Since species with low dispersal capabilities (*e.g.* small vertebrates) or desert adaptations may be unable to cross heavily shaded areas, the Wall will likely limit gene flow between populations of these species. Loss of gene flow will decrease population viability by reducing effective population size and genetic diversity, due to population bottlenecks and genetic drift, and contribute to inbreeding depression and loss of evolutionary potential (Frankham, 2005). These negative impacts may be exacerbated under climate change. Indeed, the velocity and magnitude of climate change in arid-related biomes, including the Sahel region, are expected to be greater than other biomes (Loarie, *et al*., 2009). Sahara endemics are already living close to their physiological limits (Vale and Brito, 2015), and the Wall will likely hamper their southwards dispersal to search for favourable habitats. Together with massive land-cover change created by the Wall, these factors will likely have severe impacts on species highly specialized to dryland conditions, leading to loss of unique adaptations and potentially local extinctions.

Thirdly, the Wall will increase landscape connectivity along the horizontal axis by homogenizing land-cover from the West to the East coast. If not properly planned, changing natural river systems and creating water storage structures (*e.g.* lakes and irrigation channels) along the Wall intervention zone – in addition to potentially affecting water availability in seasonal wetlands – will remove natural barriers for contemporary evolutionary processes. For instance, these changes could dilute the genetic diversity within species formed by historical natural processes over thousands of years, such as the Nile monitor (*Varanus niloticus*), species whose population structure is determined by the current hydrographic network (Dowell *et al*., 2016). The Wall could also facilitate invasive species and pathogens potentially creating uncontrollable problems for biodiversity, public health, and local economies (Davies, 2017; Muller, 2017).

Fourthly, the Wall is expected to attract human communities, boosting migration towards the intervention zone (Davies, 2017; Hutchinson *et al*., 2018). With the forecasted increases in African populations (Hutchinson *et al*., 2018) and without evidence-based management plans (*e.g.* urban and territory planning), it is expected additional habitat change and intensification of human footprint (Fig. 2.1C). Expected increases in wood collection, overgrazing pressure, and expenditure of water resources can affect vegetation cover and ultimately challenge the Wall objectives, such as already observed in Burkina-Faso (MEEVCC, 2017). The development of urban areas and linear-infrastructures can boost accessibility to previously remote and wild areas, which in turn can intensify threats to biodiversity, such as road killings, bird collisions with power lines or overhunting pressure (Davies, 2017; Hutchinson *et al*. 2018).

2.3.2. Recommendations to minimise biodiversity impacts

Informed and evidence-based planning is needed to minimise biodiversity impacts of the Wall and achieve its overall objectives. For instance, inadequate scientific input has contributed to the failure of past initiatives aiming to halt desertification in other countries (Benalia, 2009; Jiang, 2016). To avoid the same outcome in the Sahel region, is here outlined several important considerations. Firstly, given management failures in Algeria and the former Soviet Union (Benalia, 2009; Jiang, 2016), urban and territory planning for the intervention zone should explicitly account for predicted increases in human populations (Hutchinson *et al*. 2018). Secondly, ensuring water availability is important for sustaining nearby seasonal and permanent wetlands since similar afforestation projects in China were associated with significant decreases in groundwater availability (Jiang, 2016). Thirdly, as previously discussed, the spacing between planted trees should be enlarged (Brito *et al*., 2016). Fourthly, risk assessments should be conducted for potentially invasive species before including them in afforestation programs. Fifthly, given that some afforested areas in Algeria and China had insufficient rainfall (< 400 mm annual precipitation) for germination and regeneration of native vegetation (Benalia, 2009; Jiang, 2016), the spatial extent and location of the Wall intervention zone should be reviewed. One strategy to avoid this issue could be to conduct *in situ* experiments across multiple ecosystem types within the intervention zone to identify the most well-adapted native tree species for afforestation (Wade *et al*., 2018).

The original Wall agreement mandated that new protected areas should be established within the intervention zone (Dia and Duponnois, 2010). Indeed, if not disrupted and adequately managed, protected areas could help buffer local biodiversity hotspots in the central-western regions (Fig. 2.8), and some of the most emblematic and threatened African fauna from the severe land-cover changes within the Wall intervention zone (Davies, 2017). Examples include the *Nanger dama,* north-westernmost populations of African savannah elephant (*Loxodonta africana*), and the reintroduction sites of *Oryx dammah* (Fig. 2.7). Furthermore, large protected areas, such as Ouadi Rimé-Ouadi Achim in Chad and Ansongo-Ménaka and Gourma in Mali, may serve as corridors and stepping stones for biodiversity (respectively; Fig. 2.2A). Yet existing protected areas are insufficient to ensure long-term biodiversity persistence in the region (Brito *et al*., 2016). Additional protected areas are critical for the north-westernmost populations of giraffe (*Giraffa camelopardalis*) in Niger and the Wall endemics in Mali.

Southern Mauritania and Sudan lack protected areas entirely, even though protected areas are needed in these places to for the threatened red-fronted gazelle (*Eudorcas rufifrons*) sociable lapwing (*Vanellus gregarius*), and *Eudorcas tiloura*. Key Biodiversity Areas (www.keybiodiversityareas.org) and gap analysis assessments (Brito *et al.*, 2016) could be used to guide policy and ensure north-south corridors to allow species dispersal along the Wall. Long-term monitoring of vertebrate populations and habitat suitability is also needed to evaluate the success of conservation actions.

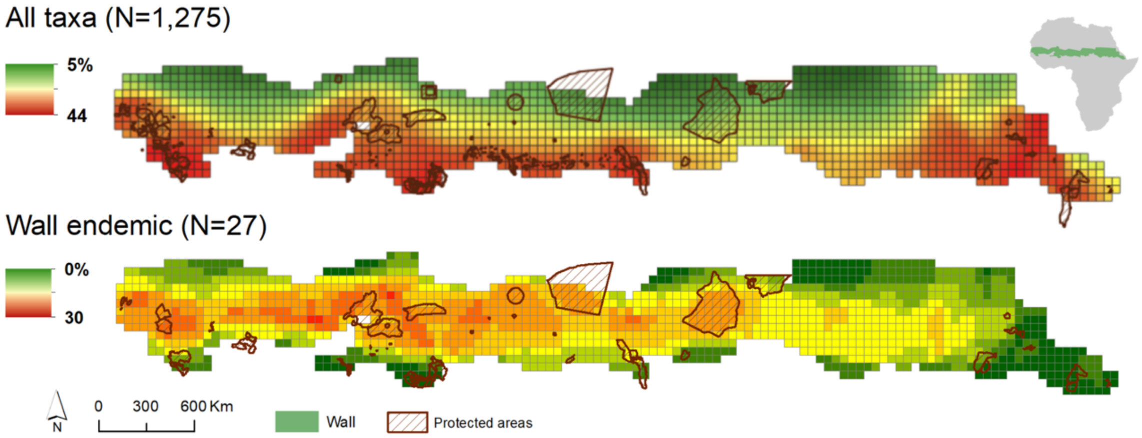

Figure 2.8 | Hotspots of species richness. Species richness of all taxa and Wall endemics. Richness is represented as percentage of species present in each grid cell of 50 km^2 resolution in relation to the total species for each category.

The challenge now is to revise the design and implementation of the Wall to ensure that its undoubtedly positive objectives such as securing livelihood conditions, promoting carbon sequestration, and restoring landscapes in the Sahel (Dia and Duponnois, 2010; Davies, 2017), can be realized with minimal impacts to biodiversity. To achieve this, the African Union and Pan-African Agency of the Great Green Wall should carefully consider biodiversity impacts of the Wall. Otherwise, the Wall can push imperilled Sahel biodiversity to extinction, and fail to aid human populations.

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Chapter III: Manuscript II

Promoting connectivity between priority freshwater sites for conservation in arid ecosystems[2]

Abstract

Habitat connectivity is key to ensure species persistence in changing arid freshwater ecosystems experiencing growing threats. Systematic conservation planning allows finding relevant areas to ensure species dispersal and to mitigate the negative effects of population isolation. This study simulates the effects of distinct longitudinal connectivity measures in finding optimised connectivity solutions between local biodiversity hotspots allocated in the hydrographic network. Twenty-six water-dependent taxa from 59 mountain rock pools (*Gueltas*) of three southern Mauritanian mountains are used as case-study. Eight scenarios were tested in Marxan to find priority conservation areas discarding and considering a measure of water residency time and different connectivity rules between *Gueltas* and the upstream areas. A new framework is presented that accounts for different strengths in connections and minimise the downstream propagation of threats by considering isolated management units in its hydrological context. Seven *Gueltas* were selected in all scenarios and are essential to achieve representativeness in the solution. Incorporating water residency time in connectivity resulted in solutions with higher water availability throughout the year, which is crucial for water-dependent species dispersal in arid regions. Incorporating connections between *Gueltas* and upstream areas resulted in solutions optimising the representation of corridors, which combine terrestrial and freshwater ecosystems that promote species persistence and prevent the propagation of potential threats into *Gueltas*. The results obtained from spatial prioritisation manipulations tests revealed important locations for local biodiversity conservation because it allows inter-mountain species dispersal. The framework developed allows addressing connectivity in conservation planning that is scalable to regions with similar wet-dry climatic conditions.

Keywords: freshwater conservation, habitat continuity, Marxan, persistence, spatial planning, species dispersal

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3.1. Introduction

Habitat fragmentation is one of the main drivers of biodiversity loss, creating small suitable habitat patches where species persist (Secretariat of the Convention on Biological Diversity, 2010). Small and isolated populations may experience a decrease in genetic variation due to genetic drift, leading to inbreeding depression, and ultimately influencing population viability by increasing extinction risks (Frankham, 2005). Integrating connectivity in spatial conservation prioritisation studies is a strategy to ensure species persistence (Mech and Hallett, 2001; Pressey *et al.*, 2007). Finding corridors between different suitable habitat patches will enhance landscape connectivity (Dehaghi *et al.*, 2018), which will maintain the genetic diversity, enhance the capacity of species to move across the landscape, and to respond to climatic or land-use changes (Mech and Hallett, 2001).

Rivers and other waterways behave as corridors through the landscape, allowing migration of water-dependent species and the maintenance of key ecological process, known as functional connectivity (Taylor *et al.*, 2006). Freshwater ecosystems can also behave as stepping stones for non-strictly aquatic species that benefit from water in some part of their life cycle (Hermoso *et al.*, 2012a) and work as a bridge between terrestrial and freshwater spatial conservation planning, improving the combination of terrestrial-freshwater habitats in a protected area network (Nel *et al.*, 2009; Beger *et al.*, 2010). Despite freshwater ecosystems being amongst the most diverse and threatened, they are still poorly represented in existing protected areas (Dudgeon *et al.*, 2006; Reid *et al.*, 2018). Freshwater connectivity is featured in three spatial dimensions (Ward *et al.*, 1989): i) longitudinal connectivity allows species migration through the hydrographic network (Hermoso *et al.*, 2012a), which is important to ensure gene flow between populations; ii) vertical connectivity, the connection between the surface and ground water; and iii) lateral connectivity between riverine and floodplain ecosystems (Ward *et al.*, 1989). Longitudinal connectivity is particularly important in regions with wet-dry seasonal climate because of the temporal changes in water residency time (Hermoso *et al.*, 2012b). Therefore, the dispersal of water-dependent species is constrained to the wet season, when the hydrographic network is connected. Water residency time fluctuations can also occur inter-annually, resulting in droughts, which are expected to increase with climate change. This is evident in West Africa, where the arid Sahel ecoregion has undergone severe droughts in the last century and rainfall is expected to decrease in the future (Zeng, 2003; Druyan, 2011).

The southern mountains of Mauritania (Fig. 3.1A) harbour relict and threatened populations of sub-Saharan species and acted as refugia during the past climate cycles

(Brito *et al*., 2014). Rock pools (locally known as *Gueltas*) in these mountains are considered local biodiversity hotspots, concentrating endemic and threatened fishes, amphibians and aquatic reptiles in small-sized wetlands (on average less than 5 ha; Padial *et al*., 2013; Vale *et al*., 2015). Freshwater connectivity in these regions is critical to the maintenance of population dynamics and its long-term viability (Velo-Antón *et al*., 2014). Metapopulation dynamics in these *Gueltas* are highly dependent on freshwater connectivity. For instance, populations of the West African crocodile (*Crocodylus suchus*) are found in *Gueltas*, which act as refugia when the seasonal rivers and associated floodplains dry out (Brito *et al*., 2011). During the wet season (July to October), the isolated *Gueltas* are connected through the hydrographic network (Campos *et al*., 2012), allowing longitudinal connectivity, and consequently crocodile dispersal and gene flow between populations (Velo-Antón *et al*., 2014). Therefore, selecting local corridors for conservation considering the temporal changes of spatial connections through rivers will guarantee the fitness and survival of the populations (Taylor *et al*., 2006). The increasing human activities in the Sahel are threatening freshwater ecosystems, in particular *Gueltas*; yet they do not hold any effective management (Vale *et al*., 2015). Moreover, water-dependent desert species inhabiting mountain areas face another threat, as freshwater and high elevation habitats are vulnerable to climate change (Griffis-Kyle *et al*., 2018; Nyboer *et al*., 2019), therefore water residency time has great importance on their persistence (Murphy *et al*., 2015). The protection of different microrefugia, with high water residency time, could reduce the vulnerability to climate change, by increasing the availability of suitable microclimatic regions (Suggitt *et al*., 2018). Although, to an effective application of conservation efforts, the planning process should take into account surrounding areas of management units (*Gueltas*), as they are within the hydrographic network. Account for the potential propagation of threats from the surroundings into priority *Gueltas* by going beyond local management of *Gueltas* to their full catchments, will increase conservation efforts by decreasing the probability of allowing threats into management units.

In recent years, new methodological improvements have been developed to find the most relevant functional corridors between suitable areas in need of protection to ensure species persistence. For instance, integrating sub-catchments, the most common freshwater-based planning units, in spatial conservation prioritisation has proven to be an efficient approach to account for the connected nature of rivers (Moilanen *et al*., 2007; Hermoso *et al*., 2011, 2012a, 2012b). Using hydrologically derived planning units helps addressing lateral and longitudinal connectivity, which allows to account for both wetland floodplain and the longitudinal river system in prioritisation studies (Reis *et al*., 2019). Prioritisation of upstream areas has been done to account with the downstream propagation of threats in rivers (Hermoso *et al.*, 2011). Additionally, using measures of water residency time throughout the year can improve spatial prioritisation in seasonal environments (Hermoso *et al.*, 2012b). Still, spatial prioritisation methods require moving beyond local planning in isolated locations such as *Gueltas*, by allocating management units into a broader landscape. Incorporating connectivity and the propagation of threats will increase the effectiveness of spatial prioritisation.

In this study, a novel framework is presented to improve conservation planning in seasonal freshwater ecosystems by going beyond local planning in isolated freshwater systems in an arid region. The novelty consists in testing the effect of integrating different connectivity measures on the prioritisation of *Gueltas* by allocating them in their hydrological context. Two alternative connectivity planning scenarios are driven by incorporating an index of water residency time along the year as a way to address temporal connectivity (Hermoso *et al.*, 2012b) and considering different strengths in connections between *Gueltas* and the surrounding catchments to maximize the effectiveness of conservation efforts. Applying this methodology is expected to emphasize connectivity in all solution and minimise the downstream propagation of threats, consequently maximising the species persistence in the area. Water-dependent taxa from southern Mauritania mountains and spatial conservation prioritisation exercises using *Gueltas* and sub-catchments as planning units are used as case-study. Specifically, this study aims to: i) identify priority areas for conservation for water-dependent species without considering connectivity; ii) test the influence of water residency time in connectivity and how it affects the identification of priority *Gueltas* for conservation; and iii) test the importance of connectivity between upstream connections in conservation prioritisation across the full hydrographic network.

3.2. Material and Methods

3.2.1. Study area

The study area encompasses nearly 99,063 km^2, comprising southern Mauritanian mountains (Tagant, Assaba and Afollé) and extending to extreme south-western Mali (Fig. 3.1B). These mountains correspond to rocky escarpments and plateaus that are hydrologically connected during the wet season (Campos *et al.*, 2012). There is a single wet season from July to October, and two dry seasons characterised by a cool period from November to February and a hot period from March to June (Cooper *et al.*, 2006). The area displays a high number of wetlands (Table 3.1), especially along the Senegal river floodplain (Campos *et al.*, 2012).

The “Lac Gabou et le réseau hydrographique du Plateau du Tagant” (hereafter Lac Gabou) Ramsar site, comprising 9,436 km^2 of land in the Tagant mountain, is the only classified area within the study area (Tellería, 2007; Fig. 3.1A), but given that the site lacks effective management, it was not considered as a managed feature in subsequent analyses.

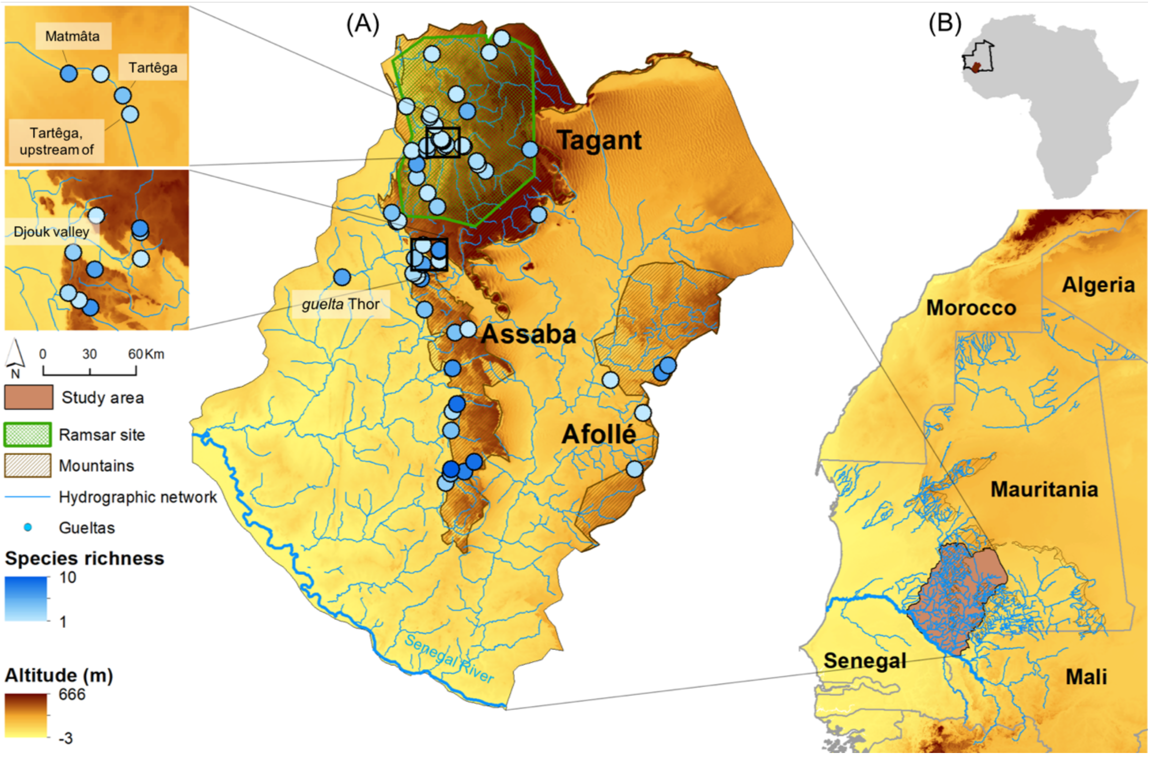


Figure 3.1 | (A) Distribution of *Gueltas* analysed in the present study, depicting taxon richness of fishes, amphibians, and aquatic reptiles, the location of Lac Gabou Ramsar site and Djouk valley, and (B) location of the study area in the West Africa and Mauritania contexts.

Table 3.1 | List of *Gueltas* present in the study area and their location and characteristics. Information on seasonality comes from Vale *et al*. (2015). The proportion of threats was calculated by the sum of all threats in each *Guelta* (Vale *et al*., 2015; Campos *et al*., 2016) divided by the total number considered by the IUCN Threats Classification Scheme (Salafsky *et al*., 2008).

Gueltas	**Mountain**	**Seasonality**	**Proportion of threats (%)**
Amzouzef	Tagant	permanent	0.40
Aouinet	Tagant	seasonal	0.33
Aouînet Nanâga	Assaba	seasonal	0.47
Aouînet Teidoûma	Tagant	seasonal	0.40
Aouînet Tenbouckit	Assaba	seasonal	0.47
Ayoûn en Na'aj	Afollé	permanent	0.40
Bâfa	Assaba	seasonal	0.60

Bajai	Tagant	permanent	0.40
Bednam	Afollé	permanent	0.40
Ch'Bayer	Tagant	permanent	0.60
Daal	Tagant	seasonal	0.40
Dâber	Tagant	permanent	0.40
Dekheïlet el ‘Aleïb (=Dekla, Ain Bâjed)	Tagant	seasonal	0.40
El Barda	Assaba	permanent	0.20
El Ghâira, source	Assaba	permanent	0.73
El Housseînîya	Tagant	permanent	0.60
El Khedia	Tagant	permanent	0.60
Emreimida	Tagant	permanent	0.60
E-n-Guinâr	Tagant	seasonal	0.47
Fanar	Tagant	seasonal	0.47
Foum el Kour	Tagant	permanent	0.20
Foum Goussas	Assaba	permanent	0.60
Galoûla	Assaba	permanent	0.60
Gamra Ouarbî	Tagant	permanent	0.33
Gânçai source	Assaba	permanent	0.20
Garaouel	Tagant	permanent	0.60
Gleitat Ej Jmel	Tagant	seasonal	0.53
Goumbel	Assaba	permanent	0.87
Gueltet Thor	Assaba	permanent	0.60
Guenétir source	Assaba	permanent	0.20
Guérou	Assaba	seasonal	0.20
Guidemballa	Assaba	permanent	0.47
Jabara	Tagant	permanent	0.47
Kabda	Tagant	permanent	0.20
Kaimel	Tagant	seasonal	0.33
Laout	Tagant	permanent	0.60
Laout, 1km S of	Tagant	permanent	0.60
Legleyta	Assaba	seasonal	0.67
Lemmollah	Tagant	seasonal	0.20
Leouel	Tagant	seasonal	0.20
Matmâta	Tagant	permanent	0.60
M'cherba	Tagant	permanent	0.53
Mechaouba	Afollé	seasonal	0.33

Mendjoura	Tagant	seasonal	0.33
Metraoucha	Afollé	permanent	0.60
Meyla	Assaba	permanent	0.20
Motoboul	Tagant	seasonal	0.53
Nouadar	Tagant	seasonal	0.60
Oumm el Mhâr	Afollé	permanent	0.73
Oumm Icheglâne	Assaba	permanent	0.47
Oumm Icheglâne, 5km NW of	Assaba	seasonal	0.40
Rh' Zembou	Tagant	permanent	0.47
Sellenbou (=Silimbo)	Tagant	seasonal	0.33
Soufa, oued	Assaba	permanent	0.40
Suklan	Tagant	seasonal	0.33
Tartêga	Tagant	permanent	0.13
Upstream of Tartêga	Tagant	permanent	0.40
Tin Waadine	Tagant	seasonal	0.67
Tkhsutin	Tagant	permanent	0.33

3.2.2. Data sources and processing

3.2.2.1. Planning units

To subdivide the study area two types of planning units were used: point-locality (*Gueltas*) and polygonal data (sub-catchments). Despite equal-sized grid cells are often used in systematic conservation planning, sub-catchments are more appropriate to capture the hydrological context (Hermoso *et al*., 2011), subdividing the nodes of the rivers and capturing its connected nature (Linke *et al*., 2007). To define the planning units relevant for an aquatic spatial prioritisation exercise, the study area was subdivided into 657 sub-catchments from a digital elevation model (DEM). The DEM was processed in order to obtain the flow direction of the hydrographic network and its respective segmentation, defining the sub-catchments by the river nodes using using ArcHydro tool from ArcGIS v.10.5 (ESRI, 2016). The result retrieved from the DEM processing was refined in the stream definition processing, to create a flow accumulation grid of 10,000 polygons, avoiding geographically distant *Gueltas* to occur in the same sub-catchment.

Sub-catchments convey a river reach and the portion of surrounding land that drains into each reach. These sub-catchments were the spatial framework used for measuring longitudinal connectivity across the study area. *Gueltas* were allocated into these sub-catchments to address longitudinal connectivity between *Gueltas* and their upstream contributing catchments in the planning process.

3.2.2.2. Conservation Features

Twenty-six species – eight fishes, ten amphibians, and eight aquatic reptiles (Fig. 3.2; Table 3.2) that are known to be dependent on freshwater ecosystems, are used in the study area as conservation features. A total of 1,927-point localities were collected in the study area from published observations (Padial, 2006; Brito *et al*., 2011; Padial *et al*., 2013; Vale *et al*., 2015). Observations were geo-referenced with a Global Positioning System (GPS) and projected to Universal Transverse Mercator coordinate system (WGS 1984 Complex UTM Zone 29), used in all following analysis. The total 1,927-point localities were intersected with *Gueltas* in ArcGIS (ESRI, 2016), using a buffer of 50 meters, to limit the conservation features to the *Gueltas* location, decreasing the observations to 776-point localities (Table 3.2). To avoid duplication error, species that were not identified were excluded. However, five fish species identified up to the genus level were included, as are unique to that genus, not representing a problem of species duplication.

A presence/absence table was created between the 26 water-dependent taxa under study and the 59 *Gueltas* to derive taxa composition in each *Guelta*. The distribution of taxa richness follows a latitudinal gradient, related with higher precipitation levels and higher primary productivity in southern areas (Brito *et al*., 2014). Therefore, southern *Gueltas* display greater number of species in relation to northern ones (Vale *et al*., 2015; Fig. 3.1A).

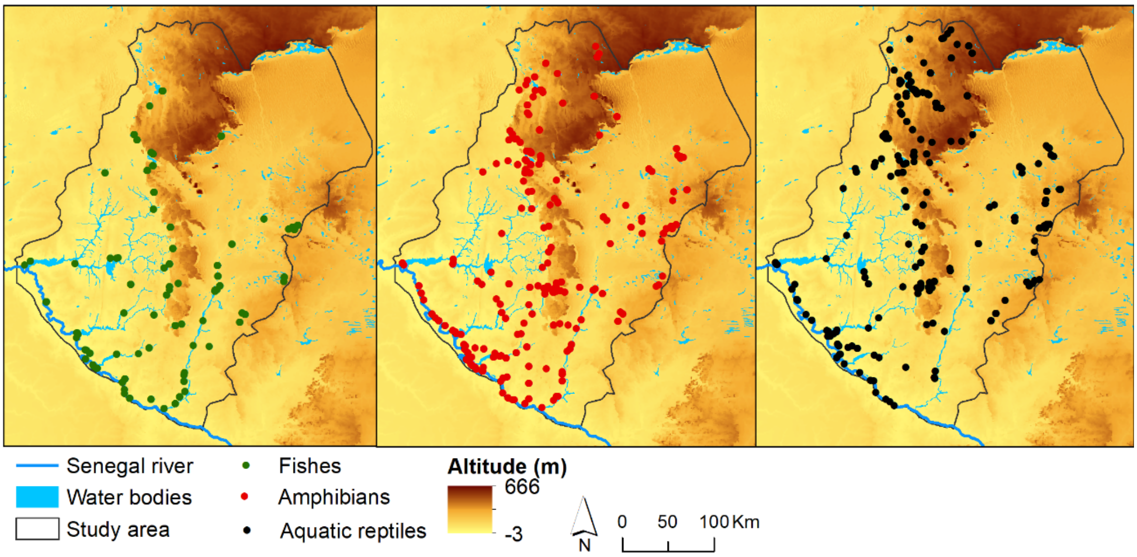


Figure 3.2 | The total 1,927-point localities of the observational data of fishes, amphibians, and aquatic reptiles within the study area used to estimate species composition in each *Guelta*.

Table 3.2 | List of species/taxa included in the study (fishes, amphibians and aquatic reptiles) and the number of observations in the 59 *Gueltas*.

Class	Species/Taxa	N observations
Actinopterygii	*Alestes* sp.	6
	Barbus macrops	10
	Barbus pobeguini	45
	Brycinus nurse	1
	Clarias sp.	45
	Sarotherodon sp.	26
	Schilbe sp.	1
	Synodontis sp.	1
Amphibia	*Hoplobatrachus aff. occipitalis*	134
	Hoplobatrachus occipitalis	3
	Kassina senegalensis	2
	Leptopelis sp.	1
	Phrynobatrachus francisci	4
	Ptychadena trinodis	2
	Sclerophrys pentoni	3
	Sclerophrys regularis	1
	Sclerophrys xeros	67
	Tomopterna milletihorsini	1
Reptilia	*Crocodylus suchus*	297
	Naja nigricollis	7
	Psammophis afroccidentalis	1
	Psammophis elegans	5
	Ptyodactylus rivapadiali	25
	Python sebae	9
	Varanus exanthematicus	4
	Varanus niloticus	47

3.2.3. Identify priority areas for freshwater biodiversity conservation

To identify the priority areas for conservation within the study area systematic conservation planning approach was followed (Margules and Pressey, 2000), which aims at identifying an optimal set of areas which contributes to adequately represent local biodiversity and assure its long-term persistence. Marxan was used as conservation planning tool (Ball *et al*., 2009), which uses a simulated annealing optimisation method to find an optimal set of sites (planning units) which retrieves the lowest value for the objective function (equation 1). This value is calculated as the sum of three parcels: the summed cost of the planning units selected, the boundary penalty, and the penalty for not achieving the targets set for conservation features.

$$\sum_{PUs} Cost + BLM \ \sum_{PUs} Boundary + \sum_{Con\ Value} SPF \times Penalty \qquad \text{(Equation 1)}$$

where PUs are planning units, BLM is boundary length modifier and SPF is species penalty factor.

The boundary length modifier (BLM) was calibrated accordingly to Ardron *et al*. (2010) and values ranged between 0.3 - 2.0. A constant value for scenarios F – H was not found, but they were all calibrated independently (see Table 3.3 for details). A target of 1 was set for each conservation feature, thus ensuring that each conservation feature was included within the priority *Gueltas* for conservation. A penalty of 10 was used to ensure that the targets were met for all species.

3.2.3.1. Cost Penalty

In order to avoid selecting highly threatened planning units as conservation priorities, measures of threats were used as surrogates for costs. Since, two types of planning units were used (*Gueltas* and sub-catchments), two measures of threats were defined: i) local threats to *Gueltas* were obtained from Vale *et al*. (2015) and Campos *et al*. (2016), classified following the IUCN Threats Classification Scheme (Salafsky *et al*., 2008) (Fig. 3.3B); and ii) threats to sub-catchments were calculated from the global human footprint at 1km grid cell size (Venter *et al*. 2018). The zonal statistics of ArcGIS v.10.5 (ESRI, 2016) was used to calculate the mean value of human footprint for each sub-catchment. This index incorporates nine global data layers, including human population pressure, human land-use and infrastructure and human access (Fig. 3.3A). Planning units with cost value of 0 were reclassified to 0.1 to avoid biasing results towards those planning units.

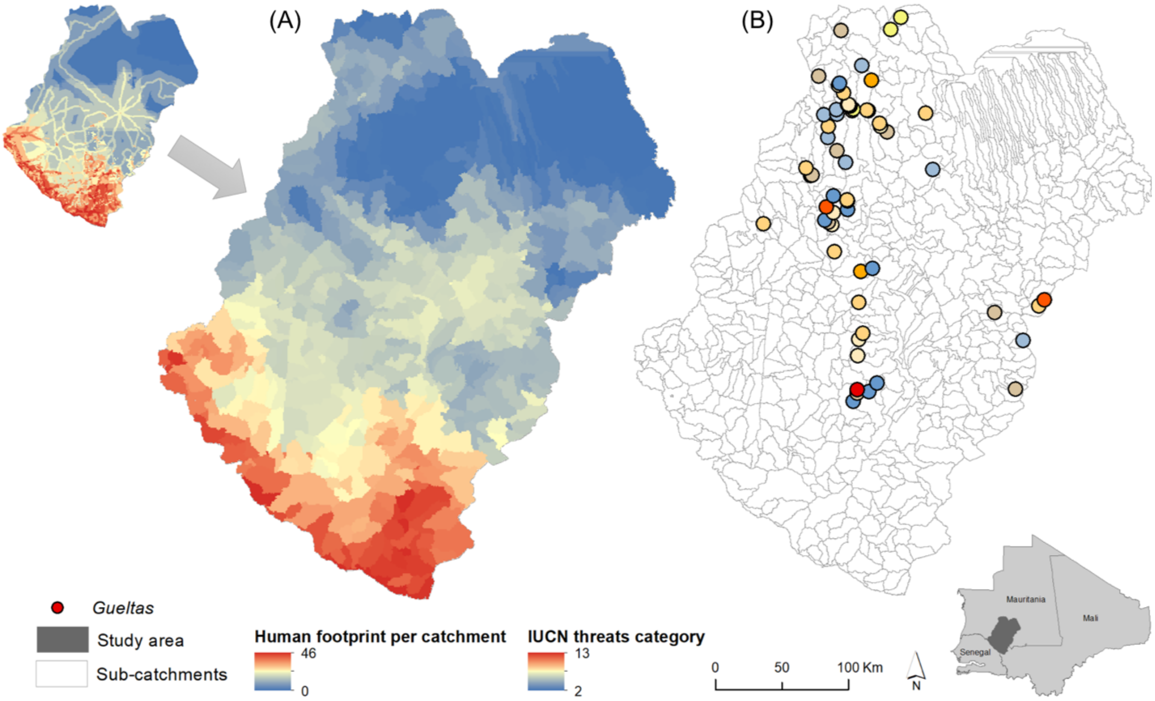


Figure 3.3 | Graphical representation of the cost penalties used in the spatial prioritisation: (A) for each sub-catchment derived by the global human footprint index (top-left small inset) (Venter *et al.*, 2018), and (B) for each *Guelta* the information retrieved from Vale *et al.* (2015) and Campos *et al.* (2016) following the IUCN Threats Classification Scheme (Salafsky *et al.*, 2008).

3.2.3.2. Connectivity framework

To identify sets of priority areas with higher connectivity, Marxan aims to minimise a penalty for fragmented solutions. Longitudinal connectivity was addressed as proposed in Hermoso *et al*. (2011) among *Gueltas* and between *Gueltas* and contributing sub-catchments. A penalty factor was added for not including upstream connections, which decreases by a factor proportional to the reciprocal of the hydrologic distance between them (equation 2). Thus, the importance of incorporating upstream sub-catchments decreases over the distance to certain sub-catchments. Incorporating upstream connections is important to account for the downstream propagation of threats through rivers, which can affect the subsequent sub-catchments (Hermoso *et al*., 2011; Linke *et al*., 2012). The distance was calculated based on the length of the river segment in each sub-catchment. The information retrieved from sub-catchments definition in ArcGIS was used to create a matrix of planning units' identification and its respective upstream connections. Sub-catchments that were hydrographically disconnected were excluded from the analysis. Then, planning units' connections were added to the connectivity penalty between them.

$$Connectivity\ penalty\ (CP) = 1/\sqrt{distanceij}(meters) \qquad \text{(Equation 2)}$$

where i and j are the two planning units being assessed.

3.2.3.3. Connectivity Scenarios

To test how different connectivity constrains affect prioritisation solutions, three types of connectivity were tested: i) excluding connectivity; ii) connectivity between *Gueltas*; and iii) Connectivity between *Gueltas* and sub-catchments:

i) Excluding connectivity

In the excluding connectivity scenario, the BLM was set to zero, which implies that the connectivity parcel of the Marxan objective function has no effect on the optimisation procedure (Scenario A).

ii) Connectivity between *Gueltas*

For the connectivity between *Gueltas* scenario, a dataset containing 59 *Gueltas* as planning units was used and connectivity strengths were calculated between each *Guelta* and upstream ones, with a total of 112 connections considered. To incorporate water residency time (Hermoso *et al*., 2012b) a measure of water presence along the year was weighted with longitudinal connectivity calculated above, modifying this connectivity penalty, hereafter referred as “Water Residency Time – Hydrologic Connectivity” (WCP). The maximum value of Gao’s normalised difference water index (NDWI) from Campos *et al*. (2012) was incorporated in equation 3, as it is the most appropriate index for detecting seasonal water in a freshwater ecosystem (Campos *et al*., 2012). A Weighting factor (W) was introduced, which can be used to calibrate the importance of NDWI relatively to the connectivity penalty. A logarithmic scale was used to ensure a positive curve when increasing the W of the NDWI from scenario C to E and added one to ensure that the final value is positive.

$$WCP = CP \times \log(W \times NDWI + 1) \qquad \text{(Equation 3)}$$

To test the influence of water residency time in connectivity and how it affects the selection of priority conservation *Gueltas*, one scenario was tested (scenario B) where W was set to zero, thus, only CP was accounted. Then, three scenarios (C - D - E) considering increasing weights (W) in equation 3 (for details see Table 3.3). The average of NDWI values between selected *Gueltas* was calculated and compared results among scenarios. The NDWI average is expected to increase proportionally to its weight in the prioritisation exercise, demonstrating a progressive higher amount of water residency time during a year from scenario C to E.

iii) Connectivity between *Gueltas* and sub-catchments

Despite only *Gueltas* have conservation features, the aim was to identify the sub-catchments most connected to important *Gueltas* for conservation and test whether some *Gueltas* under potential higher upstream pressure would be avoided for others that are under less pressure. As such, in addition to the connectivity strengths considered in the connectivity between *Gueltas* scenario (Fig. 3.4A), two other types of connections were considered: a) *Guelta* – Sub-catchment: considered the connections between *Gueltas* and its upstream sub-catchments, also considering the connection strengths as calculated in equation 2 (Fig. 3.4B); and b) Sub-catchment – Sub-catchment: considered the connection strengths between sub-catchments as calculated in equation 2 (Fig. 3.4C). In total, the dataset used in this scenario contained 159 planning units (59 *Gueltas* and 100 sub-catchments) and 777 connections. Three distance-based scenarios were developed: F - G - H) considering an increase in connectivity weights to enhance longitudinal protection of *Guelta* – sub-catchment connections in relation to the other connections (for details see Table 3.3).

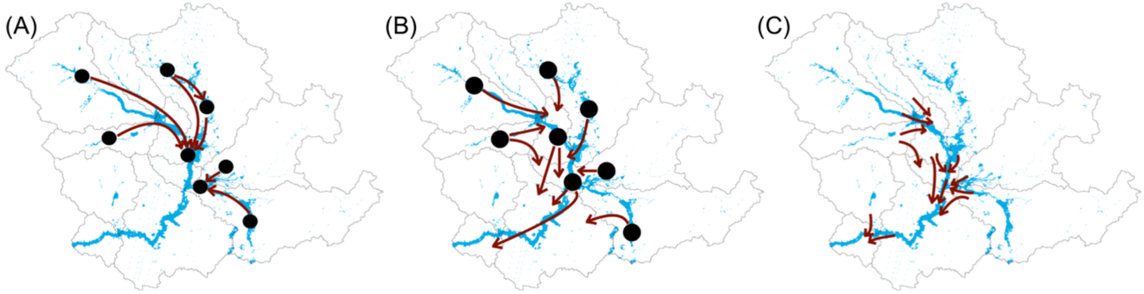


Figure 3.4 | Graphical representation of connectivity framework for the connectivity between *Gueltas* and sub-catchments: (A) connections between *Gueltas*; (B) connections between *Gueltas* and sub-catchments; and (C) connections between sub-catchments.

Table 3.3 | Methods summary table, depicting detailed information used in each prioritisation scenario according to the three objectives. N – Number; NDWI – Normalised difference water index; CP – Connectivity penalty; BLM – Boundary length modifier.

Objective	**Scenario**	**N planning units**		**Type of connectivity**	**NDWI connectivity**	**Distance-based connectivity**	**Type of boundary**	**BLM**
		Gueltas	Sub-catchments					
Excluding connectivity	A	59	0	None	No	No	None	0.0
***Guelta*-based connectivity**	B	59	0	*Gueltas*	No	Yes	CP between *Gueltas*	1.8
	C	59	0	*Gueltas*	Yes	No	CP * log (NDWI+1)	2.0
	D	59	0	*Gueltas*	Yes	No	CP * log (2*NDWI+1)	2.0
	E	59	0	*Gueltas*	Yes	No	CP * log (5*NDWI+1)	2.0
Hydrologic network connectivity	F	59	100	*Gueltas* and sub-catchments	No	Yes	1*_Guelta_ – Sub-catchment	1.0
	G	59	100	*Gueltas* and sub-catchments	No	Yes	2*_Guelta_ – Sub-catchment	0.6
	H	59	100	*Gueltas* and sub-catchments	No	Yes	5*_Guelta_ – Sub-catchment	0.3

The proportion of connectivity achieved by the best Marxan solution was calculated for all scenarios tested using the Achieved Connectivity index (equation 4). The connectivity achieved represents the sum of connectivity strengths between each pair of selected planning units. Conversely, missed connections represent the sum of connections between each selected planning units and each of the non-selected ones (example in Table 3.4). An increase of the weight of *Guelta* – sub-catchment connection is expected to translate into an increase of the final connectivity index.

$$Achieved\ Connecticity\ index\ =\ 1-\frac{missed\ connections}{connectivity\ achieved} \qquad \text{(Equation 4)}$$

Table 3.4 | Example of the calculation of the connectivity index in equation 4. Numbers underlined are hypothetical planning units selected in the final solution.

id 1	id 2	Index fraction results
<u>1</u>	<u>2</u>	Connectivity achieved
<u>1</u>	3	Missed connection
<u>1</u>	4	Missed connection
<u>2</u>	3	Missed connection
3	4	No connection

3.3. Results

3.3.1. Priority areas for conservation excluding connectivity

The solution of priority areas provided by scenario excluding connectivity is mostly restricted to the Tagant and Assaba mountains, selecting a total of 10 *Gueltas* (Fig. 3.5i, 3.6). One isolated *Guelta* in the western plains was also selected (*Guelta* Thor; see toponomies in Fig. 3.1A). The overall area selected in this scenario resulted in 27.58% of NDWI value and 4.94% of achieved connectivity.

3.3.2. Influence of water residency time in connectivity between *Gueltas*

Considering the influence of water residency time in the selection of priority areas for conservation, only *Gueltas* located in the Tagant and Assaba mountains were selected and also *Guelta* Thor. By increasing the weight of NDWI, the connectivity of the *Gueltas* selected also increased and more *Gueltas* were selected in the Tagant, but not in Assaba (Fig. 3.5ii; Table 3.5). Scenario E selected numerous *Gueltas* in the Djouk valley.

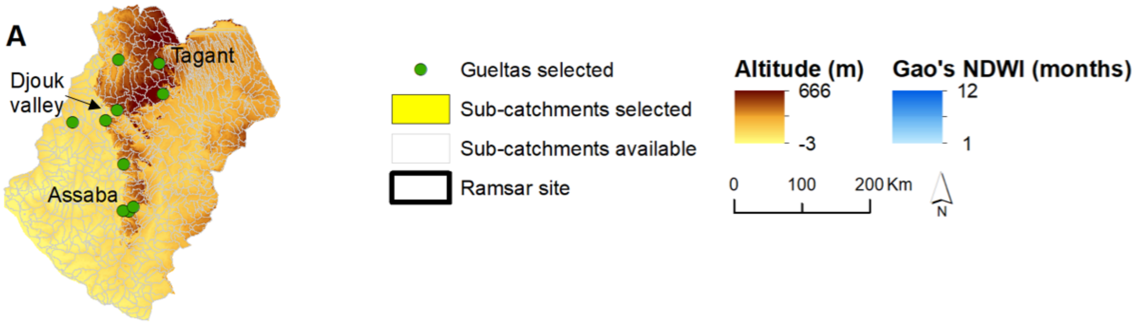
Although scenario B did not consider water residency time as a constraint, the average NDWI in this solution was 29.58% and 6.89% of achieved connectivity (Table 3.5). In scenarios C - E, the number of *Gueltas* selected increased from 12 up to 28 (Fig. 3.6). The average NDWI values in the connections between selected *Gueltas* in scenarios C - E were 24.92%, 25.58% and 29.92%, respectively, showing a positive relationship between increased weight of NDWI in the connectivity penalty and water residency time achieved in the solution. Also, connectivity also increased from scenarios C to E (Table 3.5). The cost of the solution retrieved from the connections selected in each scenario increased with the increase of NDWI value and connectivity achieved.

3.3.3. Importance of connectivity of *Gueltas* within the full hydrographic network

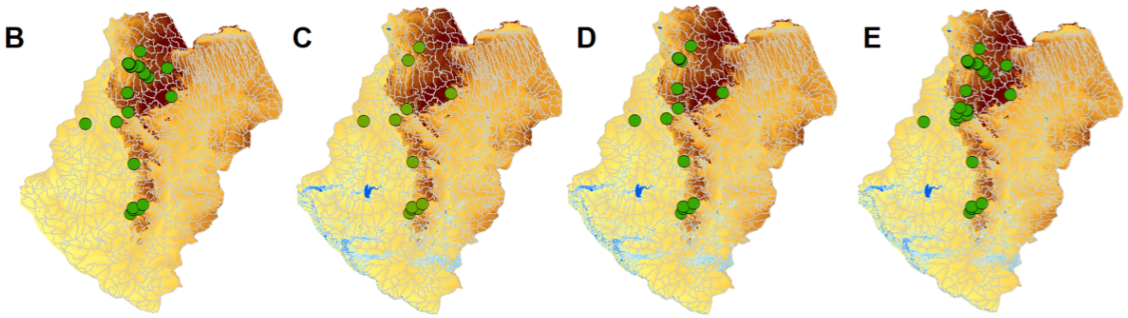
Regarding connectivity between all *Gueltas* and its upstream connections, the sub-catchments primarily selected in scenarios F, G and H were mostly restricted to the Tagant mountain and *Guelta* Thor, but sub-catchments selected in scenarios G and H also comprised locations of floodplains and the Djouk valley (Fig. 3.5iii).

Increasing the *Gueltas* – sub-catchments weight resulted in a decreasing number of *Gueltas* selected from scenarios F to H (Fig. 3.6), but the number selected was always higher or equal to remaining scenarios (A-E). Conversely, resulted in an increasing number of sub-catchments selected and in the achieved connectivity index, although the average human footprint in the connections selected also increased from scenario F to H (Table 3.5).

i) Excluding connectivity



ii) Connectivity between Gueltas



iii) Connectivity between Gueltas and sub-catchments

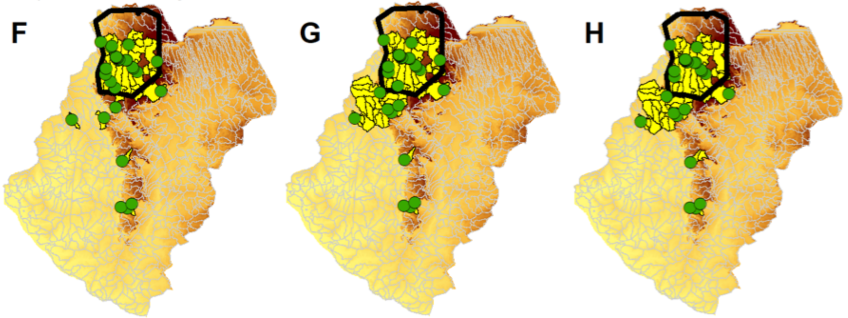


Figure 3.5 | Results of the planning units selected as priority for conservation when i) excluding connectivity (scenario A), ii) considering the influence of water residency time in connectivity (scenarios B - E), and iii) considering the influence of connectivity between upstream connections in the full hydrographic network (scenarios F - H). Planning unites presented had a selection frequency over 50% in 100 runs in Marxan. For details in each scenario see Table 3.3. Black line in scenarios F - G - H depicts the location of Lac Gabou Ramsar site.

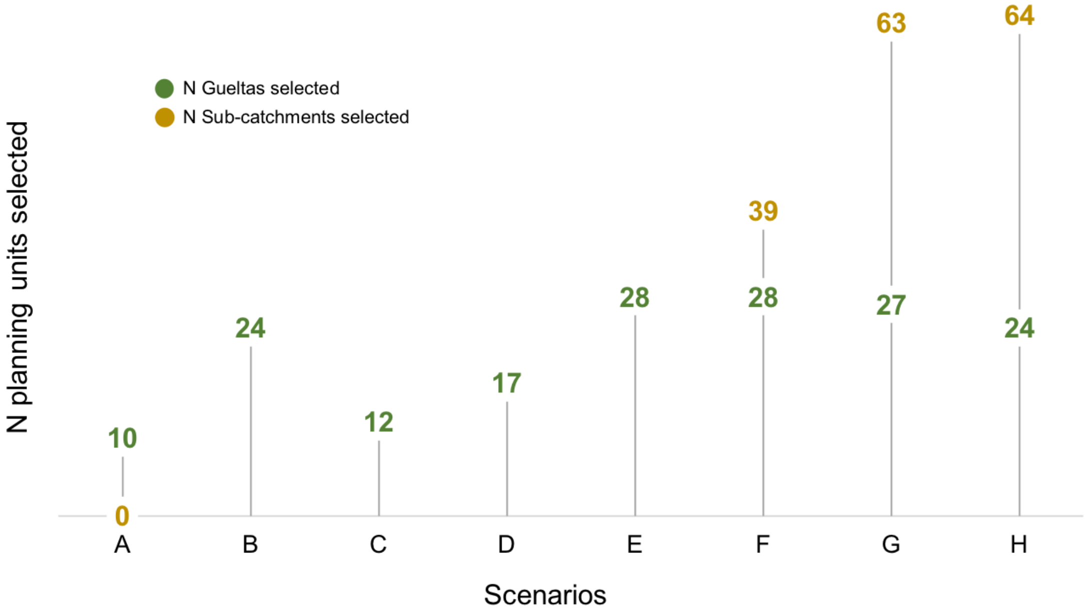


Figure 3.6 | Spatial prioritisation results of the number of planning units selected as priority for conservation in the different scenarios (A - H). Scenario A excluded connectivity, scenarios B - E use connectivity between *Gueltas*, while scenarios F - H use connectivity between *Gueltas* and sub-catchments. For details in each scenario see Table 3.3.

Table 3.5 | Results summary table, depicting the results information used in each prioritisation scenario for the normalised difference water index (NDWI) calculated for scenarios A - E, the Achieved connectivity index calculated according to equation 4 and the cost of the solution retrieved from the connections selected in each solution.

Scenarios	NDWI value (%)	Achieved Connectivity (%)	Solution cost (%)
Scenario A	27.58	4.94	43.33
Scenario B	29.58	6.89	44.17
Scenario C	24.92	3.17	41.67
Scenario D	25.58	5.04	43.14
Scenario E	29.92	6.95	44.29
Scenario F	Not applicable	43.61	52.39
Scenario G	Not applicable	54.38	58.04
Scenario H	Not applicable	74.81	58.72

3.4. Discussion

By considering different types of connections, priority *Gueltas* and sub-catchments in southern mountains of Mauritania were identified. In this arid region, it is important to account for connectivity through the hydrographic network to protect different local biodiversity hotspots following a systematic conservation planning approach (Margules and Pressey, 2000). Moreover, considering upstream connections had important implications in the identification of priority *Gueltas* for conservation and contributed to define where investments should be applied. Each connectivity scenario tested involved a different approach, always ensuring the representation of each species within the areas selected.

3.4.1. Methodological improvements and constraints

The present study combines methodologies from previous studies on freshwater spatial prioritisation, such as longitudinal connectivity (Hermoso *et al*., 2011), the incorporation of water residency time in arid freshwater ecosystems (Hermoso *et al*., 2012b) and connections between different sized planning units (Reis *et al*., 2019). In addition, innovates in the way that allocates point-localities management units into their hydrological context, rather than considering them as isolated points in the landscape. To achieve this, an innovative solution was used to address sub-catchments as they do not contain biodiversity features, although they can be incorporated to account for potential propagation of threats from upstream areas into priority *Gueltas*. The novel framework here proposed accounts for connectivity in the full hydrographic network, when increasing the strength between *Guelta* – sub-catchment connections, and led to an increase in the selection of contributing sub-catchments at the expenses of selecting less *Gueltas* (where conservation features are located), and increased the connectivity value of the solution. This framework has the potential to enhance connectivity between micro-freshwater habitats, by prioritising connections between management units (*Gueltas*) within they hydrological context and also forces the priority areas to be connected along the river network by selecting contiguous sub-catchments. This will increase the probability of persistence of conservation features by allowing species migration.

Integrating *Gueltas* in their hydrological context aids considering the potential downstream propagation of threats into priority *Gueltas* for management, such as pollution and invasive species (Hermoso *et al*., 2011). Moreover, incorporating the IUCN threats category and global human footprint as a surrogate for cost penalties allowed discarding, as priorities for conservation, *Gueltas* and sub-catchments located in degraded areas. Despite the methodological improvements in freshwater connectivity here implemented, further development would be needed to address some of the limitations of the present study. Using a global measure of human footprint entails lack of spatial accuracy and resolution when locally applied (Woolmer *et al*., 2008). For instance, the majority of *Gueltas* are isolated in mountain areas with minor land-use impacts (*e.g.* restricted agricultural fields), but the overall human footprint value for the sub-catchment may be high. Information from multiple socio-economic variables for the region, such as land degradation, will allow obtaining a better set of constraints to incorporate in the cost penalties.

The solutions provided by scenarios B - E translated in minimal differences in the average NDWI value. For instance, scenario B displays a high value of NDWI, even only considering distance-based connectivity. This result might be a consequence of similarities across scenarios such as targets and species distributions, which translated into lower flexibility in the selection of priority areas, as some *Gueltas* were always needed to achieve the targets. This result appears to be not just a consequence of including NDWI, but most likely because many endemic taxa occur in areas with high NDWI value, therefore required to be selected to achieve the targets. The importance of using different taxa in the spatial prioritisation was demonstrated in Hermoso *et al.* (2012a). By including observations from fishes, amphibians and aquatic reptiles it adequately represented the regional vertebrate freshwater biodiversity however, incorporating other aquatic taxa, for instance invertebrates or water-birds, could have strengthened the selection of priority areas for conservation. Moreover, future work should include both direct observation data as well as other techniques for species detection, such as environmental DNA (eDNA). This technique have been demonstrated to successful detect rare and endemic species in freshwater ecosystems (Jerde *et al.*, 2011), although many challenges related with water turbidity in *Gueltas* still need to be overcome to effective detect species in the Sahara-Sahel (Egeter *et al.*, 2018). Uncertainties in fish taxonomy led to the exclusion of some unidentified individuals to avoid duplication errors, which decreased the amount of observational data available. Moreover, only one site was considered as a target for each species given the limited number of planning units and nine species with only one observation (Table 3.1; 3.2). Higher targets will only be achieved by selecting almost all *Gueltas* and some species will not be able to achieve them. Although, the selection of at least one site for each species is ensured, which does not mean that all species are only found in one *Guelta*. Additionally, the seven *Gueltas* where these species were observed also harbour threatened species, such as *C. suchus* and *Ptyodactylus rivapadiali*, the latter also being endemic to Mauritania, which emphasizes the protection of these locations.

3.4.2. Importance of water residency time and connectivity

By increasing the strength of NDWI in the connectivity penalty, additional *Gueltas* were selected, and most importantly, these *Gueltas* were allocated in areas that hold water for a longer period. For instance, scenario E hold the highest levels of water residency time, which promotes connectivity between *Gueltas* and decreases their isolation, as corridors between the selected areas along the hydrographic network have been related with dispersal and population connectivity (*e.g.* Velo-Antón *et al*., 2014; Murray *et al*., 2019). Moreover, *Gueltas* may offer refugia for species and populations during the dry periods (Vale *et al*., 2015). Therefore, incorporating a measure of water residency time along the year is important in spatial prioritisation exercises developed in seasonal ecosystems with wet-dry climatic cycles (Hermoso *et al*., 2012b).

There was an inverse relationship between the number of *Gueltas* and sub-catchments selected when considering the connections between *Gueltas* within their hydrological context. Despite only *Gueltas* held conservation features, when increasing the strength of *Guelta* – sub-catchment connections, the optimisation procedure favoured the selection of neighbouring upstream sub-catchments and not an increase in the number of *Gueltas* selected. By selecting upstream areas of *Gueltas*, the corridors between local biodiversity hotspots are being ensured for conservation prioritisation, potentially decreasing the isolation-related threats in those areas. Moreover, the downstream propagation of threats into *Gueltas* is minimised throughout the protection of upstream location. When considering the *Gueltas* and their respective corridors and upstream areas for protection, an increase of connectivity was observed, which likely beneficiated the mountain isolated populations. Multiple studies have shown the importance of strong connectivity in a protected area network (*e.g.* Dehaghi *et al*., 2018; Zacarias & Loyola, 2018). Therefore, the protection of terrestrial land surrounding *Gueltas* is critical for the persistence of non-strictly aquatic species, for instance during juvenile dispersal events (Semlitsch and Bodie, 2003). Although from scenario F to H the amount of planning units selected was almost identical, the connectivity value increased substantially. Although it adds a great trade-off, because more locations are selected as priority for conservation (Fig. 3.7).

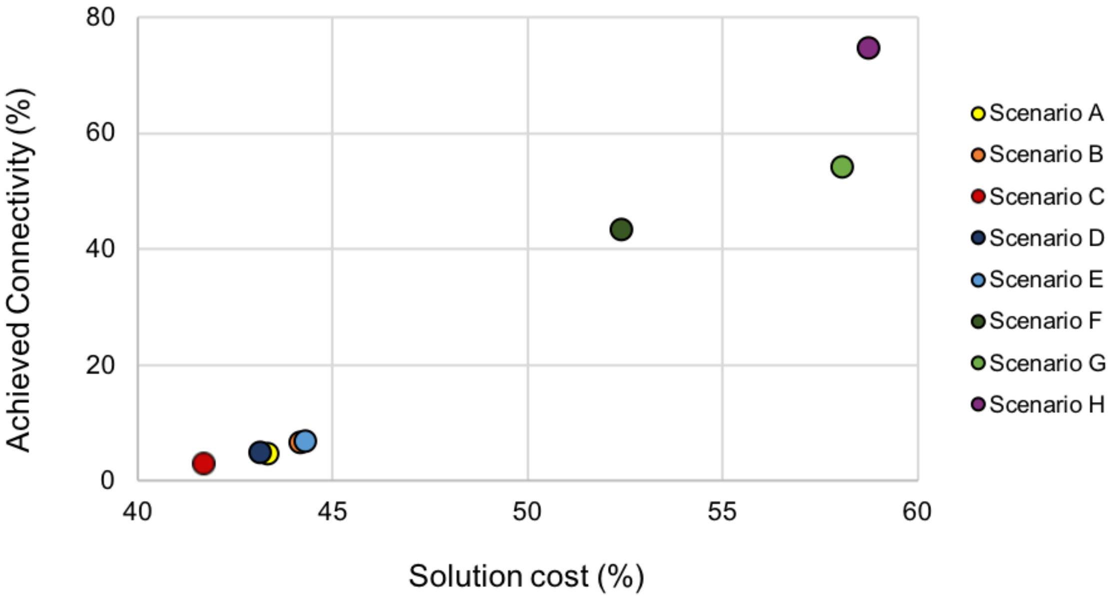


Figure 3.7 | Trade-off between the connectivity achieved in all scenario solutions, calculated in equation 4 and the associated cost retrieved from the connections selected in each solution.

3.4.3. Implications for local conservation

Seven *Gueltas* were selected as priority for conservation in every scenario (Fig. 3.8) and are essential to achieve the conservation targets as they harbour species not found in any other *Guelta*. From these seven *Gueltas*, the ones selected in Assaba mountain were previously considered priority for conservation (Vale *et al*., 2015), but *Guelta* Thor was here identified as priority for the first time. The approach considered here took into account complementarity and connectivity between selected sites, opposed to previous studies based only in species richness (Vale *et al*., 2015). Therefore, *Guelta* Thor was always selected as priority area, harbour unique species and occurs outside of mountain areas, which can be important for species dispersal. No *Gueltas* were selected in Afollé mountain in all scenarios tested, although Vale *et al*. (2015) identified two *Gueltas* priority for conservation in this region. This might suggest that even though they harbour endemic species, these species are also distributed in Tagant and Assaba mountains, and thus they were discarded from the solution to minimise its cost. Three *Gueltas* in Tagant mountain that were selected in more than 50% of the scenarios (Matmâta, Tartêga and Tartêga, upstream of; Fig. 3.1A) have been identified with ecotourism potential (Santarém *et al*., 2018). Ecotourism can help allocating investments for wildlife conservation in this region and ecotourists can take advantage of the complex topography and habitat heterogeneity surrounding these *Gueltas* (Santarém *et al*., 2018). The substantially increase in the number of *Gueltas* selected in Djouk valley in Scenario E is important to considered as it is located between Tagant and Assaba mountains. The

Djouk valley is important for species persistence during arid periods (Velo-Antón *et al.*, 2014; Gonçalves *et al.*, 2018), since it is a local ecological barrier and a contact zone, for instance responsible for the delimitation of four lineages of Boulenger's agama (*Agama boulengeri*), and considered a diversity hotspot for this species and others with similar climatic requirements (Gonçalves *et al.*, 2018). Also, in the African Groove-crowned frog (*Hoplobatrachus occipitalis*), the Djouk valley was responsible for the differentiation of this species in two lineages, one associated with highland and the other with lowlands, and for high genetic diversity, as the lowland lineage was found to be polyploid (Gonçalves and Brito, 2019). Therefore, this valley should be considered for conservation as it retains high levels of water during the year, promoting connectivity and species diversity.

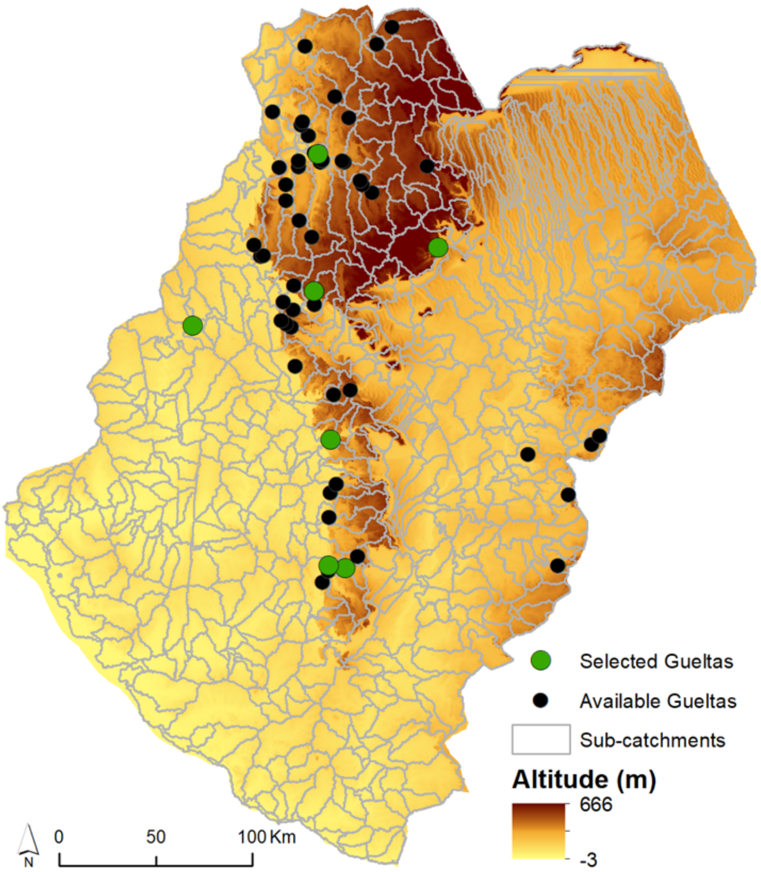


Figure 3.8 | Seven *Gueltas* selected in all scenarios with a selection frequency of 100% (green) in relation to the total 59 *Gueltas* in the analysis (black).

When incorporating connectivity between *Gueltas* and sub-catchments, several *Gueltas* from the Tagant mountain were selected for the first time, in comparison to previous scenarios. Considering the upstream connections with the sub-catchments, the optimisation procedure ensured that the whole hydrologic area important for conservation was included. Initially, in scenario F, sub-catchments selected were the ones incorporating selected *Gueltas*, but when increasing the strength of *Guelta* – sub-catchment connections, the area expanded beyond the Djouk valley to connect the northern *Gueltas* in Assaba and also *Guelta* Thor. The hydrologic corridors between mountains are important for species dispersal, maintenance of metacommunities, minimising the risk of inbreeding due to isolation, promoting their long-term survival and persistence (Frankham, 2005; Tonkin *et al*., 2018). For instance, the populations of *C. suchus* are spatially structured across southern Mauritanian mountains, however, some admixture was found in Assaba mountain between populations from Tagant and also from Afollé, which suggests inter-mountain dispersal (Velo-Antón *et al*., 2014). Moreover, *Guelta* Thor can work as stepping stone for *C. suchus* dispersal from Tagant to the Senegal River during the wet season. The protection of these areas can help maintaining natural processes and viable populations, as well as mitigating the effects of isolation-related threats. They can also benefit numerous species that use wetlands as resting and feeding areas, such as migratory birds (Morel and Morel, 1992). The southern mountains of Mauritania have already been highlighted as a diversity hotspot and climatic refugia for species with specific climatic requirements (Gonçalves *et al*., 2018), therefore their protection should be considered.

Lac Gabou Ramsar site was designated for the conservation of wetlands and mainly for the protection of aquatic migratory birds (Tellería, 2007). Our results show a high number of sub-catchments selected within the Lac Gabou Ramsar site (Fig. 3.5iii). From scenario F to H there was an overlap of 75%, 53% and 52% with the area corresponding to the Lac Gabou Ramsar site, respectively, which indicates a great importance of the area also for fishes, amphibians and aquatic reptiles. Given its importance for freshwater conservation, a management plan should be implemented to guarantee the protection of fauna and flora communities in this wetland of the Sahel.

3.5. Conclusions

The methodology here presented is scalable and replicable to other temporary systems not strictly freshwater ecosystems and to regions characterised by wet-dry cycles with permanent wetlands connected during the wet season. This is the case of other wetlands across the Sahara-Sahel mountains, for instance in the Ennedi in Chad where *C. suchus* persists in *Gueltas* probably also connected through the hydrographic network (Brito *et al*., 2011). Additionally, the methodology could be extended to Adrar Atar mountain in Mauritania where local wetlands could also benefit from protection (Trape, 2009). These mountains could potential work as biodiversity refugia under climate change scenarios (Brito *et al*., 2014), which can affect species persistence and promote alterations in river flow patterns and their connectivity, intensifying events of droughts and floods (Tonkin *et al*., 2018). Additionally, almost half of known African fishes species are vulnerable to climate change (Nyboer *et al*., 2019), therefore the definition of priority areas for conservation considering freshwater connectivity will allow the persistence of species, increase the resilience of wetlands and provide appropriate corridors for species dispersal to different suitable habitats in response to future changing conditions (Groves *et al*., 2012; Bond *et al*., 2014; Murphy *et al*., 2015). The approach presented here has implications for the future definition of local protected areas or the implementation of a management plan for the Lac Gabou Ramsar site.

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Chapter IV: Final discussion

Landscape connectivity is the milestone concerning species persistence and ecosystem resilience (Taylor *et al.*, 2006), especially in arid regions vulnerable to anthropogenic activities, such as the Sahel (Hutchinson *et al.*, 2018). Hence, this thesis presented two case studies that addressed the importance of preserve connectivity to achieve long-term persistence and guarantee effective conservation measures. Firstly, different negative impacts to biodiversity were shown due to strong land-cover and land-use changes imposed by a barrier effect that disrupts connectivity in an international level. Secondly, a new framework was tested to highlight connectivity at local level in freshwater ecosystems, that took into account the need to consider the complete hydrographic network in the incorporation of suitable corridors for species dispersal. The results provided by these case studies indicated the necessity to consider connectivity when addressing conservation measures in arid regions.

4.1. Major findings

Manuscript I demonstrated that an intensive afforestation program in a previously open area can present a threat to overlooked biodiversity adapted to drylands. Although, tree plantation is often perceived as a measure to mitigate the effects of climate change and to increase biodiversity (Wade *et al.*, 2018; Bastin *et al.*, 2019), the location where the initiatives take place should be taken into account. Massive land-cover and land-use change due to afforestation can have negative impacts on biodiversity in Sahel (Hawlena and Bouskila, 2006). Different biomes harbour different biodiversity that co-evolved to survive in a particular ecosystem. Open areas, such as the ones found in Sahel, are facing a new threat – tree planting, as many of dryland biodiversity is not adapted to dense tree cover, acting as a barrier effect (Veldman *et al.*, 2015a, 2015b). Calls for tree planting initiatives to ensure food security, to mitigate the effects of climate change and to stop desertification should be taken carefully, together with a strong scientific background. Otherwise, a healthy dryland ecosystem can be replaced by a dense forest cover, pastoral and agricultural fields, leading to the loss of species and evolutionary history (Veldman *et al.*, 2015a). Therefore, restoration of degraded habitat in the Sahel should be promoted to increase its resilience over its transformation into a new ecosystem (Bastin *et al.*, 2019; Goffner *et al.*, 2019).

Incorporating the complete hydrographic network in the spatial planning led to the prioritisation of local biodiversity hotspots needed to achieve the conservation targets, as well as the corridors that will allow species dispersal, to maintain a metapopulation dynamics, mitigating the effects of species isolation. Different works have shown the importance of addressing connectivity when defining priority areas for conservation, taking into account climate change and sustained human development (*e.g.,* Prieto-Torres *et al*., 2018; Zacarias and Loyola, 2018). A predicted increase in the African human population and a decrease in precipitation (Druyan, 2011; Hutchinson *et al*., 2018) can lead to an increase in the construction of water reservoirs, such as large dams, which can alter the river flow and the capacity of species to move to different areas. The methodological approach of Manuscript II can be easily applied as a conservation tool by incorporating different biological aspects, such as genetic information. For instance, gene flow can inform about landscape genetics, giving information on which species move across the study area and their dispersal capacity, and inform about the populations with less genetic diversity, which are particularly vulnerable to local extinction (Spice *et al*., 2019). The methodology presented can have a positive influence in future spatial prioritisation studies in arid freshwater ecosystems, where connectivity through the hydrographic network is essential to maintain the community dynamics.

The results retrieved from these two manuscripts should be taken into account when designing wildlife conservation measures in arid regions. The information collected should reach policymakers and stakeholders to proper guide and advice towards a suitable implementation of effective measures to protect biodiversity. These two studies provide useful information in conservation planning for overlooked biodiversity in the African Sahel. The synergies between priority areas for conservation and connectivity will allow the long-term persistence of the species in the region, mitigating negative effects of isolation and strong habitat change in this arid region.

4.2. Future work

The work presented in the two manuscripts should continue in order to improve the results addressing connectivity in arid regions and to give a solid basis to advice policymakers in conservation planning. Future projections accounting for climate change could improve the work described in Manuscript I and highlight the barrier effect of the Wall. Due to the high uncertainty of predicting land-cover and land-use change to the future (Alexander *et al*., 2017), the effects of the Wall as a barrier for arid adapted species cannot be projected. By combining species distributions models and future climate projections it is possible to predict where the species will likely be distributed in the future and which pathways they will use to move across the landscape. Species currently distributed north of the Wall, as the region warms (Loarie *et al*., 2009), will likely disperse southwards or to mountain areas, where the climate will be cooler (Walther *et al.*, 2002). For instance, Sahara endemic species, which comprises xeric species adapted to open areas, will find the Wall as unsuitable habitat, therefore they will be probably confined to its northern area, unless north-south corridors ensuring their dispersal are created. Without considering the increase of anthropogenic activities in the region, climate change combined with the barrier effect created by the Wall will likely lead these species towards extinction. Unlike the work developed in Manuscript I that considered the immediate effects of the Wall in local species, future work should take into account the ability of species to disperse within the region. Moreover, it should consider species currently distributed within the Wall intervention zone (Table S1) and all species present in North Africa, that in the future can be also affected. As this is a long-term initiative, this work should also consider the long-term effects, contributing to a much stronger scientific support to advice policymakers in the implementation.

Regarding Manuscript II, Mauritania still have not achieved the goal of Aichi Target 11 and the percentage of protected land connected have been stable for the past decade (Saura *et al.*, 2019). Therefore, the next step towards biodiversity conservation in Mauritania should be the identification of areas suitable for the establishment of a micro-reserve network properly connected, while promoting resilience to climate change. Assuming that taxa inhabiting *Gueltas* constitute a metapopulation system with complex spatial and temporal dynamics strongly related to dispersal abilities, a network of protected areas could be used to promote biodiversity conservation and sustainable community development. To achieve this goal, field surveys should be developed in wetlands for collecting species distribution data, tissue and water samples, the latter with environmental metagenomics (eDNA) techniques, threat factors and socioeconomic indicators. Biodiversity distribution patters should be analysed, taking into account populations genetic structure, migration rates and levels of gene flow, using microsatellites or whole genome re-sequencing when possible. Ecological niche-based models of species and communities' distribution should be used to understand how landscape connectivity will be affected under global change scenarios and to identify corridors that ensure representation and persistence of conservation features under alternative scenarios of climate change. Moreover, incorporating social data into spatial prioritisation studies can inform about the true value of the land and access conservation opportunity based on public perception, increasing the effectiveness of the reserve design (Brown *et al.*, 2019). Future work should integrate multiple research fields, dealing with different hierarchical levels of biodiversity, providing new insights into connectivity among *Gueltas* in arid ecosystems, based on combined genetic, spatial and ecological evidence, which would push forward the current knowledge obtain from manuscript II.

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Chapter V: Appendices

5.1. Supplementary material – Manuscript II

Table S1 | List of species and their characteristics analysed under the present study. Amphibians, reptiles, birds and mammals whose distribution are within the Wall intervention zone, their IUCN conservation status (IUCN, 2019), endemism status (SHR - Sahara, SHL - Sahel, WAL - Wall, and SAV - Savannah), and the percentage of the African range included in the Wall intervention zone. Species are ordered by the percentage of its African range affected and by the level of threatened category. Species in bold represent the ones included in a threatened category.

Class	Taxa	Conservation status	Endemism
	100% of African range affected		
Mammalia	***Capra walie***	**EN**	WAL
Amphibia	*Ptychadena mascareniensis*	LC	WAL
Mammalia	*Crocidura fumosa*	LC	WAL
Mammalia	*Taterillus tranieri*	LC	WAL
Reptilia	*Agama cornii*	DD	WAL
Reptilia	*Cynisca senegalensis*	DD	WAL
Mammalia	*Eptesicus platyops*	DD	WAL
Mammalia	*Gerbillus bottai*	DD	WAL
Mammalia	*Gerbillus muriculus*	DD	WAL
Mammalia	*Gerbillus principulus*	DD	WAL
Mammalia	*Gerbillus stigmonyx*	DD	WAL
Mammalia	*Kerivoula eriophora*	DD	WAL
Mammalia	*Neoromicia helios*	DD	WAL
Mammalia	*Pipistrellus aero*	DD	WAL
	75 – 99%		
Mammalia	***Nanger dama***	**CR**	WAL
Mammalia	***Eudorcas tilonura***	**EN**	WAL
Reptilia	*Elapsoidea trapei*	LC	WAL
Aves	*Passer luteus*	LC	WAL
Aves	*Prinia fluviatilis*	LC	WAL
Aves	*Spiloptila clamans*	LC	WAL
Aves	*Sylvia hortensis*	LC	WAL
Mammalia	*Crocidura cinderella*	LC	WAL
Mammalia	*Eptesicus floweri*	LC	WAL
Mammalia	*Gerbillus rupicola*	LC	WAL
Mammalia	*Taterillus petteri*	LC	WAL
Mammalia	*Taterillus pygargus*	LC	WAL

Mammalia	*Gerbillus nancillus*	DD	WAL
	50 – 74%		
Aves	***Vanellus gregarius***	**CR**	
Mammalia	***Eudorcas rufifrons***	**VU**	SHL
Aves	*Ardeotis arabs*	NT	
Aves	*Neotis nuba*	NT	SHR
Reptilia	*Agama boueti*	LC	SHL
Reptilia	*Atractaspis microlepidota*	LC	
Reptilia	*Atractaspis micropholis*	LC	SAV
Reptilia	*Echis leucogaster*	LC	
Reptilia	*Tricheilostoma bicolor*	LC	
Aves	*Anthoscopus punctifrons*	LC	SHL
Aves	*Calandrella brachydactyla*	LC	
Aves	*Calidris alba*	LC	
Aves	*Caprimulgus aegyptius*	LC	
Aves	*Caprimulgus eximius*	LC	SHL
Aves	*Caprimulgus ruficollis*	LC	
Aves	*Cercotrichas podobe*	LC	
Aves	*Cyanecula svecica*	LC	
Aves	*Dendropicos elachus*	LC	SHL
Aves	*Emberiza caesia*	LC	
Aves	*Hedydipna metallica*	LC	
Aves	*Lamprotornis pulcher*	LC	SHL
Aves	*Lanius nubicus*	LC	
Aves	*Locustella naevia*	LC	
Aves	*Lophotis savilei*	LC	
Aves	*Mirafra javanica*	LC	
Aves	*Mirafra rufa*	LC	
Aves	*Monticola solitarius*	LC	
Aves	*Myrmecocichla aethiops*	LC	
Aves	*Oenanthe cypriaca*	LC	
Aves	*Oenanthe hispanica*	LC	
Aves	*Ortyxelos meiffrenii*	LC	
Aves	*Sylvia crassirostris*	LC	
Aves	*Sylvia curruca*	LC	
Aves	*Sylvia ruppeli*	LC	

Aves	*Sylvia subalpina*	LC	
Aves	*Trachyphonus margaritatus*	LC	
Aves	*Turdoides leucocephala*	LC	
Mammalia	*Crocidura lusitania*	LC	SHL
Mammalia	*Crocidura pasha*	LC	SHL
Mammalia	*Desmodilliscus braueri*	LC	SHL
Mammalia	*Gerbillus campestris*	LC	
Mammalia	*Gerbillus rosalinda*	LC	SHL
Mammalia	*Mus haussa*	LC	
Mammalia	*Steatomys cuppedius*	LC	SHL
Mammalia	*Taterillus arenarius*	LC	SHL
Mammalia	*Taterillus lacustris*	LC	SHL
Mammalia	*Vulpes pallida*	LC	SHL
Reptilia	*Scincopus fasciatus*	DD	SHL
Mammalia	*Felovia vae*	DD	SHL
	25 – 49%		
Aves	***Gyps rueppelli***	**CR**	
Mammalia	***Addax nasomaculatus***	**CR**	SHR
Mammalia	***Equus africanus***	**CR**	
Aves	***Balearica pavonina***	**VU**	
Aves	***Crithagra ankoberensis***	**VU**	
Aves	***Streptopelia turtur***	**VU**	
Mammalia	***Nanger soemmerringii***	**VU**	
Mammalia	***Tragelaphus derbianus***	**VU**	SAV
Mammalia	*Ceratotherium simum*	NT	
Mammalia	*Papio papio*	NT	
Amphibia	*Hyperolius spatzi*	LC	
Amphibia	*Sclerophys pentoni*	LC	
Amphibia	*Sclerophys xeros*	LC	
Amphibia	*Tomopterna cryptotis*	LC	
Reptilia	*Acanthodactylus senegalensis*	LC	SHR
Reptilia	*Agama boulengeri*	LC	SHR
Reptilia	*Agama spinosa*	LC	
Reptilia	*Bamanophis dorri*	LC	SAV
Reptilia	*Chalcides delislei*	LC	SHL
Reptilia	*Chamaeleo africanus*	LC	

Reptilia	*Cynisca feae*	LC	
Reptilia	*Dasypeltis latericia*	LC	SAV
Reptilia	*Hemidactylus yerburyi*	LC	
Reptilia	*Naja senegalensis*	LC	SAV
Reptilia	*Tarentola parvicarinata*	LC	
Reptilia	*Tarentola senegambiae*	LC	
Aves	*Accipiter brevipes*	LC	
Aves	*Amadina fasciata*	LC	
Aves	*Anas crecca*	LC	
Aves	*Anas platyrhynchos*	LC	
Aves	*Anthropoides virgo*	LC	
Aves	*Anthus campestris*	LC	
Aves	*Argya fulva*	LC	SHR
Aves	*Asio flammeus*	LC	
Aves	*Batis senegalensis*	LC	
Aves	*Bubalornis albirostris*	LC	
Aves	*Bubo cinerascens*	LC	
Aves	*Buteo rufinus*	LC	
Aves	*Caprimulgus climacurus*	LC	
Aves	*Carpospiza brachydactyla*	LC	
Aves	*Cercotrichas galactotes*	LC	
Aves	*Charadrius alexandrinus*	LC	
Aves	*Chelictinia riocourii*	LC	
Aves	*Ciconia abdimii*	LC	
Aves	*Cinnyris pulchellus*	LC	
Aves	*Circaetus gallicus*	LC	
Aves	*Coracias abyssinicus*	LC	
Aves	*Corvus rhipidurus*	LC	
Aves	*Corvus ruficollis*	LC	
Aves	*Coturnix coturnix*	LC	
Aves	*Crithagra leucopygia*	LC	
Aves	*Crithagra xanthopygia*	LC	
Aves	*Cursorius cursor*	LC	
Aves	*Dendropicos goertae*	LC	
Aves	*Dendropicos pyrrhogaster*	LC	SHL
Aves	*Emberiza goslingi*	LC	

Aves	*Emberiza striolata*	LC	
Aves	*Eremalauda dunni*	LC	
Aves	*Eremopterix nigriceps*	LC	
Aves	*Euodice cantans*	LC	
Aves	*Falco alopex*	LC	
Aves	*Galerida cristata*	LC	
Aves	*Gymnoris dentata*	LC	
Aves	*Gyps fulvus*	LC	
Aves	*Hedydipna platura*	LC	
Aves	*Hirundo aethiopica*	LC	
Aves	*Iduna opaca*	LC	
Aves	*Lagonosticta virata*	LC	SAV
Aves	*Lamprotornis caudatus*	LC	
Aves	*Lamprotornis iris*	LC	SHL
Aves	*Laniarius barbarus*	LC	
Aves	*Lanius excubitor*	LC	
Aves	*Lanius excubitoroides*	LC	
Aves	*Lanius phoenicuroides*	LC	
Aves	*Lybius vieilloti*	LC	
Aves	*Lymnocryptes minimus*	LC	
Aves	*Melanocorypha bimaculata*	LC	
Aves	*Merops albicollis*	LC	
Aves	*Merops nubicus*	LC	
Aves	*Merops viridissimus*	LC	
Aves	*Mirafra cordofanica*	LC	SHR
Aves	*Oenanthe heuglinii*	LC	
Aves	*Oenanthe isabellina*	LC	
Aves	*Oenanthe melanura*	LC	
Aves	*Oenanthe oenanthe*	LC	
Aves	*Oenanthe seebohmi*	LC	
Aves	*Onychognathus albirostris*	LC	
Aves	*Passer euchlorus*	LC	
Aves	*Phylloscopus collybita*	LC	
Aves	*Phylloscopus ibericus*	LC	SAV
Aves	*Pinarocorys erythropygia*	LC	
Aves	*Platalea leucorodia*	LC	

Aves	*Ploceus badius*	LC	
Aves	*Ploceus galbula*	LC	
Aves	*Ploceus luteolus*	LC	
Aves	*Ploceus taeniopterus*	LC	
Aves	*Prinia gracilis*	LC	
Aves	*Psittacula krameri*	LC	
Aves	*Pternistis bicalcaratus*	LC	
Aves	*Pternistis clappertoni*	LC	
Aves	*Pternistis erckelii*	LC	
Aves	*Pterocles exustus*	LC	
Aves	*Pterocles lichtensteinii*	LC	
Aves	*Pterocles quadricinctus*	LC	
Aves	*Ptilopsis leucotis*	LC	
Aves	*Ptyonoprogne rupestris*	LC	
Aves	*Rhinopomastus aterrimus*	LC	
Aves	*Spatula clypeata*	LC	
Aves	*Sporopipes frontalis*	LC	
Aves	*Streptopelia decipiens*	LC	
Aves	*Streptopelia roseogrisea*	LC	
Aves	*Streptopelia vinacea*	LC	
Aves	*Struthio camelus*	LC	
Aves	*Sylvia cantillans*	LC	
Aves	*Sylvia mystacea*	LC	
Aves	*Sylvia nisoria*	LC	
Aves	*Tadorna ferruginea*	LC	
Aves	*Turtur abyssinicus*	LC	
Aves	*Urocolius macrourus*	LC	
Aves	*Vanellus leucurus*	LC	
Aves	*Vanellus spinosus*	LC	
Aves	*Vanellus tectus*	LC	
Aves	*Vidua orientalis*	LC	
Mammalia	*Acomys airensis*	LC	SHL
Mammalia	*Acomys cineraceus*	LC	
Mammalia	*Acomys johannis*	LC	SAV
Mammalia	*Acomys mullah*	LC	
Mammalia	*Arvicanthis abyssinicus*	LC	

Mammalia	*Arvicanthis niloticus*	LC	
Mammalia	*Asellia patrizii*	LC	
Mammalia	*Chaerephon major*	LC	
Mammalia	*Chlorocebus aethiops*	LC	
Mammalia	*Crocidura fulvastra*	LC	
Mammalia	*Crocidura nanilla*	LC	
Mammalia	*Crocidura smithii*	LC	
Mammalia	*Crocidura somalica*	LC	
Mammalia	*Crocidura viaria*	LC	
Mammalia	*Crocidura voi*	LC	
Mammalia	*Erythrocebus patas*	LC	
Mammalia	*Genetta abyssinica*	LC	
Mammalia	*Gerbilliscus gambiana*	LC	SAV
Mammalia	*Gerbillus henleyi*	LC	
Mammalia	*Gerbillus pyramidum*	LC	SHL
Mammalia	*Ictonyx libycus*	LC	SHR
Mammalia	*Mastomys awashensis*	LC	
Mammalia	*Mastomys huberti*	LC	
Mammalia	*Mastomys kollmannspergeri*	LC	SHL
Mammalia	*Rhinopoma microphyllum*	LC	
Mammalia	*Taphozous nudiventris*	LC	
Mammalia	*Taterillus gracilis*	LC	
Mammalia	*Theropithecus gelada*	LC	
Mammalia	*Xerus erythropus*	LC	
Reptilia	*Echis jogeri*	DD	SAV
Reptilia	*Letheobia erythraea*	DD	
Reptilia	*Trapelus schmitzi*	DD	SHR
Reptilia	*Tropiocolotes nubicus*	DD	SHR
Mammalia	*Grammomys aridulus*	DD	SHL
Mammalia	*Plecotus balensis*	DD	
Reptilia	*Myriopholis boueti*	NE	SHL
	< 25%		
Reptilia	***Cyclanorbis elegans***	**CR**	
Reptilia	***Eretmochelys imbricata***	**CR**	
Reptilia	***Mecistops cataphractus***	**CR**	
Aves	***Gyps africanus***	**CR**	

Aves	***Necrosyrtes monachus***	**CR**	
Aves	***Numenius tenuirostris***	**CR**	
Aves	***Trigonoceps occipitalis***	**CR**	
Mammalia	***Diceros bicornis***	**CR**	
Amphibia	***Xenopus largeni***	**EN**	
Reptilia	***Chelonia mydas***	**EN**	
Reptilia	***Philochortus zolii***	**EN**	SHR
Aves	***Aquila nipalensis***	**EN**	
Aves	***Falco cherrug***	**EN**	
Aves	***Neophron percnopterus***	**EN**	
Aves	***Torgos tracheliotos***	**EN**	
Mammalia	***Canis simensis***	**EN**	
Mammalia	***Gazella leptoceros***	**EN**	SHR
Mammalia	***Lycaon pictus***	**EN**	
Mammalia	***Oryx beisa***	**EN**	
Mammalia	***Pan troglodytes***	**EN**	
Mammalia	***Piliocolobus temminckii***	**EN**	
Reptilia	***Caretta caretta***	**VU**	
Reptilia	***Cyclanorbis senegalensis***	**VU**	
Reptilia	***Dermochelys coriacea***	**VU**	
Reptilia	***Lepidochelys olivacea***	**VU**	
Reptilia	***Osteolaemus tetraspis***	**VU**	
Reptilia	***Trionyx triunguis***	**VU**	
Aves	***Acrocephalus paludicola***	**VU**	
Aves	***Aquila heliaca***	**VU**	
Aves	***Aquila rapax***	**VU**	
Aves	***Aythya ferina***	**VU**	
Aves	***Bucorvus abyssinicus***	**VU**	
Aves	***Circaetus beaudouini***	**VU**	
Aves	***Clanga clanga***	**VU**	
Aves	***Cyanochen cyanoptera***	**VU**	
Aves	***Falco concolor***	**VU**	
Aves	***Marmaronetta angustirostris***	**VU**	
Aves	***Oxyura maccoa***	**VU**	
Aves	***Polemaetus bellicosus***	**VU**	
Aves	***Sagittarius serpentarius***	**VU**	

Aves	***Struthio molybdophanes***	**VU**	
Mammalia	***Acinonyx jubatus***	**VU**	
Mammalia	***Ammotragus lervia***	**VU**	SHR
Mammalia	***Capra nubiana***	**VU**	
Mammalia	***Dorcatragus megalotis***	**VU**	
Mammalia	***Gazella dorcas***	**VU**	SHR
Mammalia	***Giraffa camelopardalis***	**VU**	SAV
Mammalia	***Hippopotamus amphibius***	**VU**	
Mammalia	***Loxodonta africana***	**VU**	
Mammalia	***Myotis scotti***	**VU**	
Mammalia	***Oryx beisa ssp. beisa***	**VU**	
Mammalia	***Otomops harrisoni***	**VU**	
Mammalia	***Panthera leo***	**VU**	
Mammalia	***Panthera pardus***	**VU**	
Mammalia	***Rhinolophus guineensis***	**VU**	
Mammalia	***Smutsia gigantea***	**VU**	
Mammalia	***Smutsia temminckii***	**VU**	
Aves	*Anthus pratensis*	NT	
Aves	*Aythya nyroca*	NT	
Aves	*Buteo oreophilus*	NT	
Aves	*Calidris ferruginea*	NT	
Aves	*Circus macrourus*	NT	
Aves	*Emberiza cineracea*	NT	
Aves	*Falco vespertinus*	NT	
Aves	*Gallinago media*	NT	
Aves	*Glareola nordmanni*	NT	
Aves	*Gypaetus barbatus*	NT	
Aves	*Limosa limosa*	NT	
Aves	*Macronyx flavicollis*	NT	
Aves	*Neotis denhami*	NT	
Aves	*Numenius arquata*	NT	
Aves	*Phoeniconaias minor*	NT	
Aves	*Pternistis harwoodi*	NT	
Aves	*Rougetius rougetii*	NT	
Aves	*Rynchops flavirostris*	NT	
Aves	*Scleroptila psilolaema*	NT	

Aves	*Stephanoaetus coronatus*	NT	
Aves	*Terathopius ecaudatus*	NT	
Mammalia	*Aonyx capensis*	NT	
Mammalia	*Eidolon helvum*	NT	
Mammalia	*Felis margarita*	NT	
Mammalia	*Hipposideros jonesi*	NT	
Mammalia	*Hyaena hyaena*	NT	
Mammalia	*Hydrictis maculicollis*	NT	
Mammalia	*Litocranius Walleri*	NT	
Mammalia	*Tragelaphus imberbis*	NT	
Amphibia	*Afrixalus vittiger*	LC	
Amphibia	*Afrixalus weidholzi*	LC	
Amphibia	*Amietia nutti*	LC	
Amphibia	*Amnirana galamensis*	LC	
Amphibia	*Conraua beccarii*	LC	
Amphibia	*Hemisus guineensis*	LC	
Amphibia	*Hemisus marmoratus*	LC	
Amphibia	*Hildebrandtia ornata*	LC	
Amphibia	*Hoplobatrachus occipitalis*	LC	
Amphibia	*Hyperolius igbettensis*	LC	
Amphibia	*Hyperolius lamottei*	LC	
Amphibia	*Hyperolius nitidulus*	LC	
Amphibia	*Hyperolius viridiflavus*	LC	
Amphibia	*Kassina cassinoides*	LC	SAV
Amphibia	*Kassina fusca*	LC	SAV
Amphibia	*Kassina senegalensis*	LC	
Amphibia	*Kassina somalica*	LC	
Amphibia	*Leptopelis bufonides*	LC	SAV
Amphibia	*Leptopelis viridis*	LC	
Amphibia	*Phrynobatrachus calcaratus*	LC	
Amphibia	*Phrynobatrachus francisci*	LC	
Amphibia	*Phrynobatrachus gutturosus*	LC	
Amphibia	*Phrynobatrachus latifrons*	LC	
Amphibia	*Phrynobatrachus natalensis*	LC	
Amphibia	*Phrynobatrachus perpalmatus*	LC	
Amphibia	*Phrynomantis microps*	LC	

Amphibia	*Ptychadena anchietae*	LC	
Amphibia	*Ptychadena bibroni*	LC	
Amphibia	*Ptychadena neumanni*	LC	
Amphibia	*Ptychadena nilotica*	LC	
Amphibia	*Ptychadena oxyrhynchus*	LC	
Amphibia	*Ptychadena porosissima*	LC	
Amphibia	*Ptychadena pumilio*	LC	
Amphibia	*Ptychadena schillukorum*	LC	
Amphibia	*Ptychadena tellinii*	LC	
Amphibia	*Ptychadena tournieri*	LC	
Amphibia	*Ptychadena trinodis*	LC	
Amphibia	*Pyxicephalus edulis*	LC	
Amphibia	*Sclerophys asmarae*	LC	
Amphibia	*Sclerophys dodsoni*	LC	
Amphibia	*Sclerophys garmani*	LC	
Amphibia	*Sclerophys maculata*	LC	
Amphibia	*Sclerophys regularis*	LC	
Amphibia	*Tomopterna kachowskii*	LC	
Amphibia	*Xenopus clivii*	LC	
Amphibia	*Xenopus fischbergi*	LC	
Amphibia	*Xenopus muelleri*	LC	
Amphibia	*Xenopus tropicalis*	LC	
Reptilia	*Acanthocercus annectens*	LC	
Reptilia	*Acanthodactylus aureus*	LC	SHR
Reptilia	*Acanthodactylus dumerili*	LC	SHR
Reptilia	*Afronatrix anoscopus*	LC	
Reptilia	*Agama boensis*	LC	
Reptilia	*Agama tassiliensis*	LC	SHR
Reptilia	*Agama weidholzi*	LC	
Reptilia	*Atractaspis dahomeyensis*	LC	
Reptilia	*Atractaspis irregularis*	LC	
Reptilia	*Cerastes vipera*	LC	
Reptilia	*Chalcides pulchellus*	LC	
Reptilia	*Chalcides sphenopsiformis*	LC	SHR
Reptilia	*Chalcides thierryi*	LC	SAV
Reptilia	*Chamaeleo calcaricarensis*	LC	

Reptilia	*Chamaeleo gracilis*	LC	
Reptilia	*Chamaeleo laevigatus*	LC	
Reptilia	*Chamaeleo senegalensis*	LC	
Reptilia	*Crocodylus niloticus*	LC	
Reptilia	*Dasypeltis fasciata*	LC	
Reptilia	*Dasypeltis scabra*	LC	
Reptilia	*Dendroaspis polylepis*	LC	
Reptilia	*Dendroaspis viridis*	LC	
Reptilia	*Duberria lutrix*	LC	
Reptilia	*Echis pyramidum*	LC	
Reptilia	*Gonionotophis grantii*	LC	
Reptilia	*Hemirhagerrhis hildebrandtii*	LC	
Reptilia	*Hemitheconyx caudicinctus*	LC	
Reptilia	*Hydrophis platurus*	LC	
Reptilia	*Lycophidion albomaculatum*	LC	
Reptilia	*Lycophidion semicinctum*	LC	
Reptilia	*Lythorhynchus diadema*	LC	
Reptilia	*Mesalina olivieri*	LC	
Reptilia	*Mesalina pasteuri*	LC	SHR
Reptilia	*Mochlus mocquardi*	LC	SAV
Reptilia	*Myriopholis albiventer*	LC	
Reptilia	*Myriopholis rouxestevae*	LC	SAV
Reptilia	*Naja katiensis*	LC	SAV
Reptilia	*Natriciteres olivacea*	LC	
Reptilia	*Panaspis nimbaensis*	LC	
Reptilia	*Philothamnus irregularis*	LC	
Reptilia	*Platyceps florulentus*	LC	
Reptilia	*Pristurus rupestris*	LC	
Reptilia	*Python regius*	LC	
Reptilia	*Rhinoleptus koniagui*	LC	
Reptilia	*Scincus albifasciatus*	LC	SHR
Reptilia	*Telescopus variegatus*	LC	
Reptilia	*Trapelus boehmei*	LC	SHR
Reptilia	*Trioceros affinis*	LC	
Reptilia	*Tropiocolotes tripolitanus*	LC	SHR
Reptilia	*Uromastyx ocellata*	LC	

Reptilia	*Varanus exanthematicus*	LC
Aves	*Accipiter badius*	LC
Aves	*Accipiter erythropus*	LC
Aves	*Accipiter melanoleucus*	LC
Aves	*Accipiter minullus*	LC
Aves	*Accipiter nisus*	LC
Aves	*Accipiter ovampensis*	LC
Aves	*Accipiter rufiventris*	LC
Aves	*Accipiter toussenelii*	LC
Aves	*Acrocephalus arundinaceus*	LC
Aves	*Acrocephalus gracilirostris*	LC
Aves	*Acrocephalus griseldis*	LC
Aves	*Acrocephalus palustris*	LC
Aves	*Acrocephalus rufescens*	LC
Aves	*Acrocephalus schoenobaenus*	LC
Aves	*Acrocephalus scirpaceus*	LC
Aves	*Acrocephalus stentoreus*	LC
Aves	*Actitis hypoleucos*	LC
Aves	*Actophilornis africanus*	LC
Aves	*Agapornis pullarius*	LC
Aves	*Agapornis taranta*	LC
Aves	*Agricola pallidus*	LC
Aves	*Alaemon alaudipes*	LC
Aves	*Alcedo quadribrachys*	LC
Aves	*Alcedo semitorquata*	LC
Aves	*Alopochen aegyptiaca*	LC
Aves	*Amandava subflava*	LC
Aves	*Amaurornis marginalis*	LC
Aves	*Ammomanes cinctura*	LC
Aves	*Ammomanes deserti*	LC
Aves	*Anaplectes leuconotos*	LC
Aves	*Anas acuta*	LC
Aves	*Anas capensis*	LC
Aves	*Anas erythrorhyncha*	LC
Aves	*Anas sparsa*	LC
Aves	*Anas undulata*	LC

Aves	*Anastomus lamelligerus*	LC	
Aves	*Anhinga rufa*	LC	
Aves	*Anomalospiza imberbis*	LC	
Aves	*Anthoscopus musculus*	LC	
Aves	*Anthoscopus parvulus*	LC	SAV
Aves	*Anthreptes longuemarei*	LC	
Aves	*Anthreptes orientalis*	LC	
Aves	*Anthus cervinus*	LC	
Aves	*Anthus cinnamomeus*	LC	
Aves	*Anthus leucophrys*	LC	
Aves	*Anthus similis*	LC	
Aves	*Anthus trivialis*	LC	
Aves	*Apalis flavida*	LC	
Aves	*Apaloderma narina*	LC	
Aves	*Aplopelia larvata*	LC	
Aves	*Apus affinis*	LC	
Aves	*Apus apus*	LC	
Aves	*Apus caffer*	LC	
Aves	*Apus horus*	LC	
Aves	*Apus niansae*	LC	
Aves	*Apus pallidus*	LC	
Aves	*Aquila chrysaetos*	LC	
Aves	*Aquila fasciata*	LC	
Aves	*Aquila spilogaster*	LC	
Aves	*Aquila verreauxii*	LC	
Aves	*Ardea alba*	LC	
Aves	*Ardea brachyrhyncha*	LC	
Aves	*Ardea cinerea*	LC	
Aves	*Ardea goliath*	LC	
Aves	*Ardea melanocephala*	LC	
Aves	*Ardea purpurea*	LC	
Aves	*Ardeola ralloides*	LC	
Aves	*Argya rubiginosa*	LC	
Aves	*Asio abyssinicus*	LC	
Aves	*Asio capensis*	LC	
Aves	*Athene noctua*	LC	

Aves	*Atimastillas flavicollis*	LC
Aves	*Aviceda cuculoides*	LC
Aves	*Aythya fuligula*	LC
Aves	*Batis erlangeri*	LC
Aves	*Batis orientalis*	LC
Aves	*Bocagia minuta*	LC
Aves	*Bostrychia carunculata*	LC
Aves	*Bostrychia hagedash*	LC
Aves	*Botaurus stellaris*	LC
Aves	*Bradornis microrhynchus*	LC
Aves	*Bradypterus baboecala*	LC
Aves	*Bradypterus centralis*	LC
Aves	*Bradypterus cinnamomeus*	LC
Aves	*Bubalornis niger*	LC
Aves	*Bubo ascalaphus*	LC
Aves	*Bubo capensis*	LC
Aves	*Bubo lacteus*	LC
Aves	*Bubulcus ibis*	LC
Aves	*Bucanetes githagineus*	LC
Aves	*Buphagus africanus*	LC
Aves	*Buphagus erythrorynchus*	LC
Aves	*Burhinus capensis*	LC
Aves	*Burhinus oedicnemus*	LC
Aves	*Burhinus senegalensis*	LC
Aves	*Butastur rufipennis*	LC
Aves	*Buteo augur*	LC
Aves	*Buteo auguralis*	LC
Aves	*Buteo buteo*	LC
Aves	*Butorides striata*	LC
Aves	*Bycanistes brevis*	LC
Aves	*Calamonastes simplex*	LC
Aves	*Calandrella blanfordi*	LC
Aves	*Calendulauda alopex*	LC
Aves	*Calherodius leuconotus*	LC
Aves	*Calidris minuta*	LC
Aves	*Calidris pugnax*	LC

Aves	*Calidris temminckii*	LC
Aves	*Camaroptera brachyura*	LC
Aves	*Campephaga phoenicea*	LC
Aves	*Campethera abingoni*	LC
Aves	*Campethera maculosa*	LC
Aves	*Campethera nivosa*	LC
Aves	*Campethera nubica*	LC
Aves	*Campethera punctuligera*	LC
Aves	*Caprimulgus clarus*	LC
Aves	*Caprimulgus europaeus*	LC
Aves	*Caprimulgus fraenatus*	LC
Aves	*Caprimulgus inornatus*	LC
Aves	*Caprimulgus longipennis*	LC
Aves	*Caprimulgus natalensis*	LC
Aves	*Caprimulgus nubicus*	LC
Aves	*Caprimulgus poliocephalus*	LC
Aves	*Caprimulgus tristigma*	LC
Aves	*Ceblepyris pectoralis*	LC
Aves	*Cecropis abyssinica*	LC
Aves	*Cecropis daurica*	LC
Aves	*Cecropis semirufa*	LC
Aves	*Cecropis senegalensis*	LC
Aves	*Centropus grillii*	LC
Aves	*Centropus monachus*	LC
Aves	*Centropus senegalensis*	LC
Aves	*Centropus superciliosus*	LC
Aves	*Cercotrichas leucophrys*	LC
Aves	*Ceryle rudis*	LC
Aves	*Chalcomitra senegalensis*	LC
Aves	*Charadrius asiaticus*	LC
Aves	*Charadrius dubius*	LC
Aves	*Charadrius forbesi*	LC
Aves	*Charadrius hiaticula*	LC
Aves	*Charadrius marginatus*	LC
Aves	*Charadrius pecuarius*	LC
Aves	*Charadrius tricollaris*	LC

Aves	*Chlorophoneus sulfureopectus*	LC	
Aves	*Chrysococcyx caprius*	LC	
Aves	*Chrysococcyx cupreus*	LC	
Aves	*Chrysococcyx klaas*	LC	
Aves	*Ciconia ciconia*	LC	
Aves	*Ciconia microscelis*	LC	
Aves	*Ciconia nigra*	LC	
Aves	*Cinnyricinclus leucogaster*	LC	
Aves	*Cinnyris chloropygius*	LC	
Aves	*Cinnyris coccinigastrus*	LC	
Aves	*Cinnyris cupreus*	LC	
Aves	*Cinnyris habessinicus*	LC	
Aves	*Cinnyris mariquensis*	LC	
Aves	*Cinnyris osea*	LC	
Aves	*Cinnyris venustus*	LC	
Aves	*Circaetus cinerascens*	LC	
Aves	*Circaetus cinereus*	LC	
Aves	*Circaetus pectoralis*	LC	
Aves	*Circus aeruginosus*	LC	
Aves	*Circus cyaneus*	LC	
Aves	*Circus pygargus*	LC	
Aves	*Cisticola aberrans*	LC	
Aves	*Cisticola aridulus*	LC	
Aves	*Cisticola bodessa*	LC	
Aves	*Cisticola brachypterus*	LC	
Aves	*Cisticola brunnescens*	LC	
Aves	*Cisticola cantans*	LC	
Aves	*Cisticola chiniana*	LC	
Aves	*Cisticola cinereolus*	LC	
Aves	*Cisticola erythrops*	LC	
Aves	*Cisticola eximius*	LC	
Aves	*Cisticola guinea*	LC	SAV
Aves	*Cisticola juncidis*	LC	
Aves	*Cisticola lateralis*	LC	
Aves	*Cisticola lugubris*	LC	
Aves	*Cisticola marginatus*	LC	

Aves	*Cisticola natalensis*	LC
Aves	*Cisticola robustus*	LC
Aves	*Cisticola ruficeps*	LC
Aves	*Cisticola rufus*	LC
Aves	*Cisticola troglodytes*	LC
Aves	*Clamator glandarius*	LC
Aves	*Clamator jacobinus*	LC
Aves	*Clamator levaillantii*	LC
Aves	*Clanga pomarina*	LC
Aves	*Colius striatus*	LC
Aves	*Columba albitorques*	LC
Aves	*Columba arquatrix*	LC
Aves	*Columba guinea*	LC
Aves	*Columba livia*	LC
Aves	*Coracias caudatus*	LC
Aves	*Coracias cyanogaster*	LC
Aves	*Coracias garrulus*	LC
Aves	*Coracias naevius*	LC
Aves	*Corvinella corvina*	LC
Aves	*Corvus albus*	LC
Aves	*Corvus capensis*	LC
Aves	*Corvus crassirostris*	LC
Aves	*Corvus edithae*	LC
Aves	*Corythornis cristatus*	LC
Aves	*Cossypha albicapillus*	LC
Aves	*Cossypha heuglini*	LC
Aves	*Cossypha niveicapilla*	LC
Aves	*Cossypha semirufa*	LC
Aves	*Coturnix delegorguei*	LC
Aves	*Creatophora cinerea*	LC
Aves	*Crex crex*	LC
Aves	*Crex egregia*	LC
Aves	*Crinifer piscator*	LC
Aves	*Crinifer zonurus*	LC
Aves	*Criniferoides leucogaster*	LC
Aves	*Crithagra canicapilla*	LC

Aves	*Crithagra citrinelloides*	LC
Aves	*Crithagra dorsostriata*	LC
Aves	*Crithagra mozambica*	LC
Aves	*Crithagra reichenowi*	LC
Aves	*Crithagra striatipectus*	LC
Aves	*Crithagra striolata*	LC
Aves	*Crithagra tristriata*	LC
Aves	*Cryptospiza salvadorii*	LC
Aves	*Cuculus clamosus*	LC
Aves	*Cuculus gularis*	LC
Aves	*Cuculus solitarius*	LC
Aves	*Cursorius somalensis*	LC
Aves	*Cursorius temminckii*	LC
Aves	*Cyanomitra olivacea*	LC
Aves	*Cyanomitra verticalis*	LC
Aves	*Cypsiurus parvus*	LC
Aves	*Dendrocygna bicolor*	LC
Aves	*Dendrocygna viduata*	LC
Aves	*Dendroperdix sephaena*	LC
Aves	*Dendropicos abyssinicus*	LC
Aves	*Dendropicos fuscescens*	LC
Aves	*Dendropicos namaquus*	LC
Aves	*Dendropicos obsoletus*	LC
Aves	*Dendropicos spodocephalus*	LC
Aves	*Dicrurus adsimilis*	LC
Aves	*Dicrurus ludwigii*	LC
Aves	*Dinemellia dinemelli*	LC
Aves	*Dryoscopus gambensis*	LC
Aves	*Egretta ardesiaca*	LC
Aves	*Egretta garzetta*	LC
Aves	*Egretta gularis*	LC
Aves	*Elanus caeruleus*	LC
Aves	*Elminia longicauda*	LC
Aves	*Emberiza affinis*	LC
Aves	*Emberiza flaviventris*	LC
Aves	*Emberiza hortulana*	LC

Aves	*Emberiza sahari*	LC	
Aves	*Emberiza tahapisi*	LC	
Aves	*Ephippiorhynchus senegalensis*	LC	
Aves	*Eremomela canescens*	LC	
Aves	*Eremomela flavicrissalis*	LC	
Aves	*Eremomela icteropygialis*	LC	
Aves	*Eremomela pusilla*	LC	
Aves	*Eremopterix leucotis*	LC	
Aves	*Eremopterix signatus*	LC	
Aves	*Estrilda astrild*	LC	
Aves	*Estrilda coerulescens*	LC	SAV
Aves	*Estrilda melpoda*	LC	
Aves	*Estrilda paludicola*	LC	
Aves	*Estrilda rhodopyga*	LC	
Aves	*Estrilda troglodytes*	LC	
Aves	*Euplectes afer*	LC	
Aves	*Euplectes ardens*	LC	
Aves	*Euplectes axillaris*	LC	
Aves	*Euplectes capensis*	LC	
Aves	*Euplectes franciscanus*	LC	
Aves	*Euplectes gierowii*	LC	
Aves	*Euplectes hordeaceus*	LC	
Aves	*Euplectes laticauda*	LC	
Aves	*Euplectes macroura*	LC	
Aves	*Eupodotis senegalensis*	LC	
Aves	*Eurocephalus ruppelli*	LC	
Aves	*Eurystomus glaucurus*	LC	
Aves	*Falco amurensis*	LC	
Aves	*Falco ardosiaceus*	LC	
Aves	*Falco biarmicus*	LC	
Aves	*Falco cuvierii*	LC	
Aves	*Falco naumanni*	LC	
Aves	*Falco peregrinus*	LC	
Aves	*Falco ruficollis*	LC	
Aves	*Falco rupicoloides*	LC	
Aves	*Falco subbuteo*	LC	

Aves	*Falco tinnunculus*	LC
Aves	*Ficedula hypoleuca*	LC
Aves	*Ficedula parva*	LC
Aves	*Ficedula semitorquata*	LC
Aves	*Fraseria caerulescens*	LC
Aves	*Fraseria plumbea*	LC
Aves	*Fulica atra*	LC
Aves	*Fulica cristata*	LC
Aves	*Galerida modesta*	LC
Aves	*Galerida theklae*	LC
Aves	*Gallinago gallinago*	LC
Aves	*Gallinago nigripennis*	LC
Aves	*Gallinula angulata*	LC
Aves	*Gallinula chloropus*	LC
Aves	*Gelochelidon nilotica*	LC
Aves	*Geokichla piaggiae*	LC
Aves	*Geronticus eremita*	LC
Aves	*Glareola cinerea*	LC
Aves	*Glareola nuchalis*	LC
Aves	*Glareola pratincola*	LC
Aves	*Glaucidium perlatum*	LC
Aves	*Granatina ianthinogaster*	LC
Aves	*Grus grus*	LC
Aves	*Gymnoris pyrgita*	LC
Aves	*Gypohierax angolensis*	LC
Aves	*Halcyon chelicuti*	LC
Aves	*Halcyon leucocephala*	LC
Aves	*Halcyon malimbica*	LC
Aves	*Halcyon senegalensis*	LC
Aves	*Haliaeetus vocifer*	LC
Aves	*Hedydipna collaris*	LC
Aves	*Hieraaetus ayresii*	LC
Aves	*Hieraaetus pennatus*	LC
Aves	*Hieraaetus wahlbergi*	LC
Aves	*Himantopus himantopus*	LC
Aves	*Hippolais icterina*	LC

Aves	*Hippolais languida*	LC	
Aves	*Hippolais olivetorum*	LC	
Aves	*Hippolais polyglotta*	LC	
Aves	*Hirundo leucosoma*	LC	
Aves	*Hirundo lucida*	LC	
Aves	*Hirundo rustica*	LC	
Aves	*Hirundo smithii*	LC	
Aves	*Hydroprogne caspia*	LC	
Aves	*Hyliota flavigaster*	LC	
Aves	*Hypergerus atriceps*	LC	
Aves	*Iduna pallida*	LC	
Aves	*Indicator indicator*	LC	
Aves	*Indicator maculatus*	LC	
Aves	*Indicator minor*	LC	
Aves	*Irania gutturalis*	LC	
Aves	*Ispidina picta*	LC	
Aves	*Ixobrychus minutus*	LC	
Aves	*Ixobrychus sturmii*	LC	
Aves	*Jynx ruficollis*	LC	
Aves	*Jynx torquilla*	LC	
Aves	*Kaupifalco monogrammicus*	LC	
Aves	*Lagonosticta larvata*	LC	
Aves	*Lagonosticta nigricollis*	LC	
Aves	*Lagonosticta rara*	LC	
Aves	*Lagonosticta rubricata*	LC	
Aves	*Lagonosticta rufopicta*	LC	
Aves	*Lagonosticta senegala*	LC	
Aves	*Lagonosticta vinacea*	LC	SAV
Aves	*Lamprotornis albicapillus*	LC	
Aves	*Lamprotornis chalcurus*	LC	
Aves	*Lamprotornis chalybaeus*	LC	
Aves	*Lamprotornis chloropterus*	LC	
Aves	*Lamprotornis purpureus*	LC	
Aves	*Lamprotornis purpuroptera*	LC	
Aves	*Lamprotornis regius*	LC	
Aves	*Lamprotornis splendidus*	LC	

Aves	*Lamprotornis superbus*	LC
Aves	*Laniarius aethiopicus*	LC
Aves	*Laniarius erythrogaster*	LC
Aves	*Laniarius funebris*	LC
Aves	*Lanius collaris*	LC
Aves	*Lanius collurio*	LC
Aves	*Lanius isabellinus*	LC
Aves	*Lanius senator*	LC
Aves	*Lanius somalicus*	LC
Aves	*Larus cirrocephalus*	LC
Aves	*Larus fuscus*	LC
Aves	*Larus ridibundus*	LC
Aves	*Leptoptilos crumenifer*	LC
Aves	*Linaria cannabina*	LC
Aves	*Lissotis hartlaubii*	LC
Aves	*Lissotis melanogaster*	LC
Aves	*Locustella fluviatilis*	LC
Aves	*Locustella luscinioides*	LC
Aves	*Lophaetus occipitalis*	LC
Aves	*Lophoceros hemprichii*	LC
Aves	*Lophoceros nasutus*	LC
Aves	*Lophoceros semifasciatus*	LC
Aves	*Lophotis gindiana*	LC
Aves	*Luscinia megarhynchos*	LC
Aves	*Lybius guifsobalito*	LC
Aves	*Lybius leucocephalus*	LC
Aves	*Lybius undatus*	LC
Aves	*Macheiramphus alcinus*	LC
Aves	*Macronyx croceus*	LC
Aves	*Malaconotus blanchoti*	LC
Aves	*Malimbus nitens*	LC
Aves	*Mareca penelope*	LC
Aves	*Mareca strepera*	LC
Aves	*Megaceryle maxima*	LC
Aves	*Melaenornis chocolatinus*	LC
Aves	*Melaenornis edolioides*	LC

Aves	*Melaenornis semipartitus*	LC
Aves	*Melaniparus guineensis*	LC
Aves	*Melaniparus leucomelas*	LC
Aves	*Melaniparus leuconotus*	LC
Aves	*Melierax metabates*	LC
Aves	*Melierax poliopterus*	LC
Aves	*Melocichla mentalis*	LC
Aves	*Merops bulocki*	LC
Aves	*Merops hirundineus*	LC
Aves	*Merops lafresnayii*	LC
Aves	*Merops persicus*	LC
Aves	*Merops pusillus*	LC
Aves	*Merops superciliosus*	LC
Aves	*Microcarbo africanus*	LC
Aves	*Micronisus gabar*	LC
Aves	*Microparra capensis*	LC
Aves	*Milvus migrans*	LC
Aves	*Mirafra africana*	LC
Aves	*Mirafra albicauda*	LC
Aves	*Mirafra gilletti*	LC
Aves	*Mirafra rufocinnamomea*	LC
Aves	*Monticola rufocinereus*	LC
Aves	*Monticola saxatilis*	LC
Aves	*Monticola semirufus*	LC
Aves	*Motacilla aguimp*	LC
Aves	*Motacilla alba*	LC
Aves	*Motacilla cinerea*	LC
Aves	*Motacilla clara*	LC
Aves	*Motacilla flava*	LC
Aves	*Muscicapa adusta*	LC
Aves	*Muscicapa aquatica*	LC
Aves	*Muscicapa gambagae*	LC
Aves	*Muscicapa striata*	LC
Aves	*Musophaga violacea*	LC
Aves	*Mycteria ibis*	LC
Aves	*Myrmecocichla melaena*	LC

Aves	*Myrmecocichla nigra*	LC	
Aves	*Nectarinia famosa*	LC	
Aves	*Nectarinia tacazze*	LC	
Aves	*Neophedina cincta*	LC	
Aves	*Neotis heuglinii*	LC	
Aves	*Netta erythrophthalma*	LC	
Aves	*Nettapus auritus*	LC	
Aves	*Nilaus afer*	LC	
Aves	*Numenius phaeopus*	LC	
Aves	*Numida meleagris*	LC	
Aves	*Nycticorax nycticorax*	LC	
Aves	*Oena capensis*	LC	
Aves	*Oenanthe albifrons*	LC	
Aves	*Oenanthe deserti*	LC	
Aves	*Oenanthe familiaris*	LC	
Aves	*Oenanthe frenata*	LC	
Aves	*Oenanthe leucopyga*	LC	
Aves	*Oenanthe lugens*	LC	
Aves	*Oenanthe pleschanka*	LC	
Aves	*Oenanthe scotocerca*	LC	
Aves	*Oenanthe xanthoprymna*	LC	
Aves	*Onychognathus blythii*	LC	
Aves	*Onychognathus morio*	LC	
Aves	*Onychognathus neumanni*	LC	
Aves	*Onychognathus tenuirostris*	LC	
Aves	*Oriolus auratus*	LC	
Aves	*Oriolus monacha*	LC	
Aves	*Oriolus oriolus*	LC	
Aves	*Ortygospiza atricollis*	LC	
Aves	*Otus scops*	LC	
Aves	*Otus senegalensis*	LC	
Aves	*Pachycoccyx audeberti*	LC	
Aves	*Pandion haliaetus*	LC	
Aves	*Parophasma galinieri*	LC	
Aves	*Passer castanopterus*	LC	
Aves	*Passer cordofanicus*	LC	SHL

Aves	*Passer domesticus*	LC
Aves	*Passer eminibey*	LC
Aves	*Passer griseus*	LC
Aves	*Passer simplex*	LC
Aves	*Passer swainsonii*	LC
Aves	*Pelecanus onocrotalus*	LC
Aves	*Pelecanus rufescens*	LC
Aves	*Peliperdix albogularis*	LC
Aves	*Peliperdix coqui*	LC
Aves	*Pernis apivorus*	LC
Aves	*Petrochelidon preussi*	LC
Aves	*Phalacrocorax carbo*	LC
Aves	*Phoenicopterus roseus*	LC
Aves	*Phoeniculus purpureus*	LC
Aves	*Phoeniculus somaliensis*	LC
Aves	*Phoenicurus ochruros*	LC
Aves	*Phoenicurus phoenicurus*	LC
Aves	*Phyllastrephus strepitans*	LC
Aves	*Phyllolais pulchella*	LC
Aves	*Phylloscopus bonelli*	LC
Aves	*Phylloscopus orientalis*	LC
Aves	*Phylloscopus sibilatrix*	LC
Aves	*Phylloscopus trochilus*	LC
Aves	*Phylloscopus umbrovirens*	LC
Aves	*Pinarochroa sordida*	LC
Aves	*Platalea alba*	LC
Aves	*Platysteira cyanea*	LC
Aves	*Plectropterus gambensis*	LC
Aves	*Plegadis falcinellus*	LC
Aves	*Plocepasser mahali*	LC
Aves	*Plocepasser superciliosus*	LC
Aves	*Ploceus baglafecht*	LC
Aves	*Ploceus brachypterus*	LC
Aves	*Ploceus castaneofuscus*	LC
Aves	*Ploceus cucullatus*	LC
Aves	*Ploceus heuglini*	LC

Aves	*Ploceus intermedius*	LC
Aves	*Ploceus melanocephalus*	LC
Aves	*Ploceus rubiginosus*	LC
Aves	*Ploceus superciliosus*	LC
Aves	*Ploceus vitellinus*	LC
Aves	*Pluvianus aegyptius*	LC
Aves	*Podica senegalensis*	LC
Aves	*Podiceps cristatus*	LC
Aves	*Podiceps nigricollis*	LC
Aves	*Pogoniulus chrysoconus*	LC
Aves	*Pogoniulus pusillus*	LC
Aves	*Pogonornis bidentatus*	LC
Aves	*Pogonornis dubius*	LC
Aves	*Pogonornis rolleti*	LC
Aves	*Poicephalus flavifrons*	LC
Aves	*Poicephalus fuscicollis*	LC
Aves	*Poicephalus meyeri*	LC
Aves	*Poicephalus rufiventris*	LC
Aves	*Poicephalus senegalus*	LC
Aves	*Polihierax semitorquatus*	LC
Aves	*Polyboroides typus*	LC
Aves	*Porphyrio alleni*	LC
Aves	*Porzana porzana*	LC
Aves	*Prinia erythroptera*	LC
Aves	*Prinia rufifrons*	LC
Aves	*Prinia somalica*	LC
Aves	*Prinia subflava*	LC
Aves	*Prionops plumatus*	LC
Aves	*Prodotiscus regulus*	LC
Aves	*Psalidoprocne obscura*	LC
Aves	*Psalidoprocne pristoptera*	LC
Aves	*Pseudhirundo griseopyga*	LC
Aves	*Psophocichla simensis*	LC
Aves	*Pternistis leucoscepus*	LC
Aves	*Pternistis squamatus*	LC
Aves	*Pterocles coronatus*	LC

Aves	*Pterocles gutturalis*	LC
Aves	*Pterocles senegallus*	LC
Aves	*Ptilopachus petrosus*	LC
Aves	*Ptilostomus afer*	LC
Aves	*Ptyonoprogne obsoleta*	LC
Aves	*Ptyonoprogne rufigula*	LC
Aves	*Pycnonotus barbatus*	LC
Aves	*Pyrenestes sanguineus*	LC
Aves	*Pyrrhocorax pyrrhocorax*	LC
Aves	*Pytilia hypogrammica*	LC
Aves	*Pytilia lineata*	LC
Aves	*Pytilia melba*	LC
Aves	*Pytilia phoenicoptera*	LC
Aves	*Quelea erythrops*	LC
Aves	*Quelea quelea*	LC
Aves	*Rallus caerulescens*	LC
Aves	*Recurvirostra avosetta*	LC
Aves	*Rhinopomastus minor*	LC
Aves	*Rhinoptilus chalcopterus*	LC
Aves	*Rhinoptilus cinctus*	LC
Aves	*Rhodophoneus cruentus*	LC
Aves	*Riparia paludicola*	LC
Aves	*Riparia riparia*	LC
Aves	*Rostratula benghalensis*	LC
Aves	*Salpornis salvadori*	LC
Aves	*Sarkidiornis melanotos*	LC
Aves	*Saxicola rubetra*	LC
Aves	*Saxicola torquatus*	LC
Aves	*Scleroptila gutturalis*	LC
Aves	*Scopus umbretta*	LC
Aves	*Scotopelia peli*	LC
Aves	*Serinus flavivertex*	LC
Aves	*Serinus nigriceps*	LC
Aves	*Smutsornis africanus*	LC
Aves	*Spatula hottentota*	LC
Aves	*Spatula querquedula*	LC

Aves	*Spermestes cucullata*	LC	
Aves	*Spermestes fringilloides*	LC	
Aves	*Spilopelia senegalensis*	LC	
Aves	*Sternula albifrons*	LC	
Aves	*Streptopelia capicola*	LC	
Aves	*Streptopelia hypopyrrha*	LC	
Aves	*Streptopelia lugens*	LC	
Aves	*Streptopelia semitorquata*	LC	
Aves	*Strix woodfordii*	LC	
Aves	*Sylvia abyssinica*	LC	
Aves	*Sylvia atricapilla*	LC	
Aves	*Sylvia boehmi*	LC	
Aves	*Sylvia borin*	LC	
Aves	*Sylvia communis*	LC	
Aves	*Sylvia conspicillata*	LC	
Aves	*Sylvia deserti*	LC	SHR
Aves	*Sylvia leucomelaena*	LC	
Aves	*Sylvia lugens*	LC	
Aves	*Sylvia melanocephala*	LC	
Aves	*Sylvia nana*	LC	
Aves	*Sylvietta brachyura*	LC	
Aves	*Sylvietta leucopsis*	LC	
Aves	*Tachybaptus ruficollis*	LC	
Aves	*Tachymarptis aequatorialis*	LC	
Aves	*Tachymarptis melba*	LC	
Aves	*Tauraco leucotis*	LC	
Aves	*Tauraco persa*	LC	
Aves	*Tchagra senegalus*	LC	
Aves	*Telacanthura ussheri*	LC	
Aves	*Terpsiphone rufiventer*	LC	
Aves	*Terpsiphone viridis*	LC	
Aves	*Thalassornis leuconotus*	LC	
Aves	*Thamnolaea cinnamomeiventris*	LC	
Aves	*Threskiornis aethiopicus*	LC	
Aves	*Tmetothylacus tenellus*	LC	
Aves	*Tockus deckeni*	LC	

Aves	*Tockus erythrorhynchus*	LC
Aves	*Tockus flavirostris*	LC
Aves	*Trachyphonus erythrocephalus*	LC
Aves	*Treron calvus*	LC
Aves	*Treron waalia*	LC
Aves	*Tricholaema melanocephala*	LC
Aves	*Tringa erythropus*	LC
Aves	*Tringa glareola*	LC
Aves	*Tringa nebularia*	LC
Aves	*Tringa ochropus*	LC
Aves	*Tringa stagnatilis*	LC
Aves	*Tringa totanus*	LC
Aves	*Turdoides leucopygia*	LC
Aves	*Turdoides plebejus*	LC
Aves	*Turdoides reinwardtii*	LC
Aves	*Turdus abyssinicus*	LC
Aves	*Turdus pelios*	LC
Aves	*Turdus philomelos*	LC
Aves	*Turnix nanus*	LC
Aves	*Turnix sylvaticus*	LC
Aves	*Turtur afer*	LC
Aves	*Tyto alba*	LC
Aves	*Upupa epops*	LC
Aves	*Uraeginthus bengalus*	LC
Aves	*Vanellus albiceps*	LC
Aves	*Vanellus coronatus*	LC
Aves	*Vanellus crassirostris*	LC
Aves	*Vanellus melanocephalus*	LC
Aves	*Vanellus melanopterus*	LC
Aves	*Vanellus senegallus*	LC
Aves	*Vanellus superciliosus*	LC
Aves	*Vidua chalybeata*	LC
Aves	*Vidua interjecta*	LC
Aves	*Vidua larvaticola*	LC
Aves	*Vidua macroura*	LC
Aves	*Vidua nigeriae*	LC

Aves	*Vidua paradisaea*	LC	
Aves	*Vidua wilsoni*	LC	
Aves	*Zapornia flavirostra*	LC	
Aves	*Zapornia parva*	LC	
Aves	*Zapornia pusilla*	LC	
Aves	*Zosterops abyssinicus*	LC	
Aves	*Zosterops poliogastrus*	LC	
Aves	*Zosterops senegalensis*	LC	
Mammalia	*Acomys cahirinus*	LC	SHR
Mammalia	*Acomys louisae*	LC	
Mammalia	*Alcelaphus buselaphus*	LC	
Mammalia	*Arvicanthis ansorgei*	LC	
Mammalia	*Arvicanthis neumanni*	LC	
Mammalia	*Asellia tridens*	LC	
Mammalia	*Atelerix albiventris*	LC	
Mammalia	*Atilax paludinosus*	LC	
Mammalia	*Canis adustus*	LC	
Mammalia	*Canis mesomelas*	LC	
Mammalia	*Caracal caracal*	LC	
Mammalia	*Cardioderma cor*	LC	
Mammalia	*Cephalophus rufilatus*	LC	
Mammalia	*Cercopithecus petaurista*	LC	
Mammalia	*Chaerephon bivittatus*	LC	
Mammalia	*Chaerephon nigeriae*	LC	
Mammalia	*Chaerephon pumilus*	LC	
Mammalia	*Chlorocebus sabaeus*	LC	
Mammalia	*Chlorocebus tantalus*	LC	
Mammalia	*Civettictis civetta*	LC	
Mammalia	*Coleura afra*	LC	
Mammalia	*Colobus guereza*	LC	
Mammalia	*Cricetomys gambianus*	LC	
Mammalia	*Crocidura baileyi*	LC	
Mammalia	*Crocidura foxi*	LC	
Mammalia	*Crocidura fuscomurina*	LC	
Mammalia	*Crocidura lamottei*	LC	
Mammalia	*Crocidura olivieri*	LC	

Mammalia	*Crocidura yankariensis*	LC	
Mammalia	*Crocuta crocuta*	LC	
Mammalia	*Damaliscus lunatus*	LC	
Mammalia	*Dasymys incomtus*	LC	
Mammalia	*Dasymys rufulus*	LC	
Mammalia	*Dendromus lovati*	LC	
Mammalia	*Dendromus melanotis*	LC	
Mammalia	*Dendromus mystacalis*	LC	
Mammalia	*Desmodilliscus harringtoni*	LC	
Mammalia	*Epomophorus gambianus*	LC	
Mammalia	*Epomophorus labiatus*	LC	
Mammalia	*Epomophorus minor*	LC	
Mammalia	*Felis silvestris*	LC	
Mammalia	*Galago senegalensis*	LC	
Mammalia	*Galagoides demidoff*	LC	
Mammalia	*Galagoides thomasi*	LC	
Mammalia	*Genetta genetta*	LC	
Mammalia	*Genetta maculata*	LC	
Mammalia	*Genetta pardina*	LC	
Mammalia	*Genetta thierryi*	LC	
Mammalia	*Gerbilliscus guineae*	LC	
Mammalia	*Gerbilliscus kempi*	LC	
Mammalia	*Gerbilliscus robustus*	LC	
Mammalia	*Gerbilliscus validus*	LC	
Mammalia	*Gerbillus amoenus*	LC	SHR
Mammalia	*Gerbillus dunni*	LC	
Mammalia	*Gerbillus gerbillus*	LC	SHR
Mammalia	*Gerbillus nanus*	LC	
Mammalia	*Gerbillus nigeriae*	LC	SHL
Mammalia	*Gerbillus pusillus*	LC	
Mammalia	*Gerbillus tarabuli*	LC	SHR
Mammalia	*Gerbillus watersi*	LC	SHR
Mammalia	*Glauconycteris variegata*	LC	
Mammalia	*Graphiurus kelleni*	LC	
Mammalia	*Graphiurus microtis*	LC	
Mammalia	*Heliosciurus gambianus*	LC	

Mammalia	*Helogale parvula*	LC	
Mammalia	*Herpestes ichneumon*	LC	
Mammalia	*Herpestes sanguineus*	LC	
Mammalia	*Heterocephalus glaber*	LC	
Mammalia	*Heterohyrax brucei*	LC	
Mammalia	*Hipposideros abae*	LC	
Mammalia	*Hipposideros caffer*	LC	
Mammalia	*Hipposideros gigas*	LC	
Mammalia	*Hipposideros megalotis*	LC	
Mammalia	*Hipposideros ruber*	LC	
Mammalia	*Hipposideros tephrus*	LC	
Mammalia	*Hippotragus equinus*	LC	
Mammalia	*Hystrix cristata*	LC	
Mammalia	*Ichneumia albicauda*	LC	
Mammalia	*Ictonyx striatus*	LC	
Mammalia	*Jaculus jaculus*	LC	
Mammalia	*Kobus ellipsiprymnus*	LC	
Mammalia	*Kobus kob*	LC	
Mammalia	*Lavia frons*	LC	
Mammalia	*Lemniscomys linulus*	LC	SAV
Mammalia	*Lemniscomys zebra*	LC	
Mammalia	*Leptailurus serval*	LC	
Mammalia	*Lepus capensis*	LC	
Mammalia	*Lepus habessinicus*	LC	
Mammalia	*Lepus victoriae*	LC	
Mammalia	*Lissonycteris angolensis*	LC	
Mammalia	*Lophiomys imhausi*	LC	
Mammalia	*Madoqua saltiana*	LC	
Mammalia	*Massoutiera mzabi*	LC	SHR
Mammalia	*Mastomys erythroleucus*	LC	
Mammalia	*Mastomys natalensis*	LC	
Mammalia	*Mellivora capensis*	LC	
Mammalia	*Micropteropus pusillus*	LC	
Mammalia	*Miniopterus natalensis*	LC	
Mammalia	*Mops condylurus*	LC	
Mammalia	*Mops demonstrator*	LC	

Mammalia	*Mops midas*	LC
Mammalia	*Mungos gambianus*	LC
Mammalia	*Mungos mungo*	LC
Mammalia	*Muriculus imberbis*	LC
Mammalia	*Mus mahomet*	LC
Mammalia	*Mus mattheyi*	LC
Mammalia	*Mus musculoides*	LC
Mammalia	*Mus musculus*	LC
Mammalia	*Mus tenellus*	LC
Mammalia	*Myomyscus brockmani*	LC
Mammalia	*Myotis bocagii*	LC
Mammalia	*Myotis welwitschii*	LC
Mammalia	*Nandinia binotata*	LC
Mammalia	*Neoromicia capensis*	LC
Mammalia	*Neoromicia guineensis*	LC
Mammalia	*Neoromicia nana*	LC
Mammalia	*Neoromicia rendalli*	LC
Mammalia	*Neoromicia somalica*	LC
Mammalia	*Nycteris gambiensis*	LC
Mammalia	*Nycteris hispida*	LC
Mammalia	*Nycteris macrotis*	LC
Mammalia	*Nycteris thebaica*	LC
Mammalia	*Nycticeinops schlieffeni*	LC
Mammalia	*Oreotragus oreotragus*	LC
Mammalia	*Orycteropus afer*	LC
Mammalia	*Otomys typus*	LC
Mammalia	*Ourebia ourebi*	LC
Mammalia	*Papio anubis*	LC
Mammalia	*Papio hamadryas*	LC
Mammalia	*Paraechinus aethiopicus*	LC
Mammalia	*Pectinator spekei*	LC
Mammalia	*Phacochoerus aethiopicus*	LC
Mammalia	*Phacochoerus africanus*	LC
Mammalia	*Pipistrellus hesperidus*	LC
Mammalia	*Pipistrellus rueppellii*	LC
Mammalia	*Pipistrellus rusticus*	LC

Mammalia	*Potamochoerus larvatus*	LC	
Mammalia	*Potamochoerus porcus*	LC	
Mammalia	*Praomys daltoni*	LC	
Mammalia	*Praomys rostratus*	LC	
Mammalia	*Praomys tullbergi*	LC	
Mammalia	*Procavia capensis*	LC	
Mammalia	*Proteles cristata*	LC	
Mammalia	*Psammomys obesus*	LC	
Mammalia	*Rattus rattus*	LC	
Mammalia	*Redunca redunca*	LC	
Mammalia	*Rhinolophus alcyone*	LC	
Mammalia	*Rhinolophus clivosus*	LC	
Mammalia	*Rhinolophus denti*	LC	
Mammalia	*Rhinolophus fumigatus*	LC	
Mammalia	*Rhinolophus landeri*	LC	
Mammalia	*Rhinopoma cystops*	LC	
Mammalia	*Rhinopoma hardwickii*	LC	
Mammalia	*Rousettus aegyptiacus*	LC	
Mammalia	*Scotoecus hirundo*	LC	
Mammalia	*Scotophilus dinganii*	LC	
Mammalia	*Scotophilus ejetai*	LC	
Mammalia	*Scotophilus leucogaster*	LC	
Mammalia	*Scotophilus nigrita*	LC	
Mammalia	*Scotophilus viridis*	LC	
Mammalia	*Steatomys caurinus*	LC	SAV
Mammalia	*Stenocephalemys albipes*	LC	
Mammalia	*Stenocephalemys griseicauda*	LC	
Mammalia	*Suncus megalura*	LC	
Mammalia	*Sylvicapra grimmia*	LC	
Mammalia	*Syncerus caffer*	LC	
Mammalia	*Tachyoryctes splendens*	LC	
Mammalia	*Taphozous perforatus*	LC	
Mammalia	*Taterillus emini*	LC	
Mammalia	*Thryonomys swinderianus*	LC	
Mammalia	*Tragelaphus scriptus*	LC	
Mammalia	*Tragelaphus spekii*	LC	

Mammalia	*Tragelaphus strepsiceros*	LC	
Mammalia	*Triaenops afer*	LC	
Mammalia	*Triaenops persicus*	LC	
Mammalia	*Uranomys ruddi*	LC	
Mammalia	*Vulpes rueppellii*	LC	
Mammalia	*Vulpes vulpes*	LC	
Mammalia	*Vulpes zerda*	LC	SHR
Mammalia	*Xerus rutilus*	LC	
Amphibia	*Hyperolius papyri*	DD	
Reptilia	*Afrotyphlops blanfordii*	DD	
Reptilia	*Agama bocourti*	DD	SAV
Reptilia	*Pseuderemias striatus*	DD	
Aves	*Oenanthe dubia*	DD	
Mammalia	*Crocidura planiceps*	DD	SAV
Mammalia	*Gerbillus lowei*	DD	SHL
Mammalia	*Gerbillus somalicus*	DD	
Mammalia	*Myopterus daubentonii*	DD	
Mammalia	*Scotoecus albofuscus*	DD	
Mammalia	*Tadarida ventralis*	DD	
Amphibia	*Sclerophys blanfordii*	NE	
Amphibia	*Sclerophys kerinyagae*	NE	
Aves	*Chlidonias hybrida*	NE	
Aves	*Chlidonias leucopterus*	NE	
Aves	*Delichon urbicum*	NE	
Aves	*Porphyrio porphyrio*	NE	
Aves	*Tigriornis leucolopha*	NE	
Mammalia	*Epomops buettikoferi*	NE	
Mammalia	*Funisciurus subtriatus*	NE	SAV

5.2. References

IUCN, 2019. IUCN Red List of threatened species. Version 2019-1. (available at https://www.iucnredlist.org/; acceded in 05/03/2019)