

Assessment of the drivers of extinction risk of tropical mammal and birds

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Summary

Biodiversity loss and species loss are one of the greatest contemporary challenges for the Earth system. Despite major conservation efforts, a growing body of research shows that current trends of biodiversity loss have gone beyond safe planetary boundaries and are affecting local terrestrial biodiversity and ecological functions at unprecedented levels (Newbold et al., 2016; Johnson et al., 2017). Such loss of ecosystem functions, paralleled with habitat degradation and habitat loss due to deforestation, has disastrous consequences for animal and plant species (Pogson 2015).

Nowhere are such current losses as great as in the tropical forests (Newbold et al., 2016; Giam, 2017). Nonetheless, an important part of concerns on the state of biodiversity are based on the potential negative impacts on ecosystem services enjoyed by humans. Contrary to such anthropocentric bias in evaluating the relevance of biodiversity loss, this dissertation focuses its attention on other nonhuman forms of life threatened by anthropogenic pressures. In this way, this document aims to respond what are the drivers of the threat of extinction of mammals and birds in the tropics. The focus on the tropical region comes from the rapid pace of deforestation and habitat degradation and from the future land-use change scenarios that project that most extinctions of mammals, birds and amphibians will occur there (Powers & Jetz 2019).

Through the compilation of data from the IUCN Red List and other sources, a database was elaborated with a total of 90 tropical countries (reduced to 71) from the Afrotropics, the Neotropics and the Indomalayan region. Explanatory variables were grouped in four wider dimensions that were included in the analysis: i) agriculture, ii) socioeconomic, iii) demographics and iv) environment. The selection of the best model relied on two techniques: the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC).

The most consistent finding of this dissertation was the overall importance of geographical characteristics beyond other socioeconomic predictors. Indeed, all models presented the island factor as the most important element in advancing the risk of extinction of both mammals and birds. Continuous predictors such as population density, cereal yield and GDP appeared recurrently as associated with an increase in the odds of being endangered. Results from the analysis also provided various insights on predictors that can diminish the extinction risk for animals. Among these, protected areas appeared recurrently as the best predictor for alleviating such risks. Other variables such as the Human Development Index and the biocapacity reserve of some countries were also associated with less chances of being endangered, although at a much lower frequency.

This dissertation aims to serve as an assessment that reveals the strengths and limitations of relying on primary data for evaluating the risk of extinction of animals. Despite a regional evaluation of the various countries from the tropical region is a much needed exercise, the limitations and the quality of the data pose several constraints to the researcher that aims to conduct a proper analysis. Although more grounded levels of analysis are useful for advancing the understanding of more localized impacts, It is clear that there is still much to be done in terms of data availability and quality at broader levels to be able to conduct more refined and comprehensive analyses.

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Research during Covid-19 times

The lockdown and other measures established by the Belgian government to fight the spread of the Covid-19 did not affect significantly the elaboration of this dissertation. Since the methodology relied on a quantitative assesment based on primary data freely available in the internet, the cronogram of this thesis was not severely affected.

Nonetheless, the lockdown and the general crisis did generate various feelings of anxiety and loneliness that influenced my performance during the first months of the lockdown. The lockdown disrupted my daily life and obliged me to live by myself with no contact with anybody for various weeks. Additionally, living abroad and far away from my family, I was and I am still constantly worried for their health and living conditions. I have tried my best to overcome such constraints and to work mindfully on this dissertation.

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1. Introduction

1.1. Biodiversity status worldwide

Biodiversity loss is one of the greatest contemporary challenges for the Earth system. Despite major conservation efforts, a growing body of research shows that current trends of biodiversity loss have gone beyond safe planetary boundaries and are affecting local terrestrial biodiversity and ecological functions at unprecedented levels (Newbold et al., 2016; Johnson et al., 2017). Indeed, it is widely acknowledged that the magnitude and rapid evolution of biodiversity loss are promptly transforming several Earth's ecosystems (Lovejoy & Nobre, 2018, 2019; Sampaio et al., 2007). Global estimates suggest that only in the last century, the planet lost up to 50% of its wetlands, 40% of its forests and 35% of its mangroves (TEEB, 2009).

Nowhere are such current losses as great as in the tropical forests (Newbold et al., 2016; Giam, 2017). Tropical forests are of key importance to sustainability for various reasons: they support two-thirds of the world's biodiversity, they serve as major carbon sinks and they also provide important ecosystem services such as water supply and flood control for millions of people, even if they only cover around –or even less than- 10% of the Earth's surface (Chazdon et al., 2016; Csillik et al., 2019; Giam 2017; Shimamoto et al., 2018). Nonetheless, scholarship warns that challenges posed by recent anthropogenic pressures and climate change have reached such alarming levels that they might soon exceed the forest-savanna tipping point and turn them from carbon sinks to carbon sources (Mitchard, 2018; Franklin & Pindyck, 2018). One of the most iconic tropical forests, the Amazon rainforest, had already lost 15% of its original area by 2003 -17% in more recent years- and scholars agree that under a Business As Usual (BAU) rate of deforestation it would no longer sustain various of its ecosystem functions in the near future (Lovejoy & Nobre, 2018, 2019; Sampaio et al., 2007; Soares-Filho et al., 2006). Recent assessments suggest a similar negative tendency in African forests by 2040 (Hubau et al., 2020).

Such loss of ecosystem functions, paralleled with habitat degradation and habitat loss due to deforestation, has disastrous consequences for animal and plant species (Pogson 2015). Contrary to the established rate of extinction in geological time, the current rate of extinction is 100 to 1,000 times higher (Ceballos et al., 2015; Turvey & Crees, 2019; Pimm et al., 2014). Such rapid dynamics have lead various scientists to refer to the current times as 'the age of extinction', the 'sixth mass extinction', among others¹ (Swarts & Dixon, 2009; Naeem et al., 2012; Barnosky et al., 2011; Ceballos et al., 2015, 2017). Significantly, according to the latest Living Planet Report (WWF, 2018), only between 1970 and 2014, there has been a 60% reduction of global wildlife population. These effects have been much more pronounced in specific regions of tropical rainforests, such as the Netropics (South and Central America, as well as Caribbean countries), where vertebrate populations declined at an average rate of 4.8% annually between 1970 and 2014. In total this represents an overall decline in wildlife of 89% in 2014 compared to 1970 levels (WWF, 2018). With all the above mentioned pressures, it becomes relevant to assess the specific drivers of the threat of extinction in animals in the tropics.

¹ For a rather divergent perspective that the Anthropocene actually accelerate speciation through hybridization or rapid evolution and adaptation in anthropogenic habitats see Thomas (2013, 2017). For its critics see Bellard et al (2016), Gonzalez et al (2016) and Russell & Blackburn (2017).

1.2. Drivers of biodiversity and species loss

Extensive research has been conducted on the specific anthropogenic pressures that drive biodiversity loss and species loss. This literature has highlighted various elements that interactively contribute to this negative tendency, such as for example, overexploitation of natural resources and agriculture (Maxwell, 2016), population density and economic growth (Sol, 2019; Tilman et al., 2017), illegal poaching (van Uhm, 2016; Felbab-Brown, 2017), among several others. Nonetheless, since the drivers are so diverse and different in magnitude, it is useful to resort to general assessments that provide a systematic view of such threats.

One comprehensive source to understand the overall drivers of biodiversity loss and species loss is the Living Planet Report 2018 (WWF, 2018). Considered the world's most complete survey on the state of the Earth's health -with more than 3,268 data sources-, it has identified ever-increasing human consumption and its demand for land, water and energy as the main drivers of biodiversity loss. More specifically, such drivers can be categorized in five driving forces: i) overexploitation and agriculture, ii) habitat loss and degradation, iii) climate change, iv) pollution and v) invasive species. The interaction of these five driving forces needs some further explanation.

Agriculture is considered the major contributor to exceeding planetary boundaries² (Campbell et al 2017). It has been estimated that between 1980 and 2000, more than 55% of new land for agriculture replaced pristine forests (Gibbs et al., 2010), and that agriculture explained up to 80% of worldwide deforestation between 2000 and 2010 (Hosonuma et al., 2012). Such massive landscape transformation eases degenerative processes of habitat loss and fragmentation, which not only affects species, but also biodiversity-mediated functions, such as for example soil formation and nutrient cycling (Peh et al., 2014; WWF, 2018). In addition, modern agriculture is frequently accompanied by the large use of fertilizers and pesticides, which have been associated with soil erosion, atmospheric degradation and declines in pollinator populations (Mattei et al., 2019; Potts et al., 2010; WWF, 2018). The consequent large-scale international trade of produced goods eases the introduction of invasive species in non-native ecosystems, which compete for space, food and other resources with local populations (Hulme, 2009; Westphal et al., 2008). Finally, carbon dioxide and methane emissions related to fossil fuels and other industrial sectors that power the global economy generate major amounts of greenhouse gases that intensify climate change and produce extreme weather events that lead to pervasive effects on ecosystems and life on Earth (Hashim & Hashim 2016; Heede, 2014; Schiermeier, 2011).

Additionally, the increasing magnitude and scope of wildlife trade and bushmeat trade are putting a heavier burden on wildlife. The expanding global revenues from the legal wildlife trade accounts for \$323 billion annually (Walley 2013), whereas its illegal side is currently estimated in \$7-23 billion per year (GEF 2018). Similarly, unsustainable hunting and bushmeat trade play a role in the increasing risk of extinction of endemic animal species (Cowlshaw et al., 2005; Whytock et al., 2016; Mossoun et al., 2017). Given the global scale of the bushmeat trade and its significant demand from wealthy countries (Chaber & Cunningham, 2016; Falk et al., 2013; Musing et al., 2018), researchers are concerned with the unprecedented bushmeat crisis that currently threatens more than 300 terrestrial mammals with extinction (Nasi et al., 2008; Ripple et al., 2016; van Velden et al., 2018). Finally, aside from these factors, other

² Such impacts are not a novelty. Historically, it is estimated that up to 75% of species that have gone extinct since AD1500 were harmed by overexploitation or agriculture (WWF, 2018).

threats to forests include logging and wildfires, as well as edge effects such as isolation, which could actually double biodiversity losses from deforestation (Barlow et al., 2016).

Nonetheless, it is worth mentioning that drivers of biodiversity loss and species loss have specific dynamics and drivers across regions. Such threats have varying magnitudes as well as impacts, and are far from being homogenous at the global scale. Recently, Curtis et al (2018) used high-resolution Google Earth imagery to map and classify global forest loss since 2001 and found significant regional variations in the drivers: whereas shifting agriculture and commodity-driven deforestation were the main drivers of forest loss in tropical forests, temperate and boreal forests had forestry and wildfires as their main disturbance factors. Similarly, it has long been acknowledged that tropical countries are currently experiencing a rapid development that could be affecting biodiversity.

It has long been argued that economic development, urbanization and infrastructure development could be posing similar threats to biodiversity hotspots in Latin America, Southeast Asia and Sub-Saharan Africa (Pinto et al., 2020; Carpio et al., 2020; Sodhi et al., 2010; Tilker et al., 2020; Kruger et al., 2015; Hojas-Gascón et al., 2016). Nonetheless, it is also relevant to ask to what degree this holds true for the different constituent parts of the tropics. Altogether, the tropical region has three ecozones (Afrotropics, Neotropics and Indomalayan), which are defined by climate, soil, vegetation and fauna (Gepts, 2008). The Afrotropics covers continental Africa south of the Sahara and southwestern Arabia, the Neotropics extends south from the Mexican desert into South America and, finally, the Indomalayan region covers the Indian subcontinent to tropical Southeastern Asia and its archipelago. Given the rich biodiversity of these areas, identifying the main drivers of change in the tropics as a whole and in its different constituent parts is a relevant avenue of research.

1.3. Consequences of biodiversity loss and species loss

The consequences of biodiversity loss have the potential of causing irreversible damage on ecosystem functions and services that could ultimately affect humanity (Ceballos et al., 2015; Naeem et al., 2012; Díaz et al., 2019). There is a general consensus within the scientific community that biodiversity loss affects the capture of biologically essential resources, reduces biomass production and affects decomposition and recycling of biologically essential nutrients (Cardinale et al., 2012). The alteration of these and other functions, such as nutrient cycling and soil formation, can ultimately affect the production of food, fiber and medicines enjoyed by humans (Díaz et al., 2006). Nonetheless, such impacts on what some scholars call 'natural capital' are unequally distributed around the world and it is those who rely most directly on provisioning and regulating ecosystem services –e.g. subsistence communities and forest peoples- the most affected (Cardinale et al., 2012; Díez et al., 2006, 2019; Machado et al., 2019).

Additionally, the consequences of biodiversity loss have also been linked with the potential spread of pathogens. Zoonosis -any disease or infection naturally transmissible from vertebrate animals to humans- has risen in the last decades and it currently represents 60% of known infectious diseases and up to 75% of new infectious diseases. In this vein, some researchers argue the existence of an association between ecological disruption, biodiversity loss and newly emerging zoonotic diseases together with reemerging infections (Barrett et al., 1998; Bevins, 2016; Chin et al., 2020; Pongsiri et al., 2009). Part of this literature claims that agricultural development and deforestation's effects on habitat loss and habitat fragmentation

together with the loss of predators that dilute pathogen transmission can ease the spread of such zoonotic diseases³ (Pongsiri et al., 2009; Marzal et al., 2011; Austin et al., 2017).

Regarding the characteristics of the above mentioned impacts, sustainability scholars claim the existence of an implicit anthropocentric bias in evaluating the relevance of biodiversity loss. One way of referring to this problem is by posing the following set of questions: should nature primarily be conserved for its production of ecosystem services for the benefit of humans? (Kueffer, 2019); what else is at stake besides the negative impacts on ecosystems that could affect human's well-being?; and last but not least, do other nonhuman forms of life lack intrinsic value for ethical consideration and protection? (Kopnina et al., 2018).

One non-anthropocentric approach to evaluate the consequences of human disturbances on ecosystems is to analyze its direct and indirect impacts on non-human species. Such approach has been developed by a growing body of scholars who have become deeply concerned with the rise of extinction of animal and plant species (Butaye et al., 2005; Crooks et al., 2017; Tracewski et al., 2016). Given the magnitude of anthropogenic pressures on the environment, researchers have aimed to quantify the current extinction rate of living species. Conservative figures estimate that the current rate of species loss over the last century is up to 100 times higher than the background rate in geological time (Ceballos et al., 2015; Turvey & Crees, 2019), whereas more pessimistic assessments suggest that this rate could actually be 1,000 times higher (Pimm et al., 2014). In light of the current extinction crisis, scholars have coined several terms and concepts to depict the current trends of biodiversity loss and extinction, such as 'the age of extinction' and the 'sixth mass extinction' (Swarts & Dixon, 2009; Naeem et al., 2012; Barnosky et al., 2011; Ceballos et al., 2015, 2017).

What is more, the extent of the anthropogenic impacts on the environment is so profound that scholars have proposed the existence of a new geological age in which human activities –and no longer natural processes- are the main drivers of change on the Earth system: the Anthropocene (Crutzen, 2006; Lewis & Maslin, 2015; Steffen et al., 2007). Still, while there is a general acceptance of the scale of such impacts, the start of this period has been intensively debated in academic circles. On the one hand, the 'early-anthropogenic view' affirms that global-scale human impacts can be traced up to the dawn of agriculture a few thousands years ago (Mitchell et al., 2013; Ruddiman, 2007, 2013), whereas, on the other hand, the 'industrial view' holds that such impacts have mainly occurred since the dawn of the industrial era. While most scholars concur that early anthropogenic impacts had significant dimensions, most of them agree with the 'industrial view' and its larger consequences. Arguments include the unprecedented increase of atmospheric carbon dioxide (CO₂) and methane (CH₄) concentrations and the global scale of the aforementioned anthropogenic pressures since the industrial revolution and specially since 'the Great Acceleration' circa the 1950s⁴ (Saounis et al., 2016; Steffen et al., 2015; Zalasiewicz et al., 2019).

Nonetheless, it is important to emphasize that these anthropogenic impacts are unevenly distributed and have different scales. In this way, regional assessments have provided important insights to understand the specific drivers and consequences of animal extinction at more nuanced levels and with more precision. A recent assessment of future land-

³ Nonetheless, there is a fierce debate regarding whether or not biodiversity loss eases the spread of pathogens. For a detailed critique of the 'dilution effect' in recent scholarship that actually suggests that biodiversity may contribute to an increase infectious disease risks see Wood et al (2014) and Tucker Lima et al (2017).

⁴ By May 2019, the Anthropocene Working Group from the International Commission on Stratigraphy had voted in favour of designing the Anthropocene as a new geological epoch starting in the mid-twentieth century.

use change scenarios from Powers & Jetz (2019) projected that most extinctions of mammals, birds and amphibians would occur in South American, Southeast Asian and African countries. Thus, in light of contemporary scholarship, it seems highly relevant to pay special attention to how and to what degree are tropical regions being affected by extinction risks and species loss. The next section will present some of the contemporary surveys and indicators on the state of biodiversity and biodiversity loss that will be used in this dissertation.

1.4. Indicators on the drivers of biodiversity loss and extinction risk

This dissertation builds upon previous research that evaluates the impact of various socioeconomic variables on the threat of extinction of animals. More specifically, this document intends to evaluate the interactions of the different socioeconomic drivers of the risk of extinction of the selected taxa in countries from the tropical region to identify the best model for understanding such outcome. Additionally, it conducts a similar analysis in each of the three tropical ecozones and discusses its specific dynamics.

The analysis assessed the different impacts of a series of socioeconomic predictors on the risk of extinction of mammals and birds at the national level. The selected socioeconomic variables were: i) human population density (McKee et al., 2004; Newbold et al., 2015; Sol, 2019), ii) population growth (Ceballos et al., 2017); iii) Gross Domestic Product (Bradshaw & Di Minin, 2019; Polaina et al., 2015), iv) share of agricultural land (Maxwell 2016; Polaina et al., 2015), v) cereal yield (Donald et al., 2006; Newbold et al., 2015; Tilman et al., 2017), vi) forest cover (Polaina et al., 2015), and vii) share of protected area (Prins et al., 2013; Geldmann et al. 2019). Additionally, the Human Development Index and the Biocapacity status (reserve or deficit) from the Global Footprint Network were included to analyze how they interacted with the risk of extinction of the selected taxa. Finally, this dissertation acknowledged the importance of geographic conditions for each of the selected countries, and for that reason it controlled the differentiated impacts depending on whether the cases were island or inland countries.

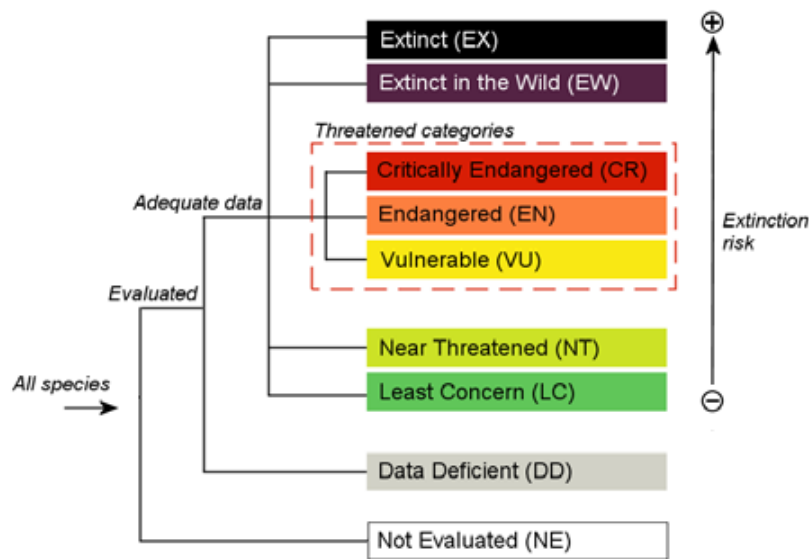
Before delving into the response variables, it is worth explaining the rationale behind the selection of the explanatory variables. As mentioned before, human consumption and its demand for resources act as key drivers of biodiversity loss (WWF, 2018). Therefore, this dissertation intends to test the effect of demographic variables, such as human population density and population growth. Regarding the predictors related to economic activities, GDP and the share of agricultural land serve as indicators of the size of an economy and are, therefore, useful tools to deepen the understanding of the magnitude of anthropogenic impacts on the environment. Regarding the problems related to agricultural land, various scholars claim that closing the yield gap could inflict less pressures on land (Mueller & Binder, 2015). Nonetheless, following the Jevons paradox, efficiency gains could not necessarily lead to resource savings (Pellegrini & Fernández, 2018). Thus, this document aims to test whether or not the effect of the cereal yield (measured in kilograms per hectare) reduces the extinction risk of the selected taxa. Finally, environmental variables were selected as mediating variables, such as forest cover, protected areas and the biocapacity status (reserve or deficit) to examine their effect on moderating the impact on biodiversity.

Since the beginning of the XXI century, indicators on the health of the world's biodiversity have proliferated and improved substantially. As it has been seen in previous pages, the Living Planet Index is based on a meta-analysis of various data sources and represents one of the most important indicators to account for the state of biodiversity.

However, it is by no means the only extensive source for biodiversity assessments. Other sources of data include the European Farmland Bird Index, the Wildlife Bird Index, among several others. For the purposes of assessing the anthropogenic impact on animal species, this dissertation will rely on the country level data from the Red List of Threatened Species (hereafter Red List) from the International Union for Conservation of Nature (IUCN).

The Red List is acknowledged as the world’s most comprehensive inventory of the conservation status of biological species and is widely used by decision-makers. Composed by more than 110,000 species assessed in the field since approximately two decades ago, the Red List is often referred to as a ‘barometer of life’. The Red List is based on 7 extinction risk categories, which are presented in the next figure:

Figure 1. Relationships between IUCN Red List categories



Source: IUCN 2012.

As Figure 1 shows, the IUCN Red List categories show to what extent a specific species is under extinction risk. It classifies a taxa as Data Deficient (DD) when appropriate data on abundance or distribution is lacking. DD together with Least Concern (LC) –which refers to widespread and abundant taxa- and Near Threatened (NT) -when a taxon is not threatened but is close to qualifying for or is likely to be threatened in the near future- do not represent any threat category. On the other hand, threatened categories are three: Vulnerable (VU), Endangered (EN) and Critically Endangered (CR). Finally, Extinct in the Wild (EW) and Extinct (EX) categories refer to exhaustive surveys that have failed to record an individual or when there is no reasonable doubt that the last individual has died. For more details on the criteria used on the categories of extinction risk (VU, EN and CR) used in this dissertation see Annex 2.

A considerable body of research has been possible due to the existence of the IUCN Red Lists. Based on its observational data, various assessments have been conducted on the driving forces of extinction risk, especially on mammals and birds (Di Marco et al., 2014; Geyle et al., 2018; Tilman et al., 2017; Torrecilha et al., 2018). The decision to privilege both taxonomic groups is based on the fact that vertebrates are among the better-documented species on Earth. Indeed, the IUCN affirms that mammals, birds, among other major taxonomic groups, have been ‘completely or almost completely assessed’ (IUCN 2020b). Therefore, selecting mammals and birds for the analysis can provide a comprehensive assessment of

how they are being impacted by anthropogenic pressures. Nonetheless, given the variety of ecozones within the tropical region, it is also important to conduct specific analysis at a more disaggregated level to explore its similarities and differences.

1.5. Objectives and structure of the dissertation

This dissertation aims to contribute to the literature of biodiversity loss and the threat of extinction of animals in the most biodiverse region of the world: the tropics. To do so, it aims to respond the following set of questions: what are the drivers of the threat of extinction of mammals and birds in the tropics?; what variables help to reduce such pressures?; which one of both taxonomic groups faces greater pressures of extinction?; are these processes homogenous in each of its ecozones?; what are the most pressing drivers per specific realm? To answer these questions, this dissertation carries out a multivariate analysis on the drivers of the risk of extinction of animals in the tropical region as a whole and in its three constituent ecozones: the Afrotropics, the Neotropics and the Indomalayan realm. Given the shared ecological and historical characteristics of the Afrotropics and Neotropics, the bulk of the comparative analysis and the discussion will be focused on these two ecozones.

After introducing some descriptive statistics and maps on the state of extinction risk in the tropics and in each ecozone, this document examines the role of the selected socioeconomic drivers on the threat of extinction of mammals and birds (categories VU, EN and CR) from the tropics as registered in the IUCN Red List. Each of these variables form part of wider dimensions that are included in the analysis. This includes: i) agriculture, ii) socioeconomic, iii) demographics and iv) environment.

The statistical analysis was conducted through the use of various Generalized Linear Model (GLM) for determining the best fit for the model of extinction risk of mammals and birds. As previously said, it also conducts the times series analysis and specific GLM analyses using the same independent variables and controls for each ecozone. In this way, this document intends to establish what drivers have the most important effects, as well as it aims to understand how environmental and socioeconomic variables can reduce such pressures. These specific assessments can help to guide more grounded policy responses to alleviate the identified pressures.

This introduction has presented a concise literature review of the global biodiversity status as well as some of the main drivers, consequences and indicators of biodiversity loss available. Chapter 2 gives a more detailed overview of the materials and methods used for the analysis. Chapter 3 shows the results through the use of graphs and maps, and it is followed by a discussion of the findings with the contemporary scholarship in Chapter 4. Finally, this dissertation closes with the conclusions and a series of recommendations for research and public policy in Chapter 5.

2. Materials and methods

This chapter provides more details into the selected variables for the statistical analysis and their sources of information. Despite IUCN data is available until 2019, data for the explanatory variables was non-existent for various countries for the same year. For this reason, the Generalized Linear Models relied on data from 2018 -or the last available year otherwise-. The set of explanatory and response variables together with their correspondent dimension, units and years are presented in the following table.

Table 1. Variables and units used in the analysis grouped by categories

Name	Units	Year ⁵
Independent variables		
I. Agriculture		
1. Agricultural land	Percentage of land area	2016
2. Cereal yield	Kg per hectare	2017
II. Demographics		
3. Population Growth	Annual percentage change	2018
4. Population density	Habitant/km ²	2018
III. Environment		
5. Forest Cover	Percentage of land area	2016
6. Protected area	Percentage of land area	2018
7. Biocapacity (reserve/deficit)	Global Hectare per capita footprint	2016
IV. Socioeconomic		
8. Gross Domestic Product	GDP in constant US\$ from 2010	2018
9. Human Development Index	Index from 0 to 1	2018
Response variables		
10. Endangered mammals	Percentage of endangered species	2018
11. Endangered birds	Percentage of endangered species	2018
Control		
12. Island/inland	Dummy variable (island=1, ~island=0)	-

In order to properly understand the set of explanatory and response variables, a more detailed description is required. The following table presents a more detailed description of each of the selected variables from their correspondent sources of information.

Table 2. Description of variables

Name	Description	Source
Independent variables		
I. Agriculture		
1. Agricultural land	Agricultural area includes arable land, permanent crops and permanent pastures and is expressed as a percentage of the total land area	FAO (2016)
2. Cereal yield	Cereal yield, measured as kilograms per hectare of harvested land, includes wheat, rice, maize, barley, oats, rye, millet, sorghum, buckwheat, and mixed grains. Data on cereals	FAO (2017)

⁵ Data for agricultural land, cereal yield and forest cover was not available for 2018. Therefore, the latest available data for these variables was compiled from years 2016 and 2017.

relate to crops harvested for dry grain only

II. Demographics

- | | | | |
|----|--------------------|---|----------------------|
| 3. | Population Growth | Population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship. Annual population growth rate for year t is the exponential rate of growth of midyear population from year $t-1$ to t , expressed as a percentage | World Bank
(2018) |
| 4. | Population density | Calculation of the total population divided by land area in km ² | World Bank
(2018) |

III. Environment

- | | | | |
|----|----------------------------------|--|----------------|
| 5. | Forest Cover | Forest area is land under natural or planted stands of trees of at least 5 m in situ, whether productive or not, and excludes tree stands in agricultural production systems (e.g. fruit plantations and agroforestry systems) and trees in urban parks and garden | FAO
(2018) |
| 6. | Protected area | Terrestrial protected areas are totally or partially protected areas of at least 1,000 hectares designated by national authorities as scientific reserves with limited public access, national parks, natural monuments, nature reserves or wildlife sanctuaries, protected landscapes, and areas managed mainly for sustainable use | WDPA
(2016) |
| 7. | Biocapacity
(reserve/deficit) | The difference between the biocapacity and Ecological Footprint of a region or country. An ecological deficit (-) occurs when the Footprint of a population exceeds the biocapacity of the area available to that population. Conversely, an ecological reserve (+) exists when the biocapacity of a region exceeds its population's footprint | GFN
(2016) |

IV. Socioeconomic

- | | | | |
|----|---|---|----------------------|
| 8. | Gross Domestic Product
(constant US\$2010) | GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products | World Bank
(2018) |
| 9. | Human Development Index | The Human Development Index (HDI) is a summary measure of average achievement in key dimensions of human development: a long and healthy life, being knowledgeable and have a decent standard of living. The HDI is the geometric mean of normalized indices for each of the three dimensions | UNDP
(2018) |

Response variables

- | | | | |
|-----|--------------------|--|----------------|
| 10. | Endangered mammals | Proportion of 'Vulnerable' (VU), 'Endangered' (EN) and 'Critically Endangered' (CR) mammals from total assessed mammal species | IUCN
(2018) |
| 11. | Endangered birds | Proportion of 'Vulnerable' (VU), 'Endangered' (EN) | |

	and 'Critically Endangered' (CR) birds from total assessed bird species	IUCN (2018)
Control		
12. Island/inland	Dummy variable (island=1, ~island=0)	-

As table 1 and 2 show, in addition to the socioeconomic predictors of extinction threat, mediating variables such as forest cover, protected area and the biocapacity reserve/deficit have been included. This dissertation aims to measure their impact on reducing the threats of extinction for the selected taxa. Finally, given the large differences between continental and island countries, a dummy variable for island and non-islands was created as a control variable to test if there were significant differences.

The statistical analysis was conducted through a set of Generalized Linear Models (GLM) for determining the best fit for assessing the drivers of the risk of extinction of mammals and birds. A logistic regression (logit) was conducted where the depended variable was coded as the probability of being endangered vs. not being endangered. In order to avoid the overfitting of adding too many parameters, the scoring and choosing among the various candidate models relied on a probabilistic model selection. This dissertation conducted two types of probabilistic model selection to evaluate the performance and complexity of the given models. The first method was the Akaike Information Criterion (AIC), which was obtained through forward selection. The second penalized-likelihood criteria incorporated for selecting the best model for endangered species was the Bayesian Information Criterion (BIC). All the analysis was conducted in R, a free software environment for statistical computing and graphics. Additionally, maps were elaborated with QGIS 2.18, a free and open source Geographic Information System software.

In order to fully explore the diversity of the data from tropical countries (n=90), this dissertation also conducted specific analysis for each of the three ecozones in the tropics (Afrotropics, Neotropics and Indomalayan). Nonetheless, after removing the null values the sample was reduced to a total of 71 observations. This removal mainly affected countries from the Neotropics. From a total of 33 countries, the set was reduced to only 19. Similarly, the Indomalayan region was affected by such removals. Their numbers dropped from 17 to 13. Afrotropical countries only lost one observation. For this reason, given the reduction in the number of observations, and also their shared ecological and historical characteristics, the comparative analysis and the bulk of the discussion will be focused on the Afrotropics and Neotropics.

This dissertation contains important limitations that need to be underscored. The first limitation is its reliance on primary data with information only at the national level. Despite some countries had data at the subnational level, they had to be discarded since few of the selected countries had IUCN Red List data at such level. Similarly, despite the existence of some 'national red lists' with sometimes different results from the IUCN Red List (Brito et al., 2010), few of the selected countries had such information, and even when they did so the last available year differed widely between them. Second, the times series analysis (2002-2019) at the beginning of Chapter 3 is based on absolute numbers rather than the proportion of endangered species from the total of assessed species per country⁶. Despite efforts to collect such data, the author was unable to acquire this information. Nonetheless, the GLM analysis is based on the proportion of endangered species (only for 2018). Third, some countries lacked considerable amounts of data for several of the predictors, and in consequence had to be

⁶ There was no publicly available assessment for the Red List in 2005.

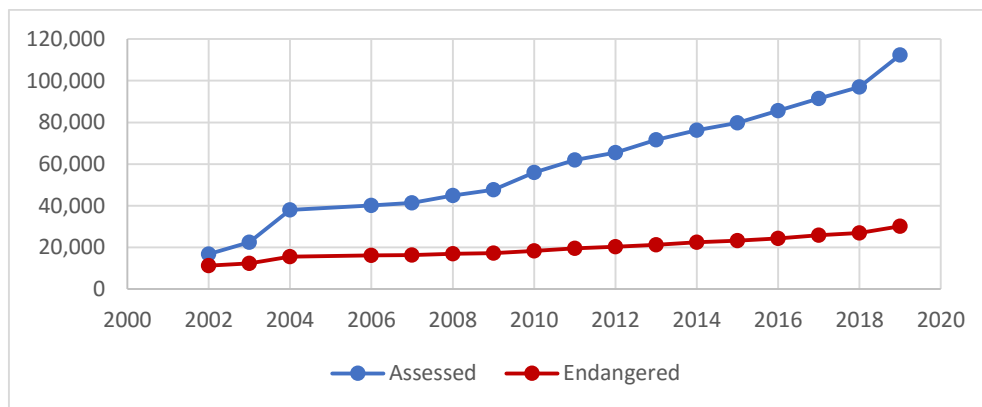
excluded from the analysis. However, when they had IUCN data regarding their threat of extinction they were considered for the elaboration of maps. Finally, biological traits of the selected taxa was not included in the analysis. Despite the proven usefulness of such sources of information, incorporating such elements was beyond the scope of this dissertation.

3. Results

3.1. Descriptive data analysis

The data analysis shows that as more species are assessed by the IUCN, the more of them are identified as being in risk of extinction. Indeed, assessment and endangered status are perfectly correlated ($r=0.99$). The amount of endangered animals is so high that from the more than 100,000 assessed species, around 25% of them are in the Vulnerable (VU), Endangered (EN) or Critically Endangered (CR) categories of extinction risk (IUCN, 2020a). Next graph shows the evolution of the number of assessed and threatened species over the last two decades.

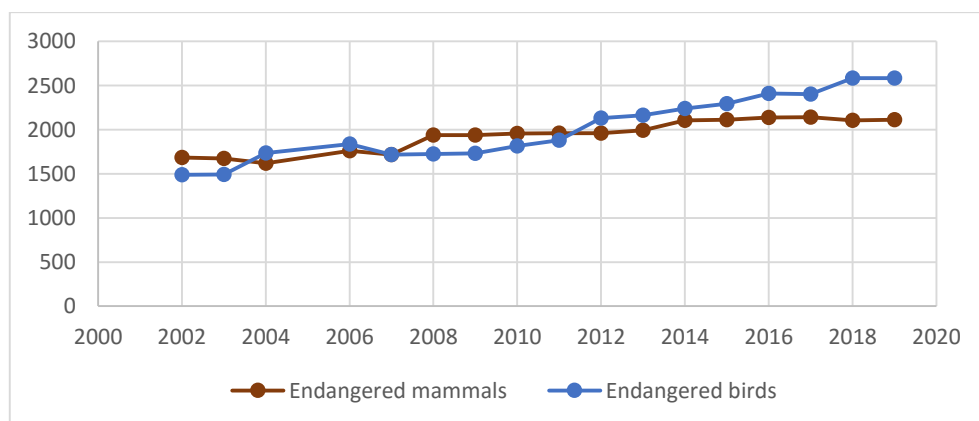
Figure 2. Assessed and threatened species in the IUCN Red List, 2002-2019



Source: IUCN Red List 2002-2019.

Mammals and birds are two taxonomic groups facing serious anthropogenic pressures that have increased their risk of extinction. Nonetheless, although they are intimately correlated ($r=0.82$), at first glance both groups show a different pace of extinction since their first assessment in 2002 until the last one in 2019. In the whole tropical region, the amount of threatened mammals increased from 1683 in 2002 to 2112 in 2019 (25.5%), whereas the amount of threatened birds significantly rose from 1487 in 2002 up to 2585 in 2019 (73.8%). This tendency is shown in the next figure.

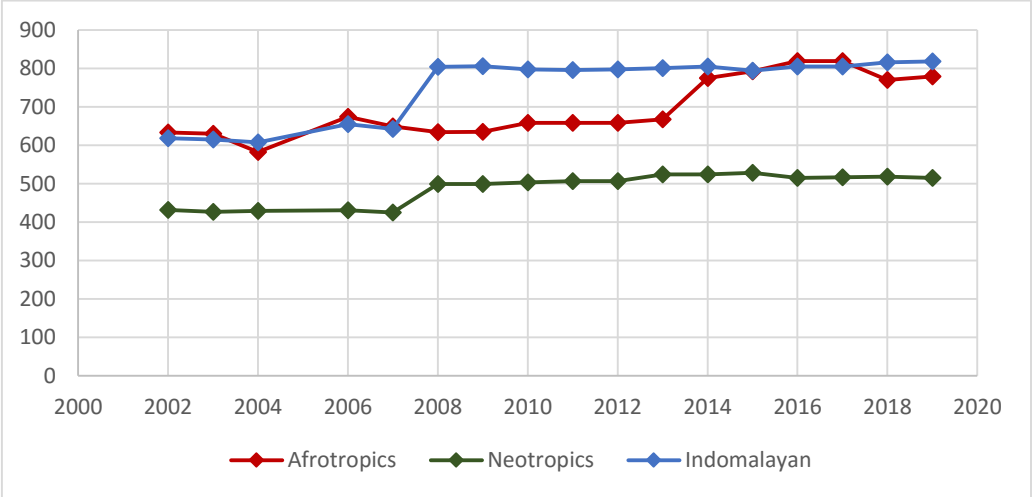
Figure 3. Evolution of mammals and birds under extinction risk in the tropics, 2002-2019



Source: IUCN Red List 2002-2019.

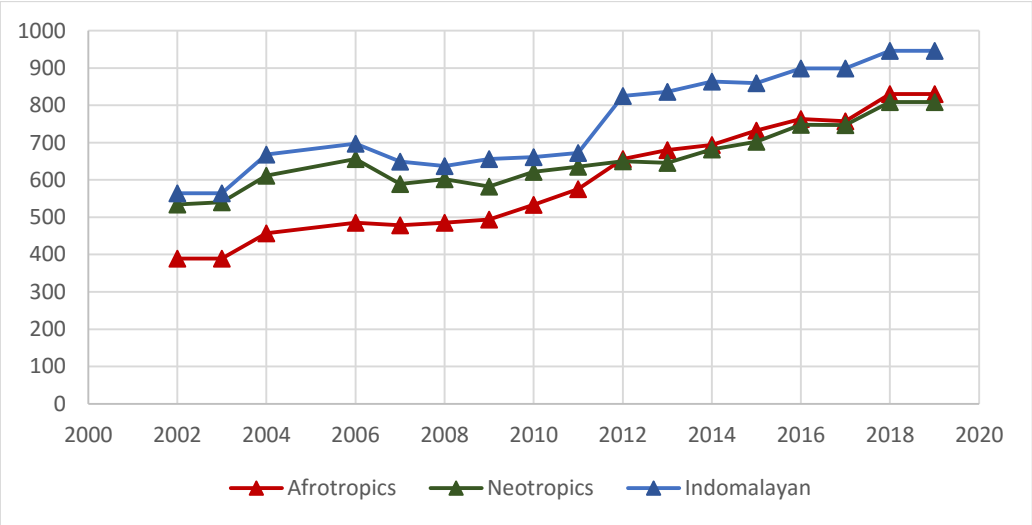
Figure 3 shows that birds experienced a more rapid increase of extinction risk than mammals. Nonetheless, given the different dynamics of the risk of extinction for both taxonomic groups and their inherent variations within the three ecozones of the tropical region, a more detailed picture is required. Figure 4 and figure 5 show the evolution of the threat of extinction for mammals and birds across the three constituent ecozones of the tropical region.

Figure 4. Mammals under threat of extinction in tropical ecozones, 2002-2019



Source: IUCN Red List 2002-2019.

Figure 5. Birds under threat of extinction in tropical ecozones, 2002-2019

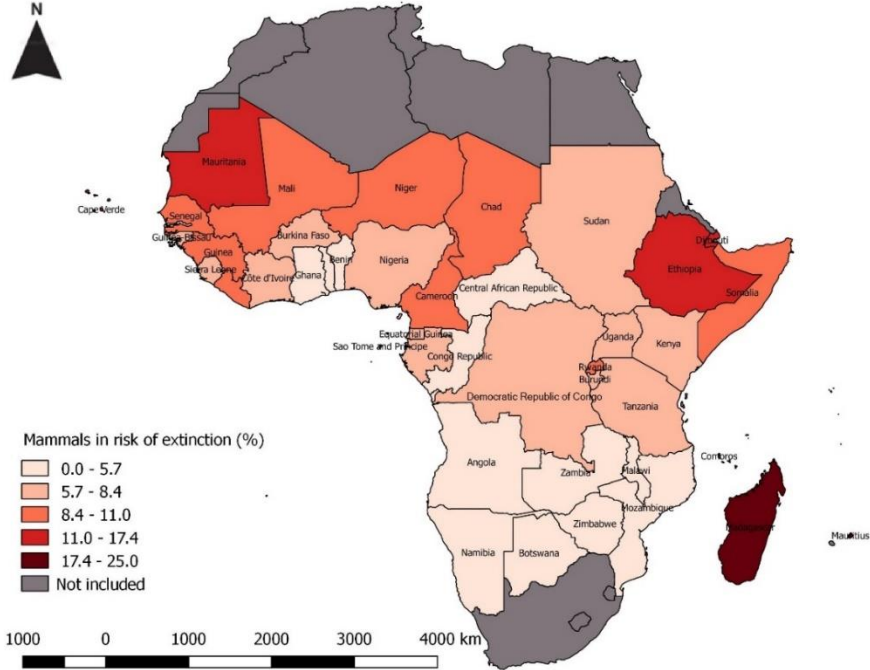


Source: IUCN Red List 2002-2019.

Figure 4 shows the increasing trend of endangered mammals in each of the tropical ecozones in the last two decades. The increase per realm is, from lower to higher, that of 19.2% in the Neotropics, 23.1% in the Afrotropics and 32.4% in the Indomalayan region for years 2002-2019. As mentioned before, birds have experienced a greater increase than mammals in the total amount of species that are under threat of extinction. Figure 5 shows, from lower to higher, that the share of birds in risk of extinction has increased in 51.5% in the Neotropics, 67.7% in the Indomalayan region, and, finally, more than 110% in the Afrotropics during 2002-2019.

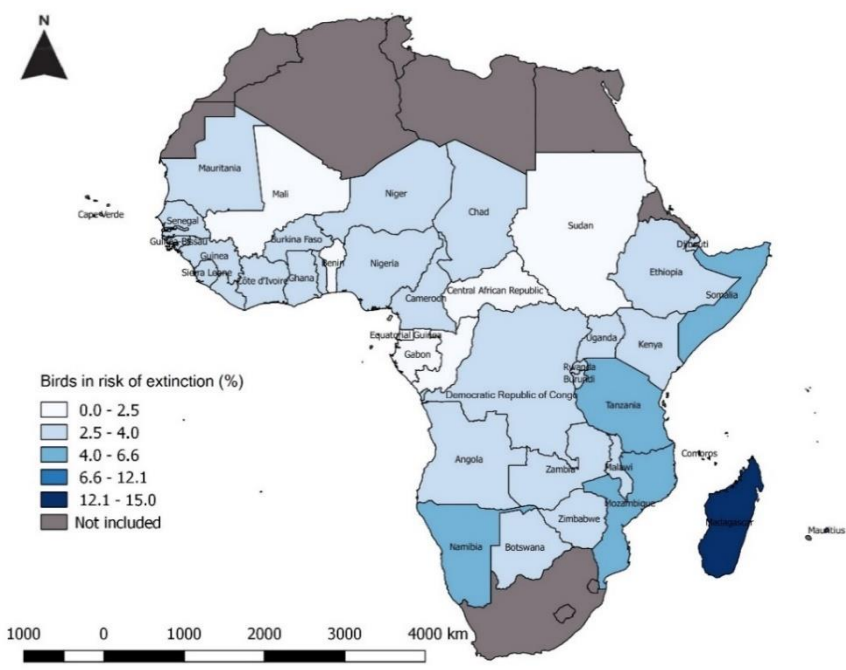
The Afrotropics accounts for nearly 37% of the endangered mammals and 29% of the endangered birds from the tropical region. The following maps represent graphically the share of endangered mammals and birds per country in the region excluding non-tropical countries.

Map 1: Endangered mammals in the Afrotropics, 2018



Source: IUCN 2018. Author’s elaboration.

Map 2: Endangered birds in the Afrotropics, 2018



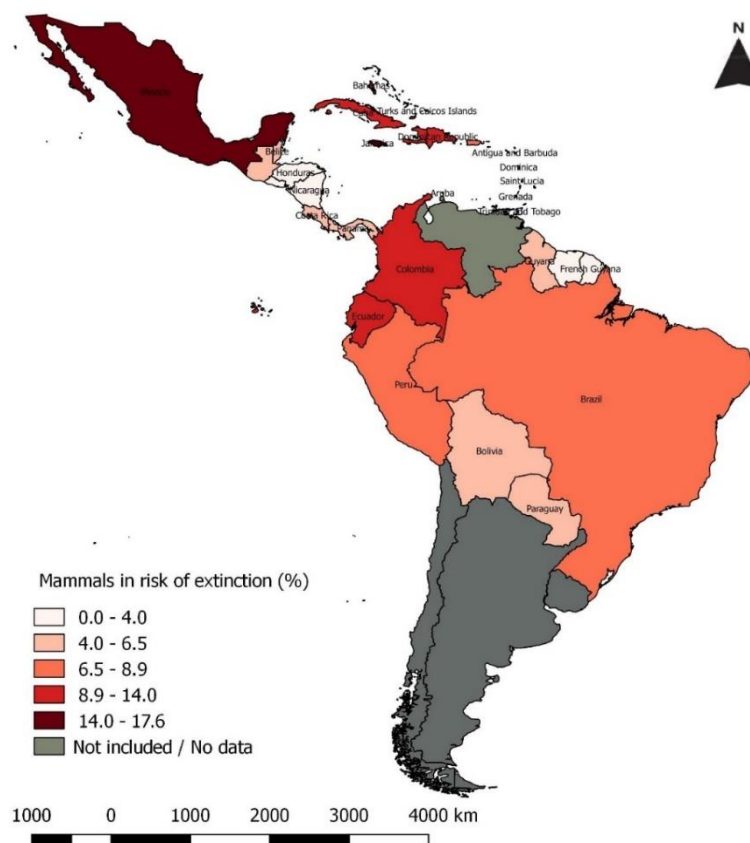
Source: IUCN 2018. Author’s elaboration.

Map 1 and Map 2 reflect different trends for endangered mammals and birds in the region. Whereas birds appear to be more endangered in Western Sub-Saharan Africa and

Eastern Sub-Saharan Africa, mammals seem to have the hardest pressures in Southeastern Sub-Saharan Africa. Besides these differences, both endangered mammals and birds share some similarities in some specific type of countries. Indeed, mammals and birds from islands –e.g. Madagascar, Mauritius- seem to have harder pressures than the rest of Sub-Saharan countries.

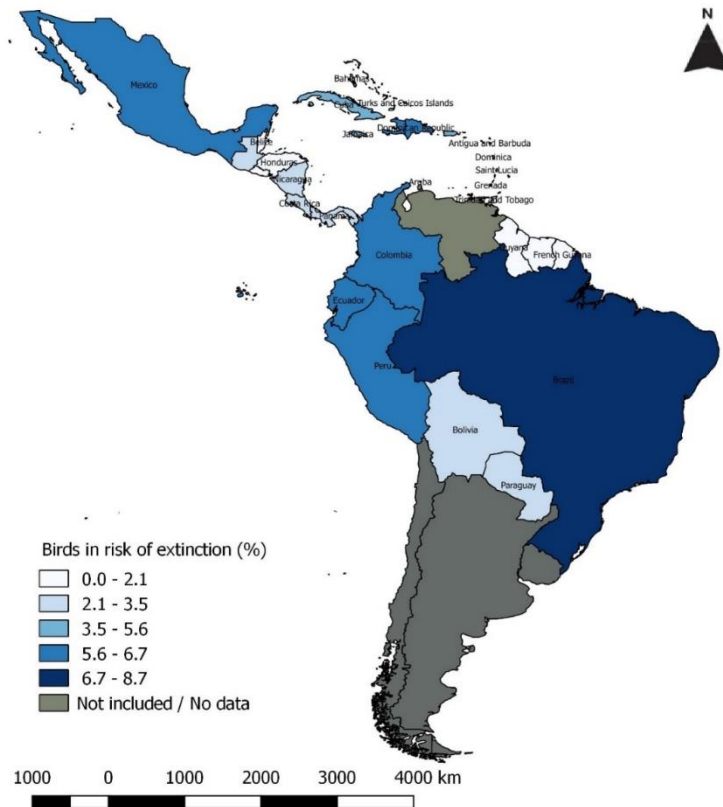
The Neotropics is the tropical ecozone with the smallest share of endangered mammals (approx. 25%). Nonetheless, the situation is rather the opposite for birds since it holds the biggest share of endangered birds (approx. 39%). As it can be seen in Map 3 and Map 4, endangered mammals and birds from the Neotropics share more aspects in common than species from the Afrotropics. Both sides of tropical South America show the high pressures for our selected taxa. More specifically, mammals from Ecuador and Colombia in northwestern South America face more pressures than the rest of the taxa, whereas birds from Brazil are the most endangered of the Neotropical region. On the other hand, pressures in Central America do not seem as high as in other parts of the continent both for mammals and birds, especially when compared with Mexico. Finally, mammals and birds from Caribbean islands are at more risk than taxa from continental countries, especially in the case of mammals.

Map 3: Endangered mammals in the Neotropics, 2018



Source: IUCN 2018. Author's elaboration.

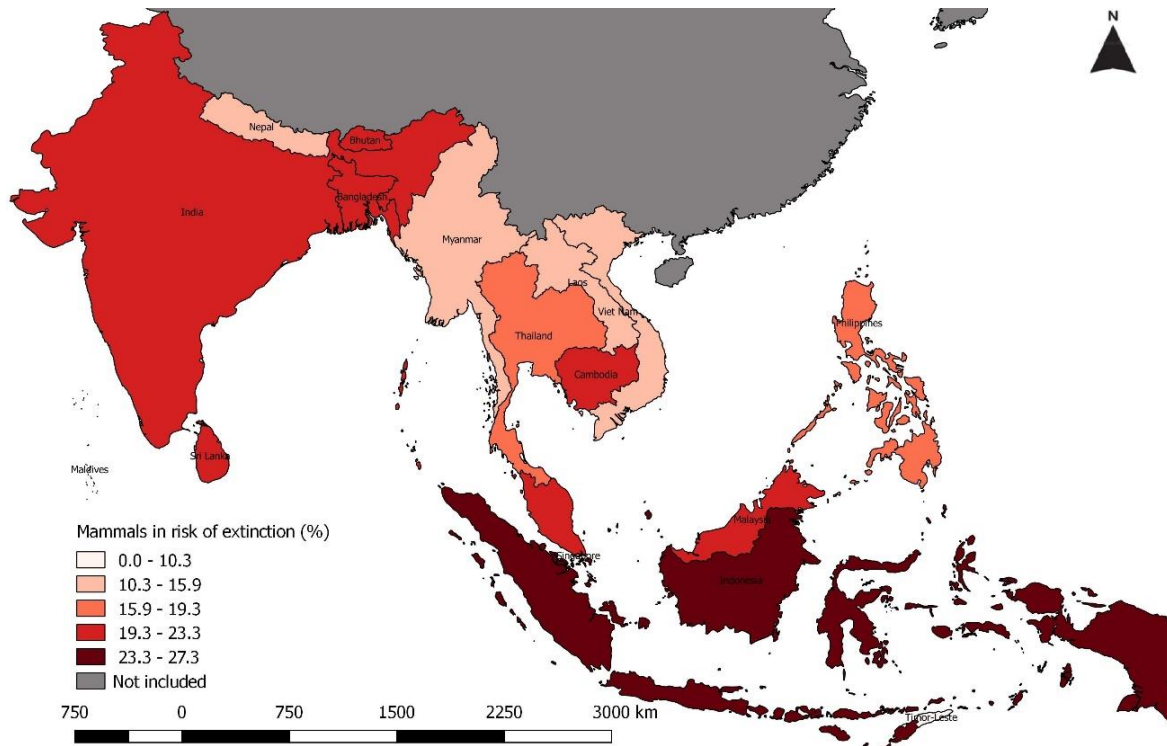
Map 4: Endangered mammals in the Neotropics (2018)



Source: IUCN 2018. Author's elaboration.

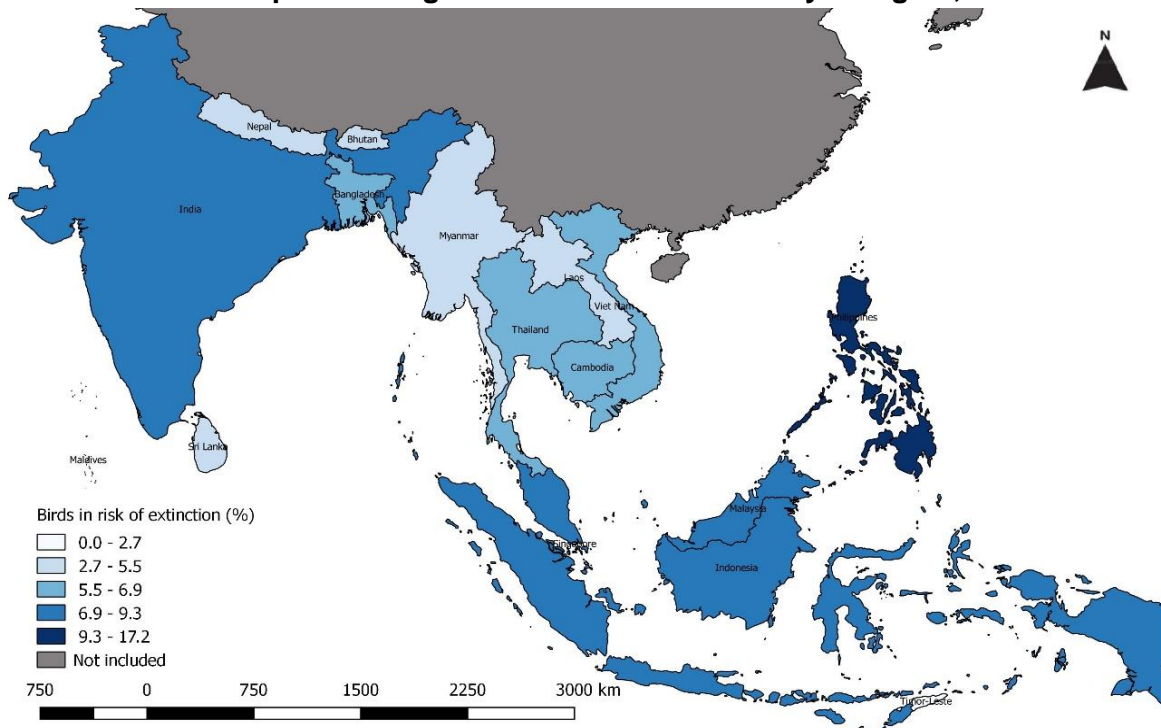
Finally, the Indomalayan region accounts for the biggest share of endangered mammals (Approx. 39%) and it is placed second in terms of endangered birds in the tropical region (Approx. 33%). As it can be seen in Map 5 and Map 6, endangered mammals and birds from the Indomalayan region portray rather a divergent picture. An important share of endangered mammals are concentrated in continental countries such as India and Bangladesh, but the strongest risk lies in the Southeastern part of the region, especially in the islands that comprise Indonesia. On the other hand, regarding bird species, they seem to have similar threats of extinction in countries from the Northwest and Southeast of the region, but the country that actually has the largest share of endangered bird species is the Philippines (Approx. 17%).

Map 5: Endangered mammals in the Indomalayan region, 2018



Source: IUCN 2018. Author's elaboration.

Map 6: Endangered birds in the Indomalayan region, 2018



Source: IUCN 2018. Author's elaboration.

The collection of maps from the three tropical ecozones shows that endangered mammals and birds face different degrees of risk of extinction. As mentioned before, on average bird species are more endangered than mammals. Geographically, the maps also portray a different picture where important variations on the threat of extinction of each taxa are found depending on their respective ecozone. Nonetheless, after having presented this preliminary and descriptive analysis, it is necessary to deepen the analysis and evaluate the possible driving forces that might be having an influence in the increase/decrease of their risk of extinction.

3.2. Multivariate analysis

3.2.1. Tropical region

The statistical analysis for this dissertation was based on 10 explanatory variables and 2 response variables. After removing the null observations and the factor variable (island dummy), the first step to get a preliminary understanding of the data was conducted through the elaboration of a correlation matrix (see Annex 3.1). The three strongest correlations between the explanatory variables with the response variables (both endangered mammal and bird species) are the following: 1) cereal yield, 2) population density, and 3) GDP. As it can be seen, some explanatory variables from similar dimensions show similar outcomes (agricultural land and cereal yield; forest cover and protected area), but also diverging results with the response variables (e.g. population growth and population density). In order to analyze them with more detail, a separate multivariate analysis was conducted for each taxonomic group. Before proceeding with the drivers of the risk of extinction in the tropical region it is necessary to find out whether the correlations from the matrix are significant or not. Figures in Annex 4.1 present preliminary linear regressions between a set of independent variables.

Annex 4.1 shows three sets of linear regression plots with the share of endangered mammals in countries from the tropical region. The first two comparative plots between agricultural land and cereal yield, and between protected area and forest cover reveal more insights than the correlation matrix previously shown. Indeed, the first set of plots shows that the share of agricultural land is not significantly correlated with the share of endangered mammals ($p=0.97$), whereas cereal yield is highly correlated ($p= 3.2e-05$). In this sense, cereal yield performs like a much better explanatory variable of endangered mammals than agricultural land. Similarly, the second set of plots portrays that forest cover association with the response variable is not significant ($p=0.37$), whereas protected areas have a significant correlation ($p=0.017$). Finally, the third set of plots reveals two problems. First, the contrasting tendencies between population density and population and, second, the existence of outliers in the first graph (population density). Nonetheless, after removing the outliers from the latter -Bangladesh, Mauritius and Rwanda-, its association with the response variable is still significant ($p=0.043$). For this reason, given that population density remains being significant after such modification, the two will be included in the full model to finally select the one that results with the smallest AIC.

Annex 4.2 shows three sets of linear regression plots with the share of endangered birds in countries from the tropical region. There, the first set of plots shows that the share of agricultural land is not significantly associated with the dependent variable at the 95% confidence interval ($p=0.099$), especially after comparing it with the association of the same variable with cereal yield ($p=0.00066$). Thus, cereal yield remains as a better explanatory variable than agricultural land for endangered birds too. The second set of plots portrays that

forest cover association with the response variable is not significant ($p=0.36$), whereas protected areas have a significant correlation ($p=0.056$). Finally, the third set reveals the same problems encountered with endangered mammals: outliers within the population density variable and contrasting tendencies between both predictors. However, in contrast with the last example, after removing the same outliers -Bangladesh, Mauritius and Rwanda-, the association becomes stronger (from 0.0021 to 0.00087), thus resulting in a more suitable predictor than population growth.

After removing agricultural land and forest cover for the above mentioned reasons, there are still 8 variables in the equation that are to be tested for the model selection. Thus, in order to use a forward selection method for choosing the final GLM, a null model and a full model from the binomial family with a logit link were constructed for each of the taxonomic groups.

Null model for the tropics:

$$\text{Ln}\left(\frac{\text{endangered}}{1-\text{endangered}}\right) = \beta_0 + \varepsilon_i$$

Full model for the tropics:

$$\text{Ln}\left(\frac{\text{endangered}}{1-\text{endangered}}\right) = \beta_0 + \beta_1\text{population growth}_1 + \beta_2\text{population density}_2 + \beta_3\text{biocapacity}_3 + \beta_4\text{protected area}_4 + \beta_5\text{GDP}_5 + \beta_6\text{HDI}_6 + \beta_7\text{cereal yield}_7 + \beta_8\text{island}_i + \varepsilon_i$$

The forward selection, a type of stepwise regression, provided various models that, starting from the null model, incorporated a new variable one by one. In each forward step, a new variable was added when it improved to the model. The selected model for endangered mammals was chosen based on the lowest Akaike Information Criterion (AIC= 506.47).

Table 3: Selected GLM for tropical endangered mammals (based on AIC)

<u>Coefficients:</u>	<u>Estimate</u>	<u>Std. Error</u>	<u>z value</u>	<u>Pr(> z)</u>
(Intercept)	-2.174e+00	1.764e-01	-12.326	< 2e-16 ***
Island(factor)	6.421e-01	8.176e-02	7.854	4.04e-15 ***
Cereal yield	1.938e-04	3.063e-05	6.326	2.51e-10 ***
Biocapacity(R/D)	-1.680e-02	3.626e-03	-4.633	3.61e-06 ***
Protected area	-1.456e+00	3.691e-01	-3.945	7.99e-05 ***
GDP	1.617e-04	4.530e-05	3.569	0.000359 ***
HDI	-7.497e-01	3.659e-01	-2.049	0.040459 *
Population density	2.717e-02	1.831e-02	1.484	0.137786

Null deviance: 543.47 on 70 degrees of freedom

Residual deviance: 184.31 on 63 degrees of freedom

AIC: 506.47

The selected GLM for endangered mammals has seven explanatory variables, instead of the eight variables from the original full model. The AIC penalized the model complexity of adding population growth and, thus, this variable was removed (otherwise the AIC would have been of 507.73). As it can be seen, the most significant predictors were, from higher to lower, being an island (factor), the output of cereal yield, the biocapacity (reserve/deficit), the share of protected area, GDP, HDI and, at a non-significant level population density. In order to get the specific value of the log odds ratios, the coefficients from the selected model were exponentiated.

Table 4: Odd ratios and confidence intervals (in descending order)

<u>Variable</u>	<u>Odds Ratio</u>	<u>2.5 %</u>	<u>97.5 %</u>
Island (factor)	1.9005	1.6179	2.2294
Population density	1.0275	0.9906	1.0644
Cereal yield	1.0002	1.0001	1.0003
GDP	1.0002	1.0001	1.0002
Biocapacity (R/D)	0.9833	0.9759	0.9899
HDI	0.4725	0.2303	0.9665
Protected area	0.2331	0.1127	0.4791
Intercept	0.1137	0.0803	0.1604

After transforming the odds ratio into percentages it was possible to assess the expected change in log odds of being endangered vs. not being endangered. As Table 5 shows, being an island has the strongest effect on the log odds. Indeed, the odds of being an endangered mammal from an island is 1.9 times the chance of being an endangered mammal in non-islands. Thus, the odds of being on risk of extinction for mammals from islands are about 90% higher than those from non-islands. Continuous predictors have a much lower effect as expected. Among them, population density, cereal yield and GDP affect log odds positively, whereas biocapacity (reserve or deficit), HDI and protected areas diminish the log odds of being endangered. From higher to lower, the log odds of being endangered are incremented in 2.75% by a one-unit increase in population density and in 0.02% by a one-united increase in cereal yield and GDP as well. On the other hand, protected areas decrease in 76% the log odds of being endangered, whereas a one-unite increase in HDI decreases in 52% the log odds of being endangered, and having a biocapacity reserve instead of a deficit decreases such log odds in 1.6%.

The second probabilistic model selection was the Bayesian Information Criterion (BIC). After calculating the BIC of the possible models, the selected model with the lowest BIC (522.3) had two less variables than the previous model based on the AIC. As it can be seen in the next table the final BIC model discarded the population density and HDI variables.

Table 5: Selected GLM for tropical endangered mammals (based on BIC)

<u>Coefficients:</u>	<u>Estimate</u>	<u>Std. Error</u>	<u>z value</u>	<u>Pr(> z)</u>
(Intercept)	2.408e+00	8.798e-02	-27.375	<2e-16 ***
GDP	1.571e-04	4.515e-05	3.481	5e-04 ***

Cereal yield	1.574e-04	2.464e-05	6.389	1.67e-10 ***
Protected area	-1.914e+00	3.207e-01	-5.968	2.41e-09 ***
Biocapacity (R/D)	-1.803e-02	3.565e-03	-5.058	4.23e-07 ***
Island (factor)	6.251e-01	8.092e-02	7.725	1.12e-14 ***

Null deviance: 543.47 on 70 degrees of freedom

Residual deviance: 190.55 on 65 degrees of freedom

BIC: 522.3

Contrary to the previous GLM, the above model, selected based on its BIC, privileged a more parsimonious model with less parameters. In this last model, the most significant predictors were, from higher to lower, being an island (factor), the output of cereal yield, the share of protected area, the biocapacity (reserve/deficit), and, finally, GDP. Similarly to the previous exercise, in order to get the specific value of their log odds ratios the coefficients were exponentiated.

Table 6: Odd ratios and confidence intervals (in descending order)

<u>Variable</u>	<u>Odds Ratio</u>	<u>2.5 %</u>	<u>97.5 %</u>
Island (factor)	1.8684	1.5930	2.1878
Cereal yield	1.0002	1.0001	1.0002
GDP	1.0002	1.0001	1.0002
Biocapacity (R/D)	0.9821	0.9748	0.9886
Protected area	0.1475	0.0784	0.2757
Intercept	0.0900	0.0756	0.1068

After transforming the odds ratio into percentages it was possible to assess the expected change in log odds of being endangered vs. not being endangered. As Table 5 shows, being an island has the strongest effect on the log odds. Indeed, the odds of being an endangered mammal from an island is 1.9 times the chance of being an endangered mammal in non-islands. Thus, the odds of being on risk of extinction for mammals from islands are about 90% higher than those from non-islands. Continuous predictors have a much lower effect as expected. Among them, population density, cereal yield and GDP affect log odds positively, whereas biocapacity (reserve or deficit), HDI and protected areas diminish the log odds of being endangered. From higher to lower, the log odds of being endangered are incremented in 2.75% by a one-unit increase in population density and in 0.02% by a one-unit increase in cereal yield and GDP as well. On the other hand, protected areas decrease in 76% the log odds of being endangered, whereas a one-unit increase in HDI decreases in 52% the log odds of being endangered, and a one-unit increase of biocapacity reserve decreases such log odds in 1.6%.

The model for endangered birds was chosen in a similar fashion than the one for endangered mammals. A forward selection was used starting from the same null model until

the same full model. The selected model was chosen based on the lowest Akaike Information Criterion (AIC= 609.34).

Table 7: Selected GLM for tropical endangered birds (based on AIC)

<u>Coefficients:</u>	<u>Estimate</u>	<u>Std. Error</u>	<u>z value</u>	<u>Pr(> z)</u>
(Intercept)	-3.465e+00	6.682e-02	-51.862	< 2e-16 ***
Cereal yield	1.432e-04	1.771e-05	8.081	6.43e-16 ***
Island (factor)	5.519e-01	5.857e-02	9.423	< 2e-16 ***
GDP	2.158e-04	3.232e-05	6.676	2.46e-11 ***
Biocapacity (R/D)	-1.349e-02	2.539e-03	-5.314	1.07e-07 ***
Protected area	-4.913e-01	2.260e-01	-2.173	0.0298 *

Null deviance: 689.48 on 70 degrees of freedom

Residual deviance: 247.49 on 65 degrees of freedom

AIC: 609.34

The selected GLM for endangered birds has five explanatory variables. Thus, this model has three less variables than the original full model and two less variables than the endangered mammals model (based on AIC). The removed variables were population growth, population density, and HDI. As it can be seen, the most significant predictors were, from higher to lower, being an island (factor), the output of cereal yield, GDP, the biocapacity (reserve/deficit) and the share of protected area, In order to get the specific value of the log odds ratios, the coefficients from the selected model were exponentiated.

Table 8: Odd ratios and confidence intervals (in descending order)

<u>Variable</u>	<u>Odds Ratio</u>	<u>2.5 %</u>	<u>97.5 %</u>
Island (factor)	1.7366	1.5471	1.9464
GDP	1.0002	1.0002	1.0003
Cereal yield	1.0001	1.0001	1.0002
Biocapacity (D/R)	0.9866	0.9815	0.9913
Protected area	0.6119	0.3923	0.9517
Intercept	0.0313	0.0274	0.0356

After transforming the odds ratio into percentages it was possible to assess the expected change in log odds of being an endangered bird vs. not being an endangered bird. As Table 9 shows, being an island has the strongest effect on the log odds. Indeed, the odds of being an endangered bird from an island is 1.73 times the chance of being an endangered

bird in non-islands. Thus, the odds of being on risk of extinction for birds from islands are about 73.6% higher than those from non-islands. Among the continuous predictors, cereal yield and GDP affect log odds positively, whereas biocapacity (reserve or deficit) and protected areas diminish the log odds of being endangered. From higher to lower, the log odds of being endangered are incremented in 0.02% by a one-unit increase in GDP and in 0.01% by a one-unit increase in cereal yield. On the other hand, protected areas decrease in 38% the log odds of being an endangered bird whereas a one-unit increase in biocapacity reserve decreases such log odds in 1.34%.

The second probabilistic model selection for endangered birds was the BIC. After calculating the BIC of the possible models, the selected model with the lowest BIC (622.91) contains the same variables and the same coefficients than the previous model based on the AIC. For such reason, no more description is required.

Given that the selected GLM for endangered birds based on the BIC is the same as the based on AIC no further description is required. The exponentiation of the coefficients gave the same results. Thus, the risk of extinction for birds from islands are about 73.6% higher than those from non-islands. Regarding the continuous predictors, from higher to lower, the log odds of being endangered are incremented in 0.02% by a one-unit increase in GDP and in 0.01% by a one-unit increase in cereal yield. On the other hand, protected areas decrease in 38% the log odds of being an endangered bird whereas a one-unit increase in biocapacity reserve decreases such log odds in 1.34%.

3.2.2. Afrotropics

Similar to the analysis conducted for the whole tropical region at the beginning of section 3.2.1, a correlation matrix was elaborated for the Afrotropics.(see Annex 3.2). The three strongest correlations between the explanatory variables with the response variables (both endangered mammal and bird species) are the following: 1) population density, 2) population growth, 2) and 3) protected area. As it can be seen, the impact of the explanatory variables on endangered mammals and birds is more diverse than in the whole tropical region. The p-values reveal that the associations between the response variables with agricultural land, biocapacity and GDP were not significant. These variables were excluded.

After removing those three variables for the above mentioned reasons, there remain 6 variables in the equation that are to be tested for the model selection. Thus, in order to use a forward selection method for choosing the final GLM, a null model and a full model from the binomial family with a logit link were constructed for each of the taxonomic groups.

Null model for the Afrotropics:

$$\text{Ln}\left(\frac{\textit{endangered}}{1 - \textit{endangered}}\right) = \beta_0 + \varepsilon_i$$

Full model for the Afrotropics:

$$\text{Ln}\left(\frac{\textit{endangered}}{1 - \textit{endangered}}\right) = \beta_0 + \beta_1 \textit{population growth}_1 + \beta_2 \textit{population density}_2 + \beta_3 \textit{forest cover}_3 + \beta_4 \textit{protected area}_4 + \beta_5 \textit{HDI}_5 + \beta_6 \textit{cereal yield}_6 + \beta_7 \textit{island}_i + \varepsilon_i$$

The forward selection, a type of stepwise regression, provided various models that, starting from the null model, incorporated a new variable one by one. In each forward step, a new variable was added when it improved to the model. The selected model for endangered mammals was chosen based on the lowest Akaike Information Criterion (AIC= 208.58).

Table 9: Selected GLM for afrotropical endangered mammals (based on AIC)

<u>Coefficients:</u>	<u>Estimate</u>	<u>Std. Error</u>	<u>z value</u>	<u>Pr(> z)</u>
(Intercept)	-2.447e+00	1.539e-01	-15.899	< 2e-16 ***
Island (factor)	6.364e-01	2.261e-01	2.815	0.00488 **
Protected area	-1.071e+00	4.815e-01	-2.224	0.02616 *
Cereal yield	1.654e-04	7.192e-05	2.299	0.02148 *
Forest cover	-4.360e-01	2.224e-01	-1.961	0.04994 *

Null deviance: 86.006 on 38 degrees of freedom				
Residual deviance: 34.867 on 34 degrees of freedom				
AIC: 208.58				

The selected GLM for endangered mammals has four explanatory variables, instead of the six variables from the original full model. The AIC penalized the model complexity of adding agricultural land, biocapacity and GDP. As it can be seen, the most significant predictors were, from higher to lower, being an island (factor), the share of protected area, the output of cereal yield and forest cover. In order to get the specific value of the log odds ratios, the coefficients from the selected model were exponentiated.

Table 10: Odd ratios and confidence intervals (in descending order)

<u>Variable</u>	<u>Odds Ratio</u>	<u>2.5 %</u>	<u>97.5 %</u>
Island (factor)	1.8896	1.1987	2.9110
Cereal yield	1.0002	1.0000	1.0003
Forest cover	0.6466	0.4170	0.9974
Protected area	0.3428	0.1325	0.8756
Intercept	0.0866	0.0639	0.1168

As Table 13 shows, being an island has the strongest effect on the log odds of being an endangered mammal in the Afrotropics. Indeed, the odds of being an endangered mammal from an island is 1.89 times the chance of being an endangered mammal in non-islands. Thus, the odds of being on risk of extinction for mammals from islands are about 89% higher than those from non-islands. Continuous predictors have a much lower effect as expected. Among them, cereal yield affects log odds positively, whereas forest cover and protected area diminish

the log odds of being endangered. The log odds of being endangered are incremented in 0.02% by a one-unit in cereal yield. On the other hand, a one-unit increase in forest cover decreases in 35% the log odds of being endangered, whereas a one-unit increase in the percentage of protected area decreases in 65.7% the log odds of being endangered.

The second probabilistic model selection was the Bayesian Information Criterion (BIC). After calculating the BIC of the possible models, the selected model with the lowest BIC (216.9) contained the same variables and the same coefficients than the previous model based on the AIC. For this reason, no further description is required for the BIC model.

The model for endangered birds was chosen in a similar fashion than the one for afro-tropical endangered mammals. A forward selection was used starting from the same null model until the same full model. The selected model was chosen based on the lowest Akaike Information Criterion (AIC= 241.3).

Table 11: Selected GLM for afro-tropical endangered birds (based on AIC)

<u>Coefficients:</u>	<u>Estimate</u>	<u>Std. Error</u>	<u>z value</u>	<u>Pr(> z)</u>
(Intercept)	-3.40120	0.03834	-88.71	<2e-16 ***
islandYes	1.46220	0.12350	11.84	<2e-16 ***

Null deviance: 157.336 on 38 degrees of freedom

Residual deviance: 54.023 on 37 degrees of freedom

AIC: 241.3

The above model portrays a very different picture from previous models. In this case, the AIC penalized the inclusion of all the predictors with the only exception of the dummy variable (island / non-island). Nonetheless, the performance of such variable is quite remarkable. As Table 13 shows, after the exponentiation of the coefficients of the AIC model for afro-tropical birds, the results reveal that the odds of being an endangered bird from an island is 330% higher than the chance of being an endangered bird in non-islands.

Table 12: Odd ratios and confidence intervals (in descending order)

<u>Variable</u>	<u>Odds Ratio</u>	<u>2.5 %</u>	<u>97.5 %</u>
Island (factor)	4.31542461	3.366754	5.466524
Intercept	0.0333333	0.030893	0.035903

After calculating the BIC of the possible models, the selected model was the same from the AIC selection. Thus, the lowest BIC (244.63) was found in the model that only contained island as an explanatory variable. No further description is required for the BIC model nor its coefficients.

3.2.3. Neotropics

Observation from the Neotropics were drastically reduced after eliminating the null values. Indeed, from the original 33 observations, this number dropped to 19. Similar to the analysis conducted for the whole tropical region at the beginning of section 3.2.1, a correlation matrix was elaborated for the Neotropics (see Annex 3.3). As it can be seen, this reduction rendered all possible associations with the explanatory variables not significant. For this reason, no GLM was built assessing the risk of extinction of neotropical mammals nor birds.

4. Discussion

This dissertation tested a set of multivariate models to understand the impact of various socioeconomic and environmental factors on the risk of extinction of mammals and birds in the tropics. The discussion of its results and its limitations –as well as its implications- conveys various topics that will be laid out here separately. First, the methodological limitations will be discussed.

Through the compilation of data from the IUCN Red List, a database was elaborated with a total of 90 tropical countries from the Afrotropics, the Neotropics and the Indomalayan region. The selection of the best model relied on two techniques: the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). The main objective was to determine the best model for explaining the endangered status of mammals and birds at the level of the whole tropical region and also at each one of its constituent ecozones. In order to carry such analysis, a forward selection method was used. Nonetheless, such method demanded the elimination of null variables from the dataset. In doing so, the number of observations dropped from 90 to 71. The elimination of observations based on null values affected the three ecozones in different degrees. By far, the most affected region was the Neotropics, whose numbers dropped from 33 to 19. Similarly, although at a lesser degree, the Indomalayan region experienced a reduction from 17 observations to 13. Under these circumstances, no sub GLM was elaborated for any of them.

In any case, elaborating small subsets for each ecozone was a difficult task given the limited amount of data for the predictors and the abundance of null values for various of the predictors. Indeed, although not explicitly mentioned in the methodological section, other socioeconomic variables were intended to be tested in the model selection, but had to be deleted due to their limited availability. One of these examples is the GINI index, which is non-existent for various countries or when found, the last year of its elaboration varies widely between different countries, thus making it difficult to include them in the analysis.

Nonetheless, besides this problem of scale for more narrow regions (with fewer observations), the GLM for the whole tropical region was constructed. The best fit for the tropical GLM was based on the AIC and the BIC for both endangered birds and mammals of the 71 selected countries from the tropics. As expected, the BIC favored a more parsimonious model with less variables than the AIC-selected model. Both of them provided various insights that can serve to establish a discussion with the literature.

The most consistent finding of this dissertation was the overall importance of geographical characteristics beyond other socioeconomic predictors. Indeed, all models presented the island factor as the most important element in advancing the risk of extinction of both mammals and birds. In the case of the tropical region as a whole, mammals and birds from islands were 90% and 86% more prone to be endangered than their counterparts from non-islands. This contrasting situation between inland and island countries is of particular relevance, especially at a more narrow level. Indeed, in the only subset that was elaborated (for the Afrotropics), birds from islands were 330% more prone to be endangered than their counterparts from non-islands. Other threats not included in this analysis such as invasive species or habitat fragmentation could be accountable for such outcome.

Although additional predictors were not incorporated for assessing the specific characteristics of islands, the findings from this dissertation are consistent with the literature that highlights the special vulnerability of species from islands with regards to continental countries (Russell & Kueffer, 2019). Both island's mammals and birds from the first to the third quartile ranges were more endangered than their counterparts from continental countries.

However, those pressures had different magnitudes between the two selected taxa. Indeed, 7 out of the 10 tropical countries with the largest number of endangered birds were island countries. In the case of endangered mammals the distribution was more fair: 50% for islands and 50% for non-islands. Thus, given the alarming pressure on birds, more attention is needed for assessing the specific drivers of the risk of extinction of these and other taxonomic groups in tropical islands.

A second contribution from this dissertation relied on the hierarchization of the assessed anthropogenic pressures together with the variables that can contribute to reduce the extinction risks. Previous works have successfully conducted global and regional assessments on the driving factors of the extinction risk of animal species (Hosonuma et al., 2012; Tilman et al 2017). This dissertation dialogues with the literature by providing not only a set of driving forces that threaten animals with extinction, but it also aims to establish which variables can contribute to reduce such negative impacts. Thus, based on the AIC model for endangered tropical mammals, the order of pressures excluding the island factors was, from higher to lower, i) population density, ii) cereal yield, and iii) GDP. In the case of the BIC model, the variable population density was removed. The remaining variables GDP together with cereal yield had a very similar and minuscule effect (0.02%).

It was particularly revealing to find that the share of agricultural land was not significantly associated with any of the response variables. However, a more narrow level of analysis with less variation between countries could bring different results for such predictor. In contrast, cereal yield constantly appeared as a driving force on the extinction risk of mammals and birds. This is highly relevant given that several times it has been proposed as a way to alleviate pressures on the land –and therefore on animals-. As the models show, the output of cereal yield (measured in kg/ha) actually appeared as a significant contributor to the extinction risk for both tropical mammals and birds in almost all the selected models. This case shows how the Jevons paradox depicts the limitations of relying on resource efficiency improvements and technology to assess the contemporary challenges of biodiversity (Alcott, 2005).

Regarding the model selection, both the AIC and BIC methods provided consistent models for assessing the drivers of extinction risk. The inclusion of both methods responded to the need to overcome the specific trade-offs of relying in only one method and, additionally, it intended to identify which predictors would be selected by both of them. The predictors that were simultaneously chosen by the AIC and BIC methods -besides the island factor- were GDP, cereal yield, protected area and biocapacity. These findings are consistent with the literature (Sol 2019; Bradshaw & Di Minin, 2019). Other variables such as the Human Development Index were also associated with less chances of being endangered, although at a much lower frequency.

The inclusion of the biocapacity predictor aimed to incorporate a fresh tool to the analysis besides traditional variables, such as GDP or protected area. Despite its last year of assessment –in the report from 2019- was that of 2016, it was significantly associated with a decrease in the log odds of being endangered both for mammals and birds in the AIC and BIC models. More indexes that account for environmental performance are needed to assess how they can reduce the extinction risks of animals.

After verifying the lack of significance in the correlation matrixes of the Neotropical and Indomalayan region (see Annex 3), the descriptive comparison between the ecozones was discarded. Still, the GLM for the Afrotropics was elaborated and it possess some characteristics that deserve to be highlighted. First, it is the ecozone that lost the smallest

amount of observations after the removal of the null values. In general, the included observations in the Afrotropics subset for endangered mammals have a pretty accurate representation of the total of Sub-Saharan countries. Therefore, it is worth mentioning how the variables related to the agricultural dimension (agricultural land and cereal yield) became not significant when assessed at this more narrow level (without bulks of missing values). Similarly, it is worth noting that no population variables were significant in the logit model -although they were significantly correlated with the percentage of endangered mammals and birds-. On the contrary, a predictor that had not appeared before, forest cover, came into scene at this specific level as a variable that decreased in 35% the log odds of being endangered.

Despite the aforementioned limitations of relying on primary data for the elaboration of the models, it is clear that more international assessments are required to have a better picture of the national variations. Naturally, such analysis would benefit from incorporating observations at the subnational level, but as the sample from this dissertation has shown there are important limitations regarding the quality and availability of data at the national level. Therefore, there is still much to be done in terms of data to be able to conduct more refined and comprehensive analyses.

5. Conclusions

Biodiversity loss and species loss are one of the greatest contemporary challenges for the Earth system. Although an important part of concerns on the state of biodiversity are based on the potential negative impacts on ecosystem services enjoyed by humans, this dissertation aimed to go beyond such anthropocentric approaches to understand the specific impacts on biodiversity. In that way, the analysis was focused on analyzing the impacts of a set of various anthropogenic impacts on the extinction risk of mammals and bird species from the tropics. Such approach is highly relevant given the rapid pace of the extinction risk for several non-human species around the globe. The tropics, where an important bulk of biodiversity is concentrated, has been identified as the region where most extinction of mammals, birds and amphibians will occur in the near future. Therefore, this dissertation focused its scope on such region.

Through the use of Generalized Linear Models this dissertation aimed to select the best models for accounting different predictors that have an impact on the extinction risk of animals. The specific taxonomic groups that were evaluated in the analysis were mammals and birds since they are among the better-documented species and are considered as 'completely or almost completely assessed' by the IUCN.

The analysis included four interconnected dimensions: agriculture, demography, environment and socioeconomic aspects. Each model selected different predictors from those dimensions depending on the type of taxa being assessed and depending on the type of criterion used for the model selection. However, those pressures had different magnitudes between the two selected taxa, which also varied depending on their geographical location. Indeed, results showed that bird species from islands were more prone to be endangered than mammals species.

What is more, the most consistent finding in all the models was the overall importance of the geographical characteristics beyond other socioeconomic predictors. Indeed, all models presented the island factor as the most important element in advancing the risk of extinction of both mammals and birds. Continuous predictors such as GDP and cereal yield also had a significant association with the probability of being at risk of extinction, although minuscule.

Results from the analysis also provided various insights on predictors that can diminish the extinction risk for animals. Among these, protected areas appeared recurrently as the best predictor for alleviating such risks. Other variables such as the Human Development Index and the biocapacity reserve of some countries were also associated with less chances of being endangered, although at a much lower frequency.

This dissertation aims to serve as an assessment that reveals the strengths and limitations of relying on primary data for evaluating the risk of extinction of animals. Despite a regional evaluation of the various countries from the tropical region is a much needed exercise, the limitations and the quality of the data pose several constraints to the researcher that aims to conduct a proper analysis. Although more grounded levels of analysis are useful for advancing the understanding of more localized impacts, It is clear that there is still much to be done in terms of data availability and quality at broader levels to be able to conduct more refined and comprehensive analyses.

References

- Alcott, B. (2005). Jevons' paradox. *Ecological economics*, 54(1), 9-21.
- Araujo, B. B., Oliveira-Santos, L. G. R., Lima-Ribeiro, M. S., Diniz-Filho, J. A. F., & Fernandez, F. A. (2017). Bigger kill than chill: The uneven roles of humans and climate on late Quaternary megafaunal extinctions. *Quaternary International*, 431, 216-222.
- Austin, K. F., Bellinger, M. O., & Rana, P. (2017). Anthropogenic forest loss and malaria prevalence: a comparative examination of the causes and disease consequences of deforestation in developing nations. *AIMS Environ Sci*, 4, 217-231.
- Barlow, J., Lennox, G. D., Ferreira, J., Berenguer, E., Lees, A. C., Mac Nally, R. & Parry, L. (2016). Anthropogenic disturbance in tropical forests can double biodiversity loss from deforestation. *Nature*, 535(7610), 144-147.
- Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O. U., Swartz, B., Quental, T. B., ... Ferrer, E. A. (2011). Has the Earth's sixth mass extinction already arrived? *Nature*, 471(7336), 51–57.
- Barrett, R., Kuzawa, C. W., McDade, T., & Armelagos, G. J. (1998). Emerging and re-emerging infectious diseases: the third epidemiologic transition. *Annual review of anthropology*, 27(1), 247-271.
- Bellard, C., Cassey, P., & Blackburn, T. M. (2016). Alien species as a driver of recent extinctions. *Biology letters*, 12(2), 20150623.
- Bevins, S. (2016). Pathogen Emergence in the Age of Pandemics. *BioScience*, Volume 66, Issue 5, 01 May 2016, 421–423.
- Bradshaw, C. J. A., & Di Minin, E. (2019). Socio-economic predictors of environmental performance among African nations. *Scientific Reports*, 9(1), 1–13.
- Brashares, J. S. (2003). Ecological, behavioral, and life-history correlates of mammal extinctions in West Africa. *Conservation Biology*, 17(3), 733-743.
- Brashares, J. S., Arcese, P., & Sam, M. K. (2001). Human demography and reserve size predict wildlife extinction in West Africa. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 268(1484), 2473-2478.
- Brito, D., Ambal, R. G., Brooks, T., De Silva, N., Foster, M., Hao, W., ... & Rodríguez, J. V. (2010). How similar are national red lists and the IUCN Red List?. *Biological Conservation*, 143(5), 1154-1158.
- Butaye, J., Adriaens, D., & Honnay, O. (2005). Conservation and restoration of calcareous grasslands: a concise review of the effects of fragmentation and management on plant species. *BASE*.
- Campbell, B. M., Beare, D. J., Bennett, E. M., Hall-Spencer, J. M., Ingram, J. S., Jaramillo, F., ... & Shindell, D. (2017). Agriculture production as a major driver of the Earth system exceeding planetary boundaries. *Ecology and Society*, 22(4).
- Cardinale, B. J., Duffy, J. E., Gonzalez, A., Hooper, D. U., Perrings, C., Venail, P., ... Grace, J. B. (2012). Biodiversity loss and its impact on humanity. *Nature*, 486(7401), 59–67.
- Carpio, A. J., Álvarez, Y., Oteros, J., León, F., & Tortosa, F. S. (2020). Intentional introduction pathways of alien birds and mammals in Latin America. *Global Ecology and Conservation*, e00949.

- Ceballos, G., Ehrlich, P. R., & Dirzo, R. (2017). Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines. *Proceedings of the National Academy of Sciences of the United States of America*, 114(30), E6089–E6096.
- Ceballos, G., Ehrlich, P. R., Barnosky, A. D., García, A., Pringle, R. M., & Palmer, T. M. (2015). Accelerated modern human-induced species losses: Entering the sixth mass extinction. *Science Advances*, 1(5), 9–13.
- Chaber, A. L., & Cunningham, A. (2016). Public health risks from illegally imported African bushmeat and smoked fish: Public health risks from African bushmeat and smoked fish. *EcoHealth*, 13(1), 135–138.
- Chazdon, R. L., Broadbent, E. N., Rozendaal, D. M., Bongers, F., Zambrano, A. M. A., Aide, T. M., ... & Craven, D. (2016). Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. *Science Advances*, 2(5), e1501639.
- Chin, A., Cui, X., Gillson, L., Nelson, D., Taylor, M. P., Vanacker, V., & Wang, E. (2020). Anthropocene in an age of pandemics. *Anthropocene* 2020 May 18: 100247.
- Cowlishaw, G., Mendelson, S., & Rowcliffe, J. M. (2005). Evidence for post-depletion sustainability in a mature bushmeat market. *Journal of applied ecology*, 42(3), 460-468.
- Crooks, K. R., Burdett, C. L., Theobald, D. M., King, S. R., Di Marco, M., Rondinini, C., & Boitani, L. (2017). Quantification of habitat fragmentation reveals extinction risk in terrestrial mammals. *Proceedings of the National Academy of Sciences*, 114(29), 7635-7640.
- Crutzen, Paul J. (2006). "The "anthropocene"." *Earth system science in the anthropocene*. Springer, Berlin, Heidelberg, 2006. 13-18.
- Csillik, O., Kumar, P., Mascaro, J., O'Shea, T., & Asner, G. P. (2019). Monitoring tropical forest carbon stocks and emissions using Planet satellite data. *Scientific reports*, 9(1), 1-12.
- Cuckston, T. (2018). Making extinction calculable. *Accounting, Auditing & Accountability Journal*, 31(3), 849-874.
- Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science*, 361(6407), 1108-1111.
- De Boer, W. F., van Langevelde, F., Prins, H. H., De Ruiter, P. C., Blanc, J., Vis, M. J., ... & Hamilton, I. D. (2013). Understanding spatial differences in African elephant densities and occurrence, a continent-wide analysis. *Biological Conservation*, 159, 468-476.
- Di Marco, M., Marasini, G. G., Boitani, L., Rondinini, C., Buchanan, G. M., Szantoi, Z., ... Tranquilli, S. (2014). Drivers of extinction risk in african mammals: The interplay of distribution state, human pressure, conservation response and species biology. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1643).
- Díaz, S., Fargione, J., Chapin III, F. S., & Tilman, D. (2006). Biodiversity loss threatens human well-being. *PLoS Biol*, 4(8), e277.
- Díaz, S., Fargione, J., Chapin III, F. S., & Tilman, D. (2006). Biodiversity loss threatens human well-being. *PLoS Biol*, 4(8), e277.
- Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Agard, J., Arneth, A., ... & Garibaldi, L. A. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science*, 366(6471).

- Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Agard, J., Arneth, A., ... & Garibaldi, L. A. (2019). Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science*, 366(6471).
- Donald, P. F., Sanderson, F. J., Burfield, I. J., & Van Bommel, F. P. (2006). Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000. *Agriculture, Ecosystems & Environment*, 116(3-4), 189-196.
- Falk, H., Dürr, S., Hauser, R., Wood, K., Tenger, B., Lörtscher, M., & Schuepbach-Regula, G. (2013). Illegal import of bushmeat and other meat products into Switzerland on commercial passenger flights. *Revue scientifique et technique-Office international des épizooties*, 32(3), 727-39.
- Felbab-Brown, V. (2017). *The Extinction Market: Wildlife Trafficking and How to Counter It*. London: C Hurst & Co Publishers Ltd.
- Franklin, S. L., & Pindyck, R. S. (2018). Tropical forests, tipping points, and the social cost of deforestation. *Ecological Economics*, 153, 161-171.
- Geldmann, J., Manica, A., Burgess, N. D., Coad, L., & Balmford, A. (2019). A global-level assessment of the effectiveness of protected areas at resisting anthropogenic pressures. *Proceedings of the National Academy of Sciences*, 116(46), 23209-23215.
- Gepts, P. (2008). Tropical environments, biodiversity, and the origin of crops. In *Genomics of tropical crop plants* (pp. 1-20). Springer, New York, NY.
- Geyle, H. M., Woinarski, J. C., Baker, G. B., Dickman, C. R., Dutson, G., Fisher, D. O., ... & Legge, S. (2018). Quantifying extinction risk and forecasting the number of impending Australian bird and mammal extinctions. *Pacific Conservation Biology*, 24(2), 157-167.
- Giam, X. (2017). Global biodiversity loss from tropical deforestation. *Proceedings of the National Academy of Sciences*, 114(23), 5775-5777.
- Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., & Foley, J. A. (2010). Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. *Proceedings of the National Academy of Sciences*, 107(38), 16732-16737.
- Global Environmental Facility – GEF (2018). *Combating Illegal Wildlife Trade*. Retrieved from: https://www.thegef.org/sites/default/files/publications/GEF_CombatingIWT2018_CRA.pdf
- Gonzalez, A., Cardinale, B. J., Allington, G. R., Byrnes, J., Arthur Endsley, K., Brown, D. G., ... & Loreau, M. (2016). Estimating local biodiversity change: a critique of papers claiming no net loss of local diversity. *Ecology*, 97(8), 1949-1960.
- Hashim, J. H., & Hashim, Z. (2016). Climate change, extreme weather events, and human health implications in the Asia Pacific region. *Asia Pacific Journal of Public Health*, 28(2_suppl), 8S-14S.
- Heede, R. (2014). Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010. *Climatic Change*, 122(1-2), 229-241.
- Hojas-Gascón, L., Eva, H. D., Ehrlich, D., Pesaresi, M., Achard, F., & Garcia, J. (2016). Urbanization and forest degradation in east Africa-a case study around Dar es Salaam, Tanzania. In *2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)* (pp. 7293-7295). IEEE.

Hosonuma, N., M. Herold, V. De Sy, R. S. De Fries, M. Brockhaus, L. Verchot, A. Angelsen, and E. Romijn. 2012. An assessment of deforestation and forest degradation drivers in developing countries. *Environmental Research Letters* 7(4).

Hubau, W., Lewis, S. L., Phillips, O. L., Affum-Baffoe, K., Beeckman, H., Cuní-Sanchez, A., ... & Sheil, D. (2020). Asynchronous carbon sink saturation in African and Amazonian tropical forests. *Nature*, 579(7797), 80-87.

Hulme, P. E. (2009). Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of applied ecology*, 46(1), 10-18.

International Union for Conservation of Nature – IUCN (2020a). 'Background & History'. Retrieved from: <https://www.iucnredlist.org/about/background-history>

International Union for Conservation of Nature – IUCN (2020b). 'Barometer of life'. Retrieved from: <https://www.iucnredlist.org/about/barometer-of-life>

International Union for Conservation of Nature – IUCN. (2012). *IUCN Red List Categories and Criteria: Version 3.1*. Gland, Switzerland and Cambridge, UK: IUCN.

Johnson, C. N., Balmford, A., Brook, B. W., Buettel, J. C., Galetti, M., Guangchun, L., & Wilmschurst, J. M. (2017). Biodiversity losses and conservation responses in the Anthropocene. *Science*, 356(6335), 270-275.

Jones, B. A., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M. Y., ... & Pfeiffer, D. U. (2013). Zoonosis emergence linked to agricultural intensification and environmental change. *Proceedings of the National Academy of Sciences*, 110(21), 8399-8404.

Jones, K. E., Patel, N. G., Levy, M. A., Storeygard, A., Balk, D., Gittleman, J. L., & Daszak, P. (2008). Global trends in emerging infectious diseases. *Nature*, 451(7181), 990-993.

Kopnina, H., Washington, H., Taylor, B., & Piccolo, J. J. (2018). Anthropocentrism: More than just a misunderstood problem. *Journal of Agricultural and Environmental Ethics*, 31(1), 109-127.

Kruger, D. J., Hamer, A. J., & Du Preez, L. H. (2015). Urbanization affects frog communities at multiple scales in a rapidly developing African city. *Urban ecosystems*, 18(4), 1333-1352.

Kueffer, C. (2019). Book Review *Inheritors of the Earth: How Nature is Thriving in an Age of Extinction*. *Basic and Applied Ecology*, 35(January), 13–17.

Lewis, Simon L., and Mark A. Maslin. "Defining the anthropocene." *Nature* 519.7542 (2015): 171-180.

Lovejoy, T. E., & Nobre, C. (2018). Amazon tipping point. *Science Advances* 21 Feb 2018: Vol. 4, no. 2, eaat2340.

Lovejoy, T. E., & Nobre, C. (2019). Amazon tipping point: Last chance for action. *Science Advances* 20 Dec 2019: Vol. 5, no. 12, eaba2949.

Machado, J., Villegas-Palacio, C., Loaiza, J. C., & Castañeda, D. A. (2019). Soil natural capital vulnerability to environmental change. A regional scale approach for tropical soils in the Colombian Andes. *Ecological Indicators*, 96, 116-126.

Marzal, A., Ricklefs, R. E., Valkiūnas, G., Albayrak, T., Arriero, E., Bonneaud, C., ... & Iezhova, T. A. (2011). Diversity, loss, and gain of malaria parasites in a globally invasive bird. *PloS one*, 6(7).

- Mattei, C., Wortham, H., & Quivet, E. (2019). Heterogeneous atmospheric degradation of current-use pesticides by nitrate radicals. *Atmospheric Environment*, 211, 170-180.
- Maxwell, S. (2016). The ravages of guns, nets and bulldozers. *Nature*, 536, 143–145.
- McKee, J. K., Sciulli, P. W., David Foose, C., & Waite, T. A. (2004). Forecasting global biodiversity threats associated with human population growth. *Biological Conservation*, 115(1), 161–164.
- Mitchard, E. T. (2018). The tropical forest carbon cycle and climate change. *Nature*, 559(7715), 527-534.
- Mitchell, L., Brook, E., Lee, J. E., Buizert, C., & Sowers, T. (2013). Constraints on the late Holocene anthropogenic contribution to the atmospheric methane budget. *Science*, 342(6161), 964-966.
- Mossoun, A., Calvignac-Spencer, S., Anoh, A. E., Pauly, M. S., Driscoll, D. A., Michel, A. O., ... & Vogler, B. R. (2017). Bushmeat hunting and zoonotic transmission of simian T-Lymphotropic Virus 1 in tropical West and Central Africa. *Journal of virology*, 91(10), e02479-16.
- Mueller, N. D., & Binder, S. (2015). Closing yield gaps: Consequences for the global food supply, environmental quality & food security. *Daedalus*, 144(4), 45-56.
- Musing, L., Norwicz, M., Kloda, J., & Kecse-Nagy, K. (2018). Wildlife trade in Belgium: An analysis of CITES trade and seizure data. TRAFFIC Report. Retrieved from: <https://wwf.be/assets/RAPPORT-POLICY/WILDLIFE/TRAFFIC-wildlife-trade-Be-report-Final-Web-compressed.pdf>
- Naeem S, Duffy JE, Zavaleta E. (2012). The functions of biological diversity in an age of extinction. *Science* 336:1401–1406.
- Nasi R, Brown D, Wilkie D, Bennett E, Tutin C, Van Tol G, Christophersen T. 2008 Conservation and use of wildlife-based resources: the bushmeat crisis. Secretariat of the Convention on Biological Diversity, Montreal. Cent. Int. for Res. CIFOR Bogor Tech. Ser. 50.
- National Red List (2012). 'Why National Red Lists?'. Retrieved from: <https://www.nationalredlist.org/support-information/context-application/>
- Newbold, T., Hudson, L. N., Arnell, A. P., Contu, S., De Palma, A., Ferrier, S., ... & Burton, V. J. (2016). Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. *Science*, 353(6296), 288-291.
- Newbold, T., Hudson, L. N., Hill, S. L. L., Contu, S., Lysenko, I., Senior, R. A., ... Purvis, A. (2015). Global effects of land use on local terrestrial biodiversity. *Nature*, 520(7545), 45–50.
- Peh, K. S-H., Lin, Y., Foster, W., Luke, S., & Turner, E. (2014). Forest fragmentation and ecosystem functioning. In C. J. Kettle, & L. P. Koh (Eds.), *Global Forest Fragmentation: Green Islands of the Anthropocene* Wallingford, GB: CABI.
- Pellegrini, P., & Fernández, R. J. (2018). Crop intensification, land use, and on-farm energy-use efficiency during the worldwide spread of the green revolution. *Proceedings of the National Academy of Sciences*, 115(10), 2335-2340.

- Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., ... & Sexton, J. O. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *Science*, 344(6187), 1246752.
- Pinto, F. A., Clevenger, A. P., & Grilo, C. (2020). Effects of roads on terrestrial vertebrate species in Latin America. *Environmental Impact Assessment Review*, 81, 106337.
- Pogson, B. (2015). Habitat fragmentation reduces biodiversity. *Science* 20 Mar 2015: Vol. 347, Issue 6228, pp. 1325.
- Polaina, E., González-Suárez, M., & Revilla, E. (2015). Socioeconomic correlates of global mammalian conservation status. *Ecosphere*, 6(9), 1–34.
- Pongsiri, M. J., Roman, J., Ezenwa, V. O., Goldberg, T. L., Koren, H. S., Newbold, S. C., ... & Salkeld, D. J. (2009). Biodiversity loss affects global disease ecology. *Bioscience*, 59(11), 945-954.
- Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in ecology & evolution*, 25(6), 345-353.
- Powers, R. P., & Jetz, W. (2019). Global habitat loss and extinction risk of terrestrial vertebrates under future land-use-change scenarios. *Nature Climate Change*, 9(4), 323-329.
- Ripple, W. J., Abernethy, K., Betts, M. G., Chapron, G., Dirzo, R., Galetti, M., ... & Newsome, T. M. (2016). Bushmeat hunting and extinction risk to the world's mammals. *Royal Society open science*, 3(10), 160498.
- Ruddiman, W. F. (2007). The early anthropogenic hypothesis: Challenges and responses. *Reviews of Geophysics*, 45(4).
- Ruddiman, W.F. (2013). "The Anthropocene." *Annual Review of Earth and Planetary Sciences* 41.1: 45-68.
- Russell, J. C., & Blackburn, T. M. (2017). The rise of invasive species denialism. *Trends in Ecology & Evolution*, 32(1), 3-6.
- Russell, J. C., & Kueffer, C. (2019). Island biodiversity in the Anthropocene. *Annual Review of Environment and Resources*, 44, 31-60.
- Salyer, S. J., Silver, R., Simone, K., & Behravesh, C. B. (2017). Prioritizing zoonoses for global health capacity building—themes from One Health zoonotic disease workshops in 7 countries, 2014–2016. *Emerging infectious diseases*, 23(Suppl 1), S55.
- Sampaio, G., Nobre, C., Costa, M. H., Satyamurty, P., Soares-Filho, B. S., & Cardoso, M. (2007). Regional climate change over eastern Amazonia caused by pasture and soybean cropland expansion. *Geophysical Research Letters*, 34(17).
- Santiago-Alarcon, D., & Delgado-V, C. A. (2017). Warning! Urban threats for birds in Latin America. In *Avian Ecology in Latin American Cityscapes* (pp. 125-142). Springer, Cham.
- Saunois, M, Bousquet, P, Poulter, B. (2016). The global methane budget 2000-2012. *Earth System Science Data* 8: 697–751.
- Schiermeier, Q. (2011). Increased flood risk linked to global warming: likelihood of extreme rainfall may have been doubled by rising greenhouse-gas levels. *Nature*, 470(7334), 316-317.

- Shimamoto, C. Y., Padial, A. A., da Rosa, C. M., & Marques, M. C. (2018). Restoration of ecosystem services in tropical forests: A global meta-analysis. *PloS one*, 13(12), e0208523.
- Soares-Filho, B. S., Nepstad, D. C., Curran, L. M., Cerqueira, G. C., Garcia, R. A., Ramos, C. A., ... & Schlesinger, P. (2006). Modelling conservation in the Amazon basin. *Nature*, 440(7083), 520-523.
- Sodhi, N. S.; Posa, M. R. C.; Lee, T. M.; Bickford, D.; Koh, L.P. & Brook, B. W. (2010). 'The state and conservation of Southeast Asian biodiversity'. *Biodiversity Conservation*, 19: 317-328
- Sol, J. (2019). Economics in the anthropocene: species extinction or steady state economics. *Ecological Economics*, 165.
- Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O., & Ludwig, C. (2015). The trajectory of the Anthropocene: the great acceleration. *The Anthropocene Review*, 2(1), 81-98.
- Steffen, W., Crutzen, P. J., & McNeill, J. R. (2007). The Anthropocene: are humans now overwhelming the great forces of nature. *AMBIO: A Journal of the Human Environment*, 36(8), 614-621.
- Swarts, N. D., & Dixon, K. W. (2009). Terrestrial orchid conservation in the age of extinction. *Annals of botany*, 104(3), 543-556.
- TEEB – The Economics of Ecosystems and Biodiversity for National and International Policy Makers (2009). Retrieved from: <http://doc.teebweb.org/wp-content/uploads/2014/04/TEEB-international-and-international-Policy-Making2011.pdf>
- Thiollay, J. M. (2006). Severe decline of large birds in the Northern Sahel of West Africa: a long-term assessment. *Bird Conservation International*, 16(4), 353-365.
- Tilker, A., Nguyen, A., Abrams, J. F., Bhagwat, T., Le, M., Van Nguyen, T., ... & Wilting, A. (2020). A little-known endemic caught in the South-east Asian extinction crisis: The Annamite striped rabbit *Nesolagus timminsi*. *Oryx*, 54(2), 178-187.
- Tilman, D., Clark, M., Williams, D. R., Kimmel, K., Polasky, S., & Packer, C. (2017). Future threats to biodiversity and pathways to their prevention. *Nature*, 546(7656), 73–81.
- Torrecilha, S., Ochoa-Quintero, J. M., Laps, R. R., & Ribeiro, D. B. (2018). Records of threatened bird and mammal species in Mato Grosso do Sul State, Brazil. *Data in brief*, 17, 1326-1330.
- Tracewski, Ł., Butchart, S. H., Di Marco, M., Ficetola, G. F., Rondinini, C., Symes, A., ... & Buchanan, G. M. (2016). Toward quantification of the impact of 21st-century deforestation on the extinction risk of terrestrial vertebrates. *Conservation Biology*, 30(5), 1070-1079.
- Tucker Lima, J. M., Vittor, A., Rifai, S., & Valle, D. (2017). Does deforestation promote or inhibit malaria transmission in the Amazon? A systematic literature review and critical appraisal of current evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 372(1722), 20160125.
- Turvey, S. T., & Crees, J. J. (2019). Extinction in the Anthropocene. *Current Biology*, 29(19), R982–R986.
- Van Uhm, D. (2016). *The Illegal Wildlife Trade*. Springer.

- Walley, J. (2013). *Wildlife Crime: Third Report of Session 2012–2013, Volume 1*. Great Britain: Parliament: House of Commons: Environmental Audit Committee, London, United Kingdom.
- Westphal, M. I., Browne, M., MacKinnon, K., & Noble, I. (2008). The link between international trade and the global distribution of invasive alien species. *Biological invasions*, 10(4), 391-398.
- Whytock, R. C., Buij, R., Virani, M. Z., & Morgan, B. J. (2016). Do large birds experience previously undetected levels of hunting pressure in the forests of Central and West Africa?. *Oryx*, 50(1), 76-83.
- Wood, C. L., Lafferty, K. D., DeLeo, G., Young, H. S., Hudson, P. J., & Kuris, A. M. (2014). Does biodiversity protect humans against infectious disease?. *Ecology*, 95(4), 817-832.
- World Wildlife Fund – WWF (2018). *Living Planet Report - 2018: Aiming Higher*. Grooten, M. & Almond, R.E.A. (Eds). WWF, Gland, Switzerland.
- Yasuoka, J., & Levins, R. (2007). Impact of deforestation and agricultural development on anopheline ecology and malaria epidemiology. *The American journal of tropical medicine and hygiene*, 76(3), 450-460.
- Zalasiewicz, J., Waters, C. N., Head, M. J., Poirier, C., Summerhayes, C. P., Leinfelder, R., ... & McNeill, J. R. (2019). A formal Anthropocene is compatible with but distinct from its diachronous anthropogenic counterparts: a response to WF Ruddiman's 'three flaws in defining a formal Anthropocene'. *Progress in Physical Geography: Earth and Environment*, 43(3), 319-333.

Annex 1. Countries included in the analysis

Afrotropics	Neotropics	Indomalayan
1. Angola	1. Belize	1. Indonesia
2. Benin	2. Bolivia	2. Malaysia
3. Botswana	3. Brasil	3. Sri Lanka
4. Burkina Faso	4. Costa Rica	4. Timor-Leste
5. Burundi	5. Dominican Republic	5. Bangladesh
6. Cameroon	6. Ecuador	6. Bhutan
7. Cape Verde	7. El Salvador	7. India
8. Central African Republic	8. Guatemala	8. Laos
9. Chad	9. Guyana	9. Myanmar
10. Comoros	10. Haiti	10. Nepal
11. Congo Republic	11. Honduras	11. Philippines
12. Côte d'Ivoire	12. Jamaica	12. Thailand
13. Democratic Republic of Congo	13. Mexico	13. Viet Nam
14. Ethiopia	14. Nicaragua	
15. Gabon	15. Panama	
16. Gambia	16. Paraguay	
17. Ghana	17. Peru	
18. Guinea	18. Surinam	
19. Guinea-Bissau	19. Trinidad and Tobago	
20. Kenya		
21. Liberia		
22. Madagascar		
23. Malawi		
24. Mali		
25. Mauritania		
26. Mauritius		
27. Mozambique		
28. Namibia		
29. Niger		
30. Nigeria		
31. Rwanda		
32. Sao Tome and Principe		
33. Senegal		
34. Sierra Leone		
35. Tanzania		
36. Togo		
37. Uganda		
38. Zambia		
39. Zimbabwe		

Annex 2. IUCN Red List criteria for critically endangered, endangered and vulnerable species

A. Reduction in population size based on any of the following	Vulnerable	Endangered	Critically Endangered
A1. Observed, estimated, inferred or suspected population size reduction of (see category) over the last 10 years through (a) direct observation, (b) an index of abundance appropriate to the taxon, (c) a decline in area of occupancy, extent of occurrence and/or quality of habitat, (d) actual or potential levels of exploitation or (e) the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites	50%	70%	90%
A2. Observed, estimated, inferred or suspected population size reduction of (see category) over the last 10 years or three generations whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible, based on (and specifying) any of (a) to (e) under A1	≥30%	≥50%	≥80%
A3. Population size reduction, projected or suspected to be met within the next 10 years or three generations, whichever is the longer (up to a maximum of 100 years), based on (and specifying) any of (b) to (e) under A1	≥30%	≥50%	≥80%
A4. Observed, estimated, inferred, projected or suspected population size reduction of (see category) over any 10 year or three generation period, whichever is longer (up to a maximum of 100 years in the future) where the time period must include both the past and the future, AND where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible, based on (and specifying) any of (a) to (e) under A1	≥30%	≥50%	≥80%
B. Geographic range in the form of either B1 (extent of occurrence) OR B2 (area of occupancy) OR both			
B1. Extent of occurrence and estimates indicating at least two of a-c: a) Severely fragmented or known to exist at only a single location; b) continuing decline, observed, inferred or projected, in any of the following: (i) extent of occurrence, (ii) area of occupancy, (iii) area, extent and/or quality of habitat, (iv) number of locations or subpopulations or (v) number of mature individuals; c) Extreme fluctuations in any of the following: (i) extent of occurrence, (ii) area of	<20,000km ²	<5,000km ²	<100km ²

occupancy, (iii) number of locations or subpopulations or (iv) number of mature individuals			
B2. Area of occupancy (see category) and estimates indicating at least two of a-c: a) Severely fragmented or known to exist at no more than five locations; b) Continuing decline, observed, inferred or projected, in any of the following: (i) extent of occurrence, (ii) area of occupancy, (iii) area, extent and/or quality of habitat, (iv) number of locations or subpopulations, or (v) number of mature individuals, or c) Extreme fluctuations in any of the following: (i) extent of occurrence, (ii) area of occupancy, (iii) number of locations or subpopulations or (iv) number of mature individuals	<20,000km ²	<500km ²	<10km ²
C. Population size of (see category) mature individuals and either	<10,000	<2,500	<250
C1. An estimated continuing decline (see category) or whichever is longer, (up to a maximum of 100 years in the future) OR	at least 10% within 10 years or 3 generations	at least 20% within 5 years or 2 generations	at least 25% within 3 years or 1 generation
C2. A continuing decline, observed, projected, or inferred, in numbers of mature individuals AND at least one of the following (a-b): a) Population structure in the form of one of the following: (i) no subpopulation estimated to contain (see category); b) Extreme fluctuations in number of mature individuals.	>1,000 mature individuals or at least all mature individuals in one subpopulation	>250 mature individuals or at least 95% of mature individuals in one subpopulation	>50 mature individuals or at least 90% of mature individuals in one subpopulation
D. Population size estimated to (see category)	<1,000 mature individuals	<250 mature individuals	<50 mature individuals
E. Quantitative analysis showing the probability of extinction in the wild is (see category) up to a maximum of 100 years	at least 10% within 100 years	at least 20% within 20 years or 5 generations	at least 50% within 10 years or 3 generations

Annex 3. Correlation matrix of explanatory and response variables

I. Tropical region

Correlations (Pearson)

	Population growth	Population density	Agricultural land	Cereal yield	Forest cover	Protected area	Biocapacity R/D	HDI	GDP	Endangered mammals	Endangered birds
Population growth	1	-0.26	0.29	-0.57	-0.21	0.04	-0.17	-0.72	-0.27	-0.34	-0.27
Population density	-0.26	1	0.46	0.2	-0.35	-0.36	-0.21	0.08	0.12	0.39	0.36
Agricultural land	0.29	0.46	1	-0.21	-0.59	-0.23	-0.35	-0.3	0.08	0.01	0.2
Cereal yield	-0.57	0.2	-0.21	1	0.36	-0.08	0.19	0.59	0.37	0.47	0.39
Forest cover	-0.21	-0.35	-0.59	0.36	1	0.29	0.47	0.36	0.02	-0.11	-0.11
Protected area	0.04	-0.36	-0.23	-0.08	0.29	1	-0.06	0.2	-0.09	-0.28	-0.23
Biocapacity R/D	-0.17	-0.21	-0.35	0.19	0.47	-0.06	1	0.13	-0.05	-0.22	-0.19
HDI	-0.72	0.08	-0.3	0.59	0.36	0.2	0.13	1	0.27	0.23	0.24
GDP	-0.27	0.12	0.08	0.37	0.02	-0.09	-0.05	0.27	1	0.34	0.31
Endangered mammals	-0.34	0.39	0.01	0.47	-0.11	-0.28	-0.22	0.23	0.34	1	0.63
Endangered birds	-0.27	0.36	0.2	0.39	-0.11	-0.23	-0.19	0.24	0.31	0.63	1

p-values

	Population growth	Population density	Agricultural land	Cereal yield	Forest cover	Protected area	Biocapacity R/D	HDI	GDP	Endangered mammals	Endangered birds
Population growth		0.03	0.01	0.00	0.08	0.74	0.15	0.00	0.02	0.00	0.02
Population density	0.03		0.00	0.09	0.00	0.00	0.09	0.53	0.33	0.00	0.00
Agricultural land	0.01	0.00		0.08	0.00	0.05	0.00	0.01	0.52	0.97	0.10
Cereal yield	0.00	0.09	0.08		0.00	0.49	0.12	0.00	0.00	0.00	0.00
Forest cover	0.08	0.00	0.00	0.00		0.01	0.00	0.00	0.89	0.37	0.36
Protected area	0.74	0.00	0.05	0.49	0.01		0.62	0.10	0.46	0.02	0.06
Biocapacity R/D	0.15	0.09	0.00	0.12	0.00	0.62		0.29	0.67	0.07	0.10
HDI	0.00	0.53	0.01	0.00	0.00	0.10	0.29		0.02	0.05	0.04
GDP	0.02	0.33	0.52	0.00	0.89	0.46	0.67	0.02		0.00	0.01
Endangered mammals	0.00	0.00	0.97	0.00	0.37	0.02	0.07	0.05	0.00		0.00
Endangered birds	0.02	0.00	0.10	0.00	0.06	0.10	0.04	0.04	0.01	0.00	

II. Afrotropics

Correlation (Pearson)

	Population growth	Population density	Agricultural land	Cereal yield	Forest cover	Protected area	Biocapacity R/D	HDI	GDP	Endangered mammals	Endangered birds
Population growth	1	-0.28	0.22	-0.31	-0.02	0.09	0.05	-0.54	0.06	-0.38	-0.38
Population density	-0.28	1	0.49	0.47	-0.21	-0.34	-0.35	0.18	0.04	0.35	0.42
Agricultural land	0.22	0.49	1	0.2	-0.32	-0.07	-0.4	-0.09	0.23	-0.01	0.23
Cereal yield	-0.31	0.47	0.2	1	0.01	-0.19	-0.15	0.28	0	0.6	0.51
Forest cover	-0.02	-0.21	-0.32	0.01	1	0.28	0.51	0.17	-0.15	-0.31	-0.09
Protected area	0.09	-0.34	-0.07	-0.19	0.28	1	0.22	0.16	-0.06	-0.52	-0.22
Biocapacity R/D	0.05	-0.35	-0.4	-0.15	0.51	0.22	1	0.21	-0.08	-0.2	-0.24
HDI	-0.54	0.18	-0.09	0.28	0.17	0.16	0.21	1	0.09	0.22	0.3
GDP	0.06	0.04	0.23	0	-0.15	-0.06	-0.08	0.09	1	-0.07	-0.11
Endangered mammals	-0.38	0.35	-0.01	0.6	-0.31	-0.52	-0.2	0.22	-0.07	1	0.63
Endangered birds	-0.38	0.42	0.23	0.51	-0.09	-0.22	-0.24	0.3	-0.11	0.63	1

p-values

	Population growth	Population density	Agricultural land	Cereal yield	Forest cover	Protected area	Biocapacity R/D	HDI	GDP	Endangered mammals	Endangered birds
Population growth		0.09	0.17	0.06	0.90	0.59	0.75	0.00	0.74	0.02	0.02
Population density	0.09		0.00	0.00	0.20	0.04	0.03	0.28	0.81	0.03	0.01
Agricultural land	0.17	0.00		0.23	0.05	0.66	0.01	0.59	0.16	0.96	0.15
Cereal yield	0.06	0.00	0.23		0.97	0.25	0.37	0.09	0.99	0.00	0.00
Forest cover	0.90	0.20	0.05	0.97		0.08	0.00	0.29	0.36	0.05	0.59
Protected area	0.59	0.04	0.66	0.25	0.08		0.18	0.34	0.72	0.00	0.18
Biocapacity (R/D)	0.75	0.03	0.01	0.37	0.01	0.18		0.21	0.62	0.23	0.14
HDI	0.00	0.28	0.59	0.09	0.29	0.34	0.21		0.57	0.17	0.06
GDP	0.74	0.81	0.16	0.99	0.36	0.72	0.62	0.57		0.69	0.52
Endangered mammals	0.02	0.03	0.96	0.00	0.05	0.00	0.62	0.57	0.69		0.00
Endangered birds	0.02	0.01	0.15	0.00	0.59	0.18	0.14	0.06	0.5206	0.00	

III. Neotropics

Correlation (Pearson)

	Population growth	Population density	Agricultural land	Cereal yield	Forest cover	Protected area	Biocapacity R/D	HDI	GDP	Endangered mammals	Endangered birds
Population growth	1	-0.36	0.14	0.07	-0.01	0.27	-0.27	-0.14	-0.16	0.02	0.05
Population density	-0.36	1	0.55	-0.65	-0.71	-0.39	-0.4	-0.36	-0.22	0.18	0.11
Agricultural land	-0.14	0.55	1	-0.26	-0.84	-0.4	-0.49	-0.32	0.11	0.31	0.33
Cereal yield	0.07	-0.65	-0.26	1	0.57	0.09	0.33	0.45	0.47	0.03	0.2
Forest cover	-0.01	-0.71	0.84	0.57	1	0.18	0.73	0.44	0.06	-0.24	-0.22
Protected area	0.27	-0.39	-0.4	0.09	0.18	1	-0.32	0.41	0.1	-0.23	-0.12
Biocapacity R/D	-0.27	-0.4	-0.49	0.33	0.73	-0.32	1	-0.1	-0.09	-0.25	-0.31
HDI	-0.14	-0.36	-0.32	0.45	0.44	0.41	-0.1	1	0.29	0.13	0.09
GDP	-0.16	-0.22	0.11	0.47	0.06	0.1	-0.09	0.29	1	0.34	0.64
Endangered mammals	0.02	0.18	0.31	0.03	-0.24	-0.23	-0.25	0.13	0.34	1	0.74
Endangered birds	0.05	0.11	0.33	0.2	-0.22	-0.12	-0.31	0.09	0.64	0.74	1

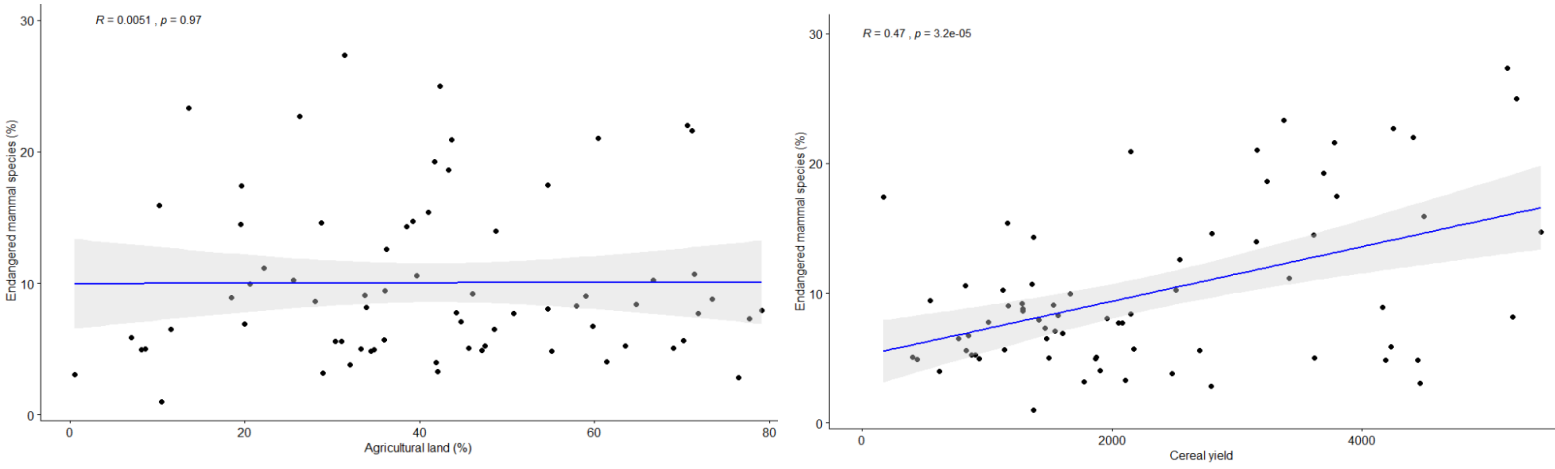
p-values

	Population growth	Population density	Agricultural land	Cereal yield	Forest cover	Protected area	Biocapacity R/D	HDI	GDP	Endangered mammals	Endangered birds
Population growth		0.1324	0.5809	0.7802	0.9669	0.2571	0.2629	0.5574	0.55	0.9441	0.8323
Population density	0.1324		0.015	0.0026	0.0007	0.1	0.0915	0.1306	0.37	0.4582	0.6581
Agricultural land	0.5809	0.015		0.2906	0	0.094	0.0339	0.1757	0.67	0.1975	0.1724
Cereal yield	0.7802	0.0026	0.2906		0.0107	0.7158	0.17	0.0505	0.04	0.9125	0.411
Forest cover	0.9669	0.0007	0	0.0107		0.457	0.0004	0.0602	0.81	0.3267	0.3696
Protected area	0.2571	0.1	0.094	0.7158	0.457		0.1813	0.0814	0.69	0.334	0.6284
Biocapacity R/D	0.2629	0.0915	0.0339	0.17	0.0004	0.1813		0.6944	0.7	0.3013	0.2024
HDI	0.5574	0.1306	0.1757	0.0505	0.0602	0.0814	0.6944		0.7	0.3013	0.2024
GDP	0.5002	0.3662	0.6473	0.0438	0.809	0.6883	0.7009	0.225		0.1483	0.003
Endangered mammals	0.9441	0.4582	0.1925	0.9125	0.3267	0.334	0.3013	0.5959		0.1483	0.003
Endangered birds	0.8323	0.6581	0.1724	0.4111	0.3696	0.6284	0.2024	0.7089	0	0.0003	

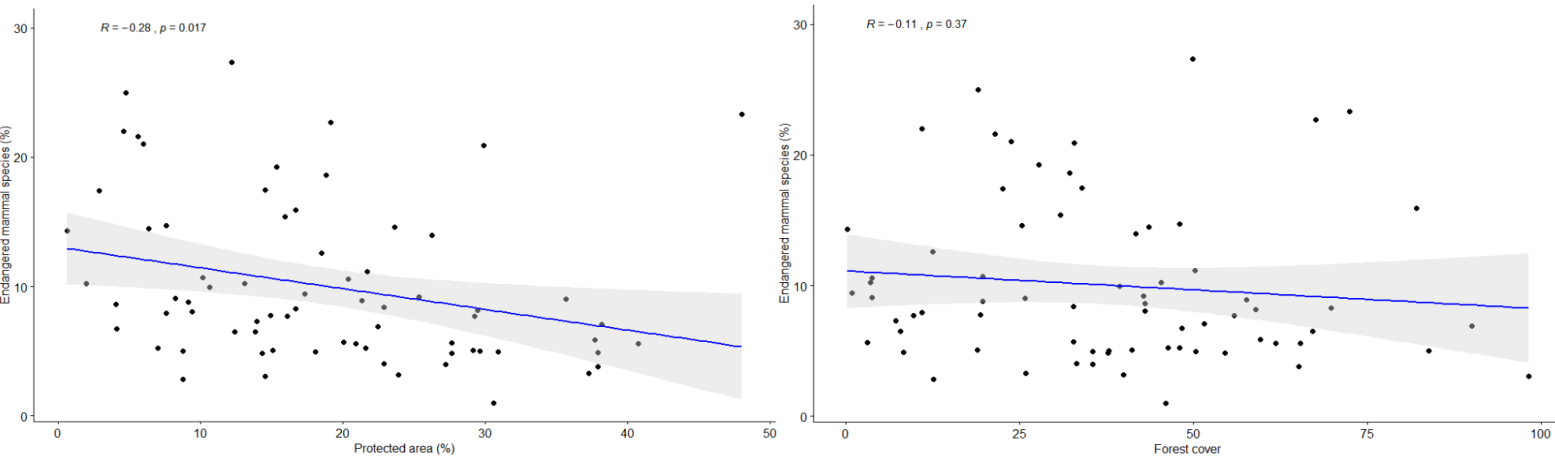
Sources for all tables: FAO 2016, 2017, 2018; World Bank 2018; WDPA 2016; GFN 2016; UNDP 2018; IUCN 2018. Author's elaboration.

Annex 4.1: Linear plots of endangered mammals in tropical regions

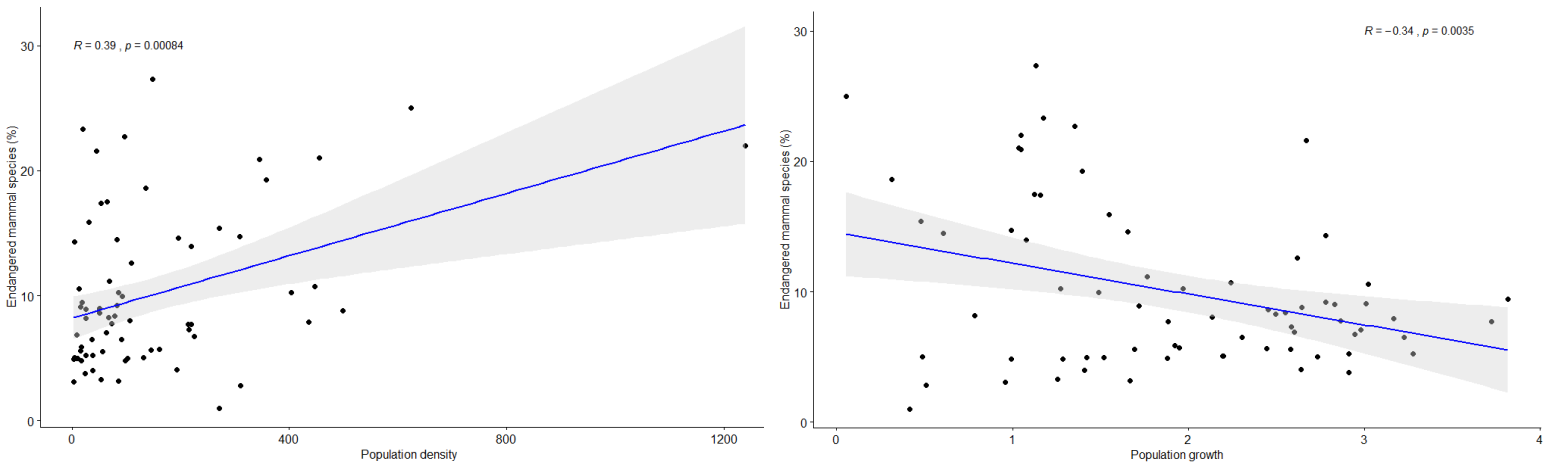
I. Agricultural land and cereal yield (kg/ha)



II. Protected area and forest cover



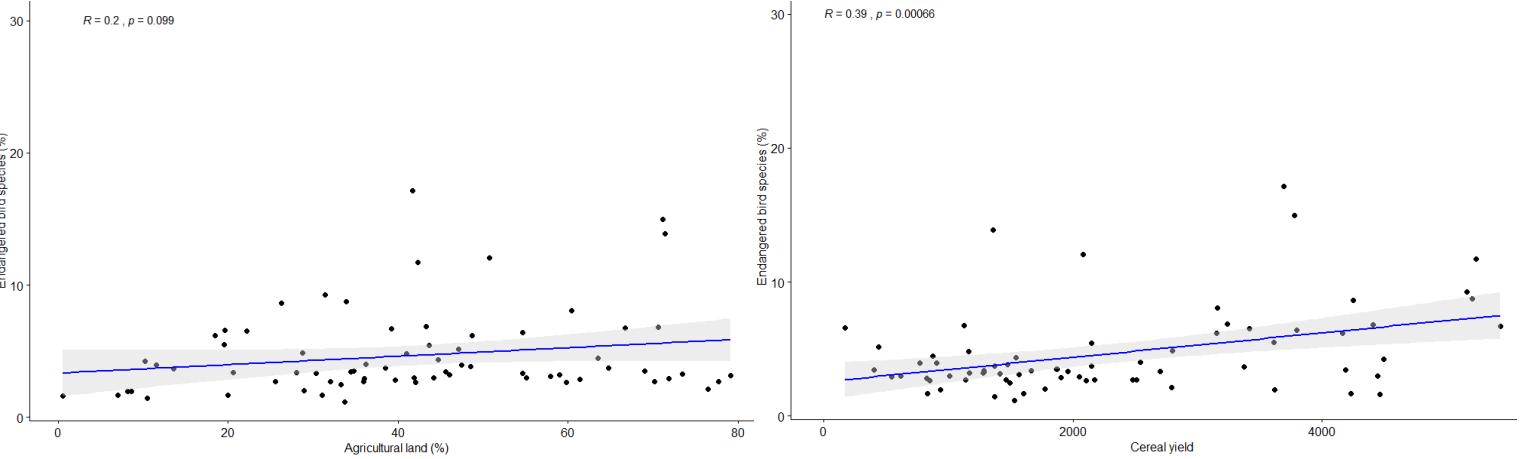
III. Populations density and population growth



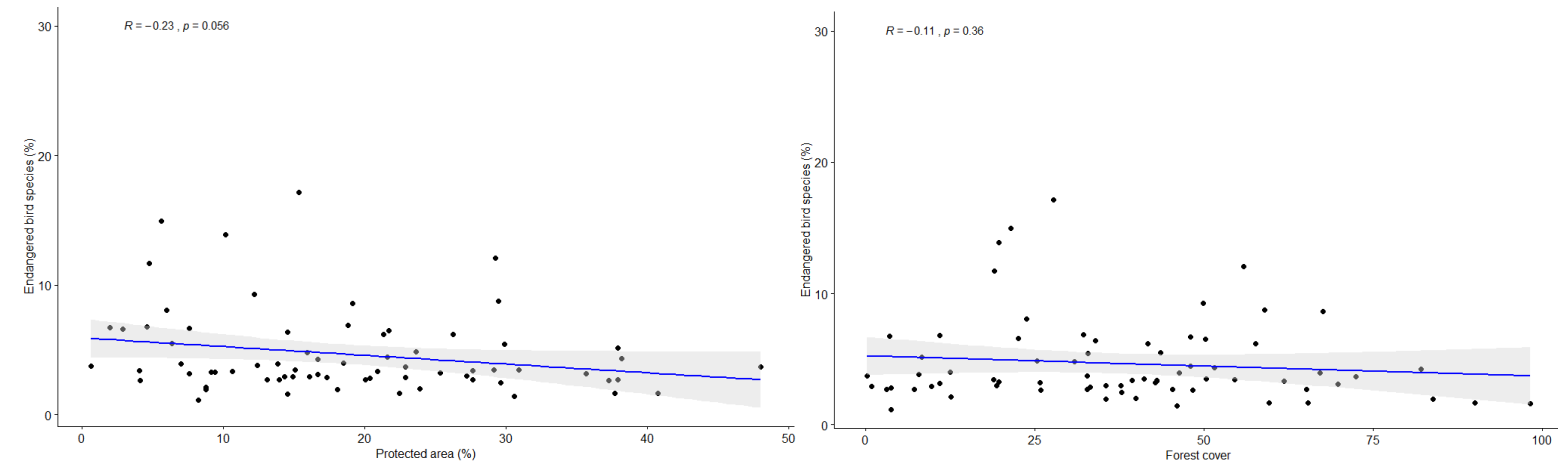
Source: FAO 2016, 2017, 2018; World Bank 2018; WDPA 2016.

Annex 4.2. Linear plots of endangered birds in tropical regions

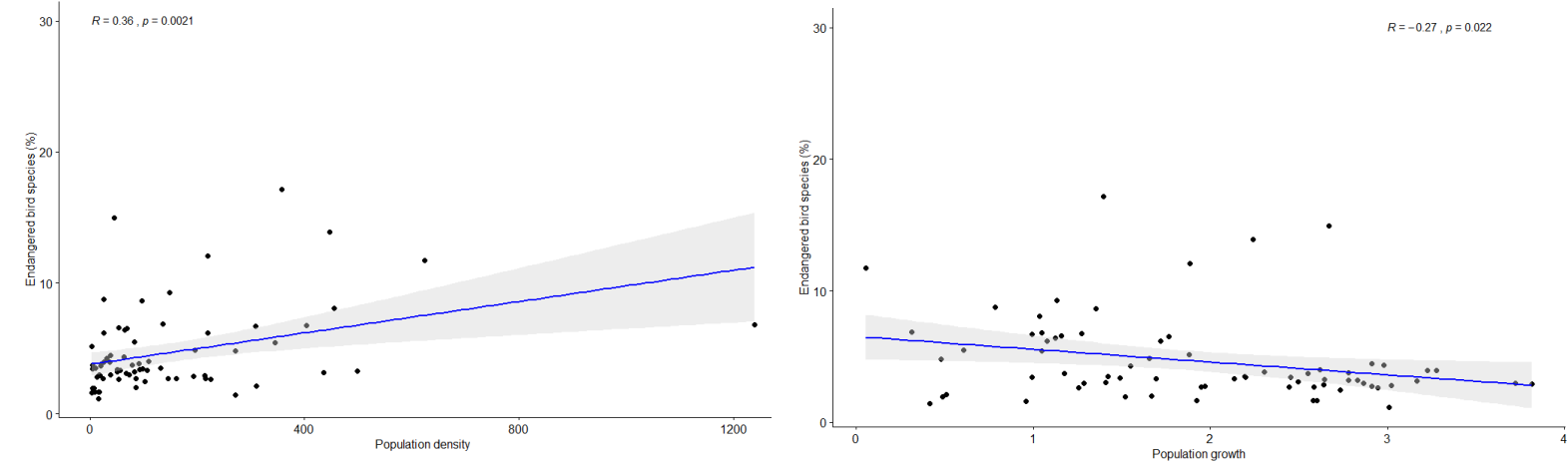
I. Agricultural land and cereal yield (kg/ha)



II. Protected area and forest cover



III. Populations density and population growth



Source: FAO 2016, 2017, 2018; World Bank 2018; WDPA 2016.

Annex 5. Internship report

The Belgian Biodiversity Platform (BBP) is a research organization that brings together the most important and prestigious federal and regional research institutes. Its staff is comprised by internationally recognized scientists in the areas of biodiversity research. As a research organization, the BBP aims to: 1) answer policy needs, 2) to catalyse the improvement of research processes, 3) facilitate knowledge interfacing and sharing, and 4) enable data publication and data use.

During my internship at the BBP I collaborated in the elaboration of a policy brief about the wildlife trade of exotic species in Europe. I had several meetings with the staff from the BBP to frame my research design and to get acquainted with the research outputs that they expected. Regular meetings were held in order to monitor the advance of the document. The final report was to be used as an input for an international conference on the state of the wildlife trade in European countries.

Although my tasks during my internship at the BBP were mainly academic, it was a unique experience to get acquainted with important policy areas that focus their attention on biodiversity problems I was unaware of back then. It also allowed me to lose my fear of using quantitative data to assess the contemporary trends of the wildlife trade. The comparison between different sources of information (and the acknowledgement of their strengths and limitations) allowed me to get a better understanding about the assessment of such a difficult subject of study.

Additionally, I was able to get some insights about the preparation of the conference and its urgency. During the event, various panels with experts were held and, after that, there were various discussion groups between policy makers, academic and NGOs. Attending the conference was very important because it allowed me to interact with researchers, workers from NGOs and other sectors and to collect their impressions on the information needed for having better policies for regulating the wildlife trade at the European Union level. Having acquired all these inputs was decisive for the elaboration of my final report, which included several perspectives from different stakeholders and that summarized the academic literature on the subject. A few months later, the BBP rearranged and published three policy briefs with some of my inputs from my report together with the lessons learned from the conference.

Although I think that I could have a more active part in the organization event, the academic task was quite pressing, and given the relevance and attendance of internationally recognized scholars to the event I had to spend considerable amounts of time in preparing a good report. I received a very good feedback from my supervisor and academic staff at the BBP during the elaboration of my report and after its conclusion.