

# Geographical variations in the sensitivity of terrestrial biodiversity to anthropogenic pressures

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25/08/2022

**A thesis submitted in partial fulfilment of the requirements for the degree of Master of  
Science at Imperial College London**

**Submitted for the MSc in Computational Methods in Ecology and Evolution**

14 **Declaration**

15 Data was obtained from existing online databases, and therefore I was not responsible for data  
16 processing or cleaning.

17 Were any mathematical models developed by you or by your supervisor?

18 What role, if any, did your supervisor play in developing the analyses presented?



20	<b>Contents</b>	
21	<b>Introduction</b>	<b>4</b>
22	<b>Literature Review</b>	<b>6</b>
23	<b>Methods</b>	<b>7</b>
24	Overview . . . . .	7
25	Data . . . . .	8
26	Method 1: model for each country . . . . .	9
27	Individual Pressures . . . . .	9
28	Multi-pressure model . . . . .	9
29	Method 2: dummy variables . . . . .	9
30	Individual Pressures . . . . .	9
31	<b>Results</b>	<b>10</b>
32	Method 1: ANOVAs of gradients . . . . .	10
33	Method 2: dummy variables . . . . .	11
34	<b>Discussion</b>	<b>12</b>
35	<b>Conclusion</b>	<b>13</b>
36	<b>Data and Code Availability</b>	<b>14</b>
37	<b>Acknowledgements</b>	<b>15</b>

## Introduction

Biodiversity is important because it supports life on earth via the ecosystem services provided. When ecosystems have their biodiversity intact, they can provide services such as clean air and pollination, which makes the earth habitable for humans. Biodiversity loss leads to unstable environments, as ecosystems with low biodiversity are less resistant to change. Biodiversity loss diminishes ecosystem productivity (Duffy et al., 2017) and threatens all life on earth, including human well-being (Díaz et al., 2006).

Biodiversity is impacted by both natural and anthropogenic pressures (Nobel et al., 2020), however any mention of 'biodiversity pressures' in this study refers only to the latter. Understanding the impacts of anthropogenic pressures on biodiversity is important for creating accurate environmental policies and conservation strategies, and therefore more effective ones. Aside from traditional efforts for protecting biodiversity, another response to the biodiversity crisis (Ogar et al., 2020) is the beginning of a global movement towards sustainable business and biodiversity-conscious investment (PRI, 2020)(Forum, 2020)(WWF, 2020).

Assessing the impact that investments/companies have on biodiversity involves calculating their contributions towards the main pressures (e.g. deforestation, pollution etc.). It is also useful to know where in the world these effects are taking place, so that we know how much biodiversity is at risk (as the world's biodiversity is not equally distributed). Creating a tool which assesses the overall biodiversity impact of a company can help guide investors. This is something that various parties are currently developing (Alliance, 2022)(ICCS, 2020). The World Benchmarking Alliance is using an approach centred around researching published materials from top companies. Dissimilarly, 'Benchmark for Nature' is a project which is using open-source data from news articles that have been web-scraped, in an effort to gain the maximum amount of data possible about the links that companies/sectors have with each biodiversity pressure.

Benchmark for Nature is a project at the University of Oxford's Internet Institute, emerging from the global movement towards sustainable business. The project aims to use data science to develop a framework for assessing investment impacts on biodiversity (ICCS, 2020), similar to the ESG framework currently in place. The ESG information currently available only assesses an investments' impact on the environment, but not on living nature and biodiversity. The purpose of the project is to better inform investors so that more biodiversity-conscious decisions can be made, in an effort to aid the biodiversity loss crisis (Gasu et al., 2021), and also indirectly, the climate (Shin et al., 2022).

One question that has been raised within the project is whether biodiversity pressures have equal impacts on biodiversity regardless of geography. Studies show impacts of socioeconomic status and cultural impacts on biodiversity vary geographically (Kinzig et al., 2005). This gives reason to believe that other contributors towards biodiversity loss could have varying impacts based on their location. For example, this research question would aim to provide answers for whether the sensitivity of biodiversity to pressures acting on it, differs geographically.

Although there is no available data about how biodiversity sensitivity differs geographically, it is

81 well known that there is variation in how each species responds. It would be useful to include this  
82 sensitivity variation when analysing how biodiversity responds to pressures around the world. Though  
83 useful, just knowing sensitivity at the species level is impractical when it comes to creating tools like  
84 in Benchmark for Nature. For this reason, if countries/regions on the whole differ in their sensitivity  
85 to biodiversity pressures, this information could make models / predictions about the impact of pres-  
86 sures more accurate. Relative values for the sensitivity of each country, or continent's biodiversity to  
87 each pressure could allow tools to better predict impacts. Rather than just including how biodiversity  
88 in general is likely to respond, it would be more useful to know how local biodiversity in that specific  
89 region is likely to respond.

90

91 In the context of Benchmark for Nature's tool, web articles are unlikely to mention the exact  
92 species that a company is having an impact on, and is more likely to mention the general region the  
93 impact is taking place (e.g. "This company is causing deforestation in Brazil"). In order to find out  
94 which level of sensitivity insight would be useful (e.g. country, continent), I will assess the articles  
95 already collected by the Benchmark project to determine the most commonly mentioned (and there-  
96 fore most useful) location terminology.

97

98 Given that anthropogenic impact on the environment is worldwide ([Plumpton et al., 2021](#)), the  
99 question should be raised of whether the geographic location of biodiversity pressures affects their  
100 impact on global biodiversity. If such geographic differences exist, they should be taken into account  
101 when attributing biodiversity-related merit to investments. To widen the scope of impact outside of the  
102 Benchmark for Nature project, taking into account geographic variations in sensitivity to biodiversity  
103 pressures could make estimates about biodiversity impact more accurate. Better understanding of  
104 biodiversity pressures will aid a better understanding of the implications of investments (and other  
105 policies) on natural ecosystems.

106

## Literature Review

Literature is abundant on how biodiversity varies geographically and why this may be (Gaston, 2000) (Ricklefs, 2004) (McRae et al., 2017), including how various direct and indirect pressures correlate with these differences (Sunday et al., 2015), (Ament et al., 2019) (Velde, 2022). Also, various studies have mapped the magnitude of biodiversity pressures across regions/biomes (Millennium ecosystem assessment, 2005) (Sala et al., 2000), and their spatial couplings (Bowler et al., 2020).

Bowler et al.(2020) concluded that despite any patterns observed in magnitude of pressures, there will always be variation in biodiversity response to such pressures due to species' varying sensitivities. Research about species-specific sensitivities in each ecosystem is useful for local conservation policy however it would be more useful for large scale projects/policies to have information about the sensitivity of regions/biomes on the whole. An assumption in some literature and models of biodiversity response is that whilst magnitude of pressures varies, sensitivity to these pressures is constant across biomes (Sala et al., 2000), however there is no research to support this assumption. To our knowledge, very little prior research has studied geographic differences in sensitivity to biodiversity pressures. Hence, studying geographical variation in sensitivity would be useful in comparing the impact of pressures on global biodiversity.

There is adequate research showing that inter-species responses to biodiversity pressures vary (Foden et al., 2013). Given that species vary in their sensitivity, and therefore response, to biodiversity pressures, and that each region of the world comprises different combinations of species groups (van Goethem and van Zanden, 2021), there is reason to believe that sensitivity to biodiversity pressure could vary depending on location.

A wider spectrum study examined sensitivity to environmental change at a broader level, and found variation between taxa (Sunday et al., 2015). This between-taxa variation further supports the concept that sensitivity to biodiversity pressures could vary between countries, and the authors emphasise that their findings suggest that sensitivity to environmental change should not be assumed to be constant across taxa. Given that there have been differences in sensitivity to pressures found at both the species, and taxa level, then grouping species into even broader categories (such as country) could continue to show such differences. This supports the idea that researching differences between countries' sensitivity, could contribute to more accurate predictions of how biodiversity pressures impact biodiversity.

One of the papers which studied sensitivity of species to environmental pressures (Louette et al., 2010), developed a set of sensitivity scores for European species, determining which species will benefit from, be indifferent to, or be negatively affected by environmental change. This 'Bioscore' study used such sensitivity scores to create a tool for predicting the effect of a policy change on Europe's biodiversity. The proportion of affected species in each region was used to map the effects of a change in each biodiversity pressure. The sensitivity scores for each species were obtained from published literature about individual species' responses to change in different environmental variables. The BioScore tool suggests that even if the magnitude of a biodiversity pressure is constant across Europe, biodiversity's response can still vary according to country, due to varying sensitivity

150 of the species within such country. This study is a predictive tool based on published studies about  
151 individual species, and a wider-breadth study is necessary to observe worldwide variances in coun-  
152 tries sensitivities to biodiversity pressures. The BioScore tool's predictions support the concept that  
153 country-wide differences in sensitivity could exist.

154

155 Another reason that studying sensitivity at a broader scale than species is useful, links to research  
156 about intra-specific variation. It is common practice among both meta-analyses and projects such as  
157 the IUCN redlist to extrapolate findings about a population's sensitivity to the species on the whole (?)  
158 (?). Studies have shown high intraspecific variation in response to biodiversity pressures like climate  
159 change (?) (?). This could mean that extrapolating findings about one population of a species to  
160 the species on the whole could be problematic.

161 Though it is understood that there are both time, money, and staff constraints on studying more  
162 than one population of each species, such extrapolations should at the very least be acknowledged  
163 more often in the literature. An understanding of the sensitivity of biodiversity of an entire region could  
164 be a more accurate metric for studies of a global scale.

165

166 ?mayor2016assessing) of the studies which found intraspecific variation in response to a biodi-  
167 versity pressure (habitat loss)

168 Despite the few aforementioned papers, the understanding of variations in biodiversity sensitivity,  
169 along with many other aspects of biodiversity, has knowledge gaps which desperately need filling  
170 (Pereira et al., 2012). This research aims to investigate whether the location of a pressure affects its'  
171 level of impact on biodiversity which is important more so now than ever (Ceballos et al., 2015).

172

## 173 **Methods**

### 174 **Overview**

175 The focus of this study is on anthropogenic biodiversity pressures only. Anthropogenic pressures on  
176 biodiversity are typically grouped, in the current literature, into 5 main pressures; climate change, land  
177 use change, pollution, invasive species and overexploitation. In order to assess whether sensitivity  
178 to each pressure varies by country, data was needed in the form of time series (how each of these  
179 pressures had been changing in each country over time, as well as how each country's biodiversity  
180 had been changing over time). The time series of biodiversity in a country was compared to the time  
181 series of a pressure on biodiversity in that country, in order to extract a 'sensitivity score' for each  
182 country to assess any effect of geography.

183

184 First, each pressure's geographic relationship with biodiversity was assessed in isolation. It is  
185 important to look at individual biodiversity pressures, as opposed to an aggregated pressure on  
186 biodiversity, because the pressures have spatial differences (Steffen et al., 2015), meaning the geo-  
187 graphical magnitude of each pressure varies. Therefore in order to understand how countrys differ  
188 in their responses to biodiversity pressures, it must be taken into account the magnitude of each  
189 pressure that each country experiences.

190



## Data

BD data = 18 years, 240 countries The variable chosen to represent biodiversity was biodiversity intactness. The National History Museum's (NHM) Biodiversity Intactness Index (BII)([Heather Phillips, 2021](#)) was chosen as it presents biodiversity in the context of how many original species remain (relative to reference populations). The NHM's Index is the best for this project as the database used is that of the PREDICTS project, which more geographically representative than other datasets ([Purvis et al., 2018](#)). This allows for direct comparison of these changes, with the changes in anthropogenic pressures. Historical BII data spanned 1970 - 2014.

Climate data = 120 years, 230 countries Time series data for climate change was obtained in the form of annual average temperature for each country. The temperature dataset chosen was from the World Bank's Climate Change Knowledge Portal. This dataset was chosen because it contains comprehensive historical data, providing an annual average temperature for every year from 1900 until 2020.

Built Land data = 4 years, 249 countries (years is big problem!) To represent land use change, the dataset used was The Global Human Settlement Layer data package ([A et al., 2019](#)). The data contains information on built-up area change over time, which is the variable chosen to represent land use change. Collective land use change is difficult to quantify from land use statistics. Although satellite data is available to categorise land cover type over time, calculating annual land use change from the proportion of each land cover type is not necessarily accurate, as land use change can be multi-directional. Current studies assessing the impact of land use change on biodiversity are often meta-analyses or use a natural regional situation as the reference land type ([De Baan et al., 2013](#)) as opposed to observing direct impacts of land use change. Statistics

GHG data = 31 years, 63 countries (countries is problem!) With the focus being on terrestrial biodiversity, greenhouse gases (GHG) were used as the representative variable for 'pollution' as a biodiversity pressure. The dataset used to access GHG emissions for each country over time was the 'National Inventory Submissions' section of the United Nations - Climate Change website (?). GHG emissions are presented both including and excluding 'Land Use, Land-Use Change and Forestry (LULUCF)' related emissions data. When assessing pollution and biodiversity links in isolation, LULUCF was included. However, when modelling all biodiversity pressures together, LULUCF was tested for collinearity with the land use change variable, and consequently included/excluded.

The OECD.stat website was used to download the land use change and pollution data.

Overexploitation was excluded for multiple reasons. Firstly, overexploitation is the vaguest of the main pressures, and is usually used in the context of fishing (marine biodiversity being beyond the scope of this project). One of the most relevant aspects of overexploitation to is deforestation, which is (maybe remove this part depending on methods) already represented in the variable used for land use change. Though there are other aspects of overexploitation that would be relevant (e.g. illegal wildlife trading), there are no databases/studies available representing overexploitation by country.

## 233 **Method 1: model for each country**

### 234 **Individual Pressures**

235 For each country, a linear model was fit with biodiversity as the response variable, and the biodi-  
236 versity pressure (e.g. pollution) as the explanatory variable. For those countries where the gradient  
237 was found to be statistically significant ( $p < 0.05$ ), the gradient was recorded as a 'sensitivity score'.  
238 This sensitivity score is representative of the sensitivity of that country's biodiversity, to the particular  
239 biodiversity pressure (e.g., sensitivity of Spain's biodiversity to one unit of pollution)

241 Sensitivity scores were then used to visualise the differences between countries. (I could insert a  
242 map with a colour scale representing the sensitivity score values from different countries)

244 Sensitivity scores were then compared between continents using a linear model. Important to  
245 note that this method only tests for differences between each category, and the reference category,  
246 and therefore does not test differences between all groups. To see the differences between all groups,  
247 a Tukey test was ran.

### 249 **Multi-Pressure Model**

## 250 **Method 2: dummy variables**

### 251 **Individual Pressures**

252 For each biodiversity pressure, a linear model was created for each country using time series of  
253 biodiversity data and the corresponding pressure's time series. For each country in which the pres-  
254 sure was found to have a significant effect on biodiversity ( $p < 0.05$ ), the coefficient of the gradient was  
255 recorded as that country's 'sensitivity score', representing such country's 'sensitivity' to this particular  
256 biodiversity pressure.

258 Each data set has data from a different combination of years, and countries. For each pressure  
259 being investigated, only data from years and countries that are shared between that particular dataset  
260 and the biodiversity dataset is included.

262 For each pressure, the datasets were wrangled and refined to obtain two time series (at an annual  
263 level) for each country; biodiversity and the magnitude of the particular pressure.

264 The data for all countries was pooled into one dataset, and a column added for continent. Be-  
265 cause assessing differences between each country would remove too many degrees of freedom,  
266 differences between the sensitivities of continents were assessed. A multiple linear model was cre-  
267 ated for each pressure. Continent was coded as a factor, in order for R to treat it as a dummy variable.  
268 The alphabetically first continent acting as the reference variable (usually Africa), in order to avoid  
269 multicollinearity. So that the slopes of each continent could be compared, interactions were also  
270 added between continent and the climate

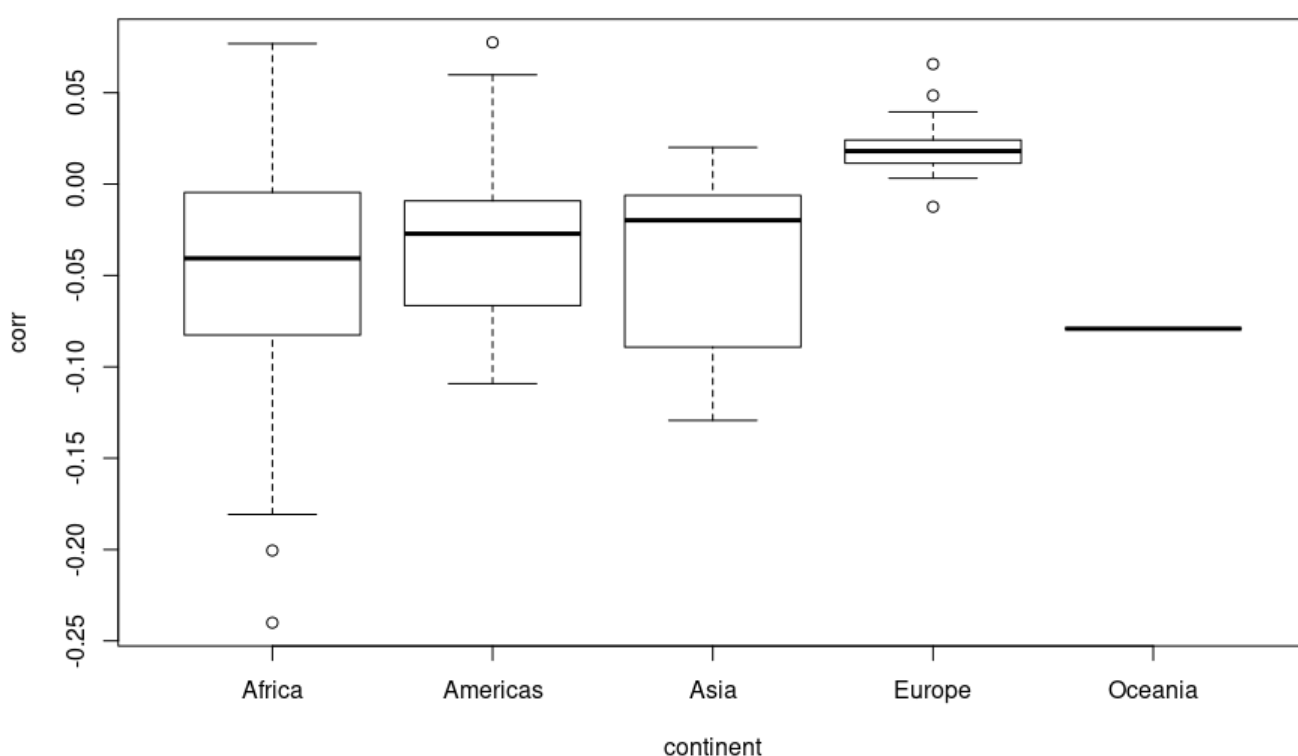
## Results

### Method 1: ANOVAs of gradients

#### Climate

158 countries and 18 years matched between these datasets and 88 gave significant gradient results

Africa was significantly different from zero, and Asia and Oceania did not differ from Africa. The Americas were statistically different, being 0.03 higher, and Europe's sensitivity scores were also significant, being 0.07 higher.



#### Built Land

175 countries and 3 years matched between datasets. only 1 country gave significant result.

Didn't work with built land data because there were only 3 years that matched in the dataset and only 1 country came back as having a significant relationship.

#### Pollution

There were only 43 countries and 16 years that matched between the datasets, and only 7 of these had significant results

#### Invasive

147 countries matched between datasets but the whole thing is a shitshow so let's ignore this one

## Method 2: dummy variables

Africa is reference level for all models.

### Invasive species

Intercept for Africa was statistically significantly different from zero (0.78), and no other continents had a significantly different intercept apart from Europe's which was 0.68.

There was no significant relationship found between number of invasive species and biodiversity in Africa. Slope was not statistically significant from zero. Slopes from all other continents were not significantly different from Africa's.

### Pollution

Intercept was statistically significant for Africa, but slope was not. Europe, Oceania and South America all had statistically significantly different intercepts from Africa but the other continents did not.

Europe and Oceania's slopes were significantly different from Africa's but the other continents were not.

### Built Land

Africa's intercept was significant but slope was not. Europe, North America and Oceania all had significantly different intercepts to Africa's.

No slopes were significantly different from Africa's and therefore none were different from zero.

### Climate

All intercepts and slopes were significantly different from each other. But I still need to correct for average temperature.



326 **Conclusion**

327 optional section

## 328 **Data and Code Availability**

329 Data and CodeAvailabilitystatement: At the end of your Main text, before the References section, you  
330 must provide a statement titled “Data and Code Availability”, where you name a data (e.g., Dropbox,  
331 FigShare, Zenodo, etc) and a code (e.g., Dropbox, GitHub, etc.) archive 20from where the data and  
332 code can be obtained that will allow replication of your results. The code may be in the form of a  
333 single script file.

## Acknowledgements

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