

**THE INFLUENCE OF ACCESSIBILITY TO CITIES ON BIODIVERSITY CHANGE**

*By*

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Ecological and Environmental Sciences with Management

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# Abstract/ Summary

Globally, biodiversity is changing in complex ways in a time of accelerating human impact. We know little about how large-scale anthropogenic activity, as a prominent contemporary global change driver, is influencing the reshuffling of ecological communities. I quantify the influence on ecological assemblages by human activities, such as roads and urbanisation, worldwide and across taxa by analysing change in 181 time series studies. I predict to find higher temporal and spatial turnover with greater exposure to roads and urbanisation. Linking human impact with biodiversity change can provide the needed evidence and predictions for better international policy making in the light of our rapidly changing Anthropocene.

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# Acknowledgments

I would like to thank blab la and blab la.

# List of abbreviations

# Introduction

* *Split objectives?*
* *Is last paragraph intro same as objectives and RQ part?*

*The dissertation comprises an introduction discussing the research question, reviewing the relevant literature, and setting out the research questions and hypotheses to be tested. The introduction should introduce the reader to the subject area and clarify the knowledge gap that the dissertation research will fill. The Introduction must set the context for the dissertation by reviewing the relevant literature. The primary research questions and hypotheses should be listed in the final paragraph of the introduction. The introduction should not be just a ‘Literature Review’ but should include relevant references to general (theoretical papers and reviews) and specific (specific to the particular question addressed) literature, to justify the research that has been undertaken and define the question being addressed.*

## Background (not sure whether to title this section)

First paragraph

* Globally, biodiversity is changing in complex ways in a time of accelerating human impact.
* Acceleration of global change
* Abundance, richness and composition of ecological assemblages are changing in complex ways
* Need for understanding the factors driving the change across geography and taxa (or general different levels)
* Importance of biodiversity, link to ecosystem services
* Ecological reshuffling and link to global biodiversity change
* Research gap:
  + Limited understanding global change driver, eg land-use change, that drive those heterogenous patterns of BD change
  + Disentangle sources of heterogeneity across full spectrum of change (across taxa and population etc)
  + Effects of global change driver on ecological changes (but so far only forest loss, warming)
  + Joint anthropogenic activites are influencing (check references prereg 6,7,12)

Middle paragraphs

* Distribution of global change drivers (land-use change, habitat change, pollution, invasion by non-native species, climate change)
* Link global bd change to local bd change
* On top of geographic patterns in exposure to human activities, differentiation at population level/ species vulnerability
  + Certain species traits can moderate/ be more vulnerable
  + Important understanding to focus conservation efforts
* Population dynamics theory, taylor’s power law?
* Threats to species (other than anthropogenic as well)
* So far: space for time and modelling projection approaches (Newbold reference)
  + Don’t account for ecological lags and community self-regualtion
* Controversy about diverse impact of habitat fragmentation on biodiversity (check references from forest loss 18-20)
* Amplification of effects when globacl change drivers are acting together?
* Explanations what anthropogenic activity could cause: land-use change -> cooler habitats, rising temp -> species vulnerability goes up
* Roads and urbanisation, land-use change (effects of human accessibility)
* Conflict development and conservation?
* Human population density
* Calls for understanding drivers BD change
  + What have they looked at?
  + Why not sufficient? Little temporally matched data
  + Multiple drivers?
* Difference of scales?
* Anthopogenic causes of biodiversity change -> importance for conservation and ecosystem blabla
* Anthropogenic activity and the negative consequences; many captured in metric accessibility
* Different global change drivers
* Species different vulnerabilities to them
* Different drivers acting together

## Objectives and research questions

*This should be a concise statement of the objectives, research questions and hypotheses of the study. You may also include in this section if you wish. Hypotheses should be explicitly and outline the anticipated results should be discussed: “If hypothesis H1 is supported than this will indicate… However, if H2 is supported that this will suggest…”.*

My aim is to quantify how global change drivers influence ecological communities over time. Specifically, I will focus on the effects of urbanisation and roads, captured in the metric accessibility to cities, and human population density on temporal changes on ecological community composition overall and across taxa. These drivers are an indirect representation of large- scale human activity and capture big parts of the alteration of our planet. I will test if these drivers of global change explain heterogenous biodiversity change found across our planet. To achieve this, I investigate the influence of accessibility to cities on ecological assemblages worldwide and across taxa by analysing change in 5078 time series. I assess variation in biodiversity change across blablabla taxa. I will address the following research questions:

1. Do sites with higher accessibility to cities experience more changes in assemblage composition over time (temporal turnover) than locations with lower accessibility?
   1. How does the duration of ecological monitoring influence the magnitude of detected temporal turnover trends?
2. How does temporal turnover of ecological communities respond to levels of accessibility across taxa (birds, mammals, terrestrial invertebrates, terrestrial plants)?
3. How is temporal turnover influenced by an interaction between human population density and accessibility?

## Research hypotheses

I hypothesize that there will be a positive relationship between higher accessibility to cities and greater temporal turnover. The magnitude of temporal turnover increases for sites which have been monitored over longer durations. When looking at individual taxa, I hypothesize that taxa will have different responses to high and low levels of accessibility, with both positive and negative relationships present. The relationship between accessibility to cities and temporal turnover is steeper, when human population density is higher (all positive). Those hypotheses will be tested against the null hypotheses of no relationship (or negative relationship) between level of accessibility and temporal turnover, and human population density and temporal turnover.

* *Sites with higher accessibility to cities correspond with greater temporal turnover*
* *The magnitude of temporal turnover increases for sites which have been monitored over longer durations*
* *Ecological communities of taxa respond differently to high and low levels of accessibility.*
* *The relationship between accessibility to cities and temporal turnover is steeper, when human population density is higher (all positive)*

## Predictions

I predict greater temporal turnover with greater exposure of accessibility to cities, as an alteration of the natural environment benefits some species, while damaging others, influencing community composition. I predict greater temporal turnover in sites which have been monitored over longer durations, as the effect of turnover becomes more apparent over time. I predict both positive and negative trends to be present among taxa, as they have differences in ecological requirements. I predict the relationship between accessibility and temporal turnover to be steeper, when human population density is higher, as high HPD increases the pressures on the natural systems, leading to higher turnover.

If I find support for my null hypotheses, this will indicate that the metric accessibility to cities cannot capture the most relevant human impact on biodiversity, questioning the justification for humanly undisturbed places. If the results are in line with my alternative hypotheses, this will demonstrate the importance of humanly undisturbed places for the conservation of biodiversity.

We predict larger turnover with larger exposure to all types of global change because the

different drivers all alter ecosystems, which might create beneficial conditions for some

species, and detrimental conditions for others, resulting in community composition

changes43,44.

# Methods

*The methods should explain as concisely as possible where you worked and what you did. Only include the required methods to repeat your study, do not include methods for data you do not present in the dissertation. Standard analyses or techniques need only be given a reference to published accounts or protocols. Use clear subheadings to structure your methods for the reader. Discuss data manipulations, statistical approaches used and the statistical software in a statistical analysis section.*

To quantitively test the consequences on ecological communities of large-scale anthropogenic activity globally, I used 3 global databases.

## Databases

WHERE TO PUT FIGURE BIOTIME?  
ADD OTHER FIGURES?  
SAMPLE SIZES?  
CONCEPTUAL DIAGRAM?

***BioTIME Database – biodiversity time series data***

The currently largest database of temporal community time series spans 4,970,128 (UPDATE) records of richness and abundances of species globally, covering a range of taxa, including birds, mammals, invertebrates and plants (Dornelas *et al.*, 2018). I analysed 5788 time series from 181 different studies from terrestrial (UNIQUE?) places around the globe that are part of the BioTIME database as of 12/03/2020. I used all available data that met my inclusion criteria: part of the terrestrial realm, minimum study duration of 5 years, at least 15 studies per taxa, no more than 2000 plots per study, plot fixed to one location and at least 2 survey points per plot. The time-series used represent repeated studies of species abundance and identity of all species found within an ecological community. The data collection of BioTIME was consistent within studies but not between studies.

The BioTIME database is limited in its even representation of different taxa and latitudes. It underrepresents reptiles and amphibians and the tropics and polar regions (see Figure 1).

PROTECTED AREAS?

***Accessibility to cities 2015 data***

To quantify large scale human impact (of roads and urbanisation), I extracted an accessibility to cities metric from the malariaatlas project Accessibility to cities 2015 global database. This database calculates least-cost-path land-based travel time to the nearest densely populated area (between 85 degrees north and 60 degrees south) at a 30 arc seconds X and Y resolution. Areas with >1,500 inhabitants/km² or a majority of built-up land cover types coincident with a population centre of at least 50,000 inhabitants are defined as densely populated areas.

***Human population density dataset***

I derived population density data from the Gridded Population of the World, Version 4: Population Density, Revision 11 database (CIESIN, 2018). Human population density was defined as number of persons per square kilometre, based on national censuses counts and population registers. Data is available 2015 at a 30 arc-second resolution.

## Data processing

MENTION R?  
MENTION PACKAGES?  
MENTION BIOMASS TYPES ETC?   
MENTION THAT BIOTIME WAS NOT STANDARDISED CELL SIZE/SAMPLE EFFORT?  
CENTERING OTHER VARIABLES?  
GLOBAL GRID CELL?  
MENTION BD DOES NOT COVER RANGE OOF ACCESSIBLITY AND HPD? Extra paragraph  
TURNOVER INDEPENDENT OF RICHNESS CHANGE?

I quantified temporal changes in community composition within sites, as the turnover component of beta diversity (species replacement rather than abundance) at the last data point available relative to the first observation data point within the time period outlined above. This was the dominant part of biodiversity change in the BioTIME dataset (REF). I bound the scores of turnovers between zero and one, where zero is no change in community composition and one indicates that all of the original species have been replaced.

I harmonized both accessibility and human population density dataset to a standard global grid size of 25km² by taking the mean value of the grid cell. MENTION SENSITIVITY TO SCALE FROM SENSITVITY ANALYSIS. I bound the scores extracted between zero and one, where zero is not accessible/low human population density and one is very accessible/ high human population density respectively.

## Statistical/data analysis

EXACT MODEL (LINEAR?)  
DISTRIBUTION INTERCEPT ~1? LOGIT LINK FUNCTION? % FALLING INTO EACH CATEGORY (0,1,0-1)  
FORMULAS?

All statistical analysis was conducted in R v. 3.6.1. (REF R). To quantify the influences of accessibility and human population density on turnover of ecological communities, I used a hierarchical Bayesian modelling framework based on a Markov chain Monte Carlo (MCMC) method. All Bayesian models were created in a Stan computational framework and accessed through the {brms} package (REF). The models are based one a zero one inflated beta distribution to reflect the properties of turnover (bound between, and including, zero and one).

**Explanation models response variables, fixed effects, random effects**

CENTERING OF DATA HERE?  
STATE MODEL EQUATION?

I modelled turnover as my response variable. Fixed effects were (scaled) accessibility and duration of the time-series. Area was not included as a fixed effect, as it did not have a significant effect on turnover (SAME FOR DURATION THOUGH?). To answer Research question 3, human population density was included as a fixed effect, as well as the interaction between accessibility and human population density. To account for autocorrelation of both methods and to some extent space, Study ID was included as a random effect. A model including a grid cell, more directly accounting for spatial autocorrelation did not converge, so the term was excluded. Taxa was included as a random effect, as I wanted to remove the variation of different taxa to the overall/ no expected effect taxa and turnover?

Ggpredict?

(Coding scheme for categorical value of human population density)

**Model explanation (priors, iterations).**

The models will be based on a zero one inflated beta distribution.(HERE OR BEFORE?)

I ran the model first with both random intercepts and slopes for taxa but as no model convergence was achieved, I ran them with only random intercept. Allowed turnover to vary by random slope and intercept?

I used the default priors as they are weakly informative and I have no ecological backup to assume otherwise. The default priors are:

I ran the models with 6000 iterations, with a warmup of 2000 iterations. Alpha? Treedepth? I assessed convergence visually by examining trace plots and by using Rhat values.

As I will be using a Bayesian framework, my inferences will be based on the posterior distribution of each fixed effect. They will be considered significant if the lower and upper 95% credible intervals don’t overlap zero. I will conclude all results, regardless of the direction or magnitude of the effect size.

**Alternatives to measuring variables?**

**Sensitivity analysis**Different scales extraction  
Better temporally matched data

Full R script in appendix, preregistration

# Results

*The Results Section contains text that summarises the findings of the research referring to all figures, tables and statistical results. Include the primary results, ordered logically (often from most important to least works well). Maintain the order that you present your results through out all parts of the dissertation. Data should only be presented once in either tables or figures in the main text or appendix. Often, it is recommended to write the results section first, so that you can write the methods that are appropriate to describe the results presented, then you can write the discussion next about these results, the introduction to introduce the relevant literature for the scientific story that you are telling and finally the conclusions and abstract – this approach is called writing backwards.*

*Statistical results when reported in the text, tables or figure captions must include the test used (ANOVA, Linear model, Linear mixed effects model, GLM, etc.), sample size (N) or degrees of freedom, effect size and error (e.g., slope and error around the slope), test statistic (t-value, F statistic, etc.), model fit (R2, pseudo R2, etc.) if appropriate and p-value. P-values alone are incomplete statistical reporting (see http://www.nature.com/news/statisticians-issue-warning-overmisuse-of-p-values-1.19503). Full statistical results, additional figures or tables and raw data can be included in an Appendix. For guidelines on how to report specific statistical tests refer to the scientific*

*literature and discuss you're your supervisor. All code for statistical analyses should be included in the appendix for students that are using coding based statistical software such as R.*

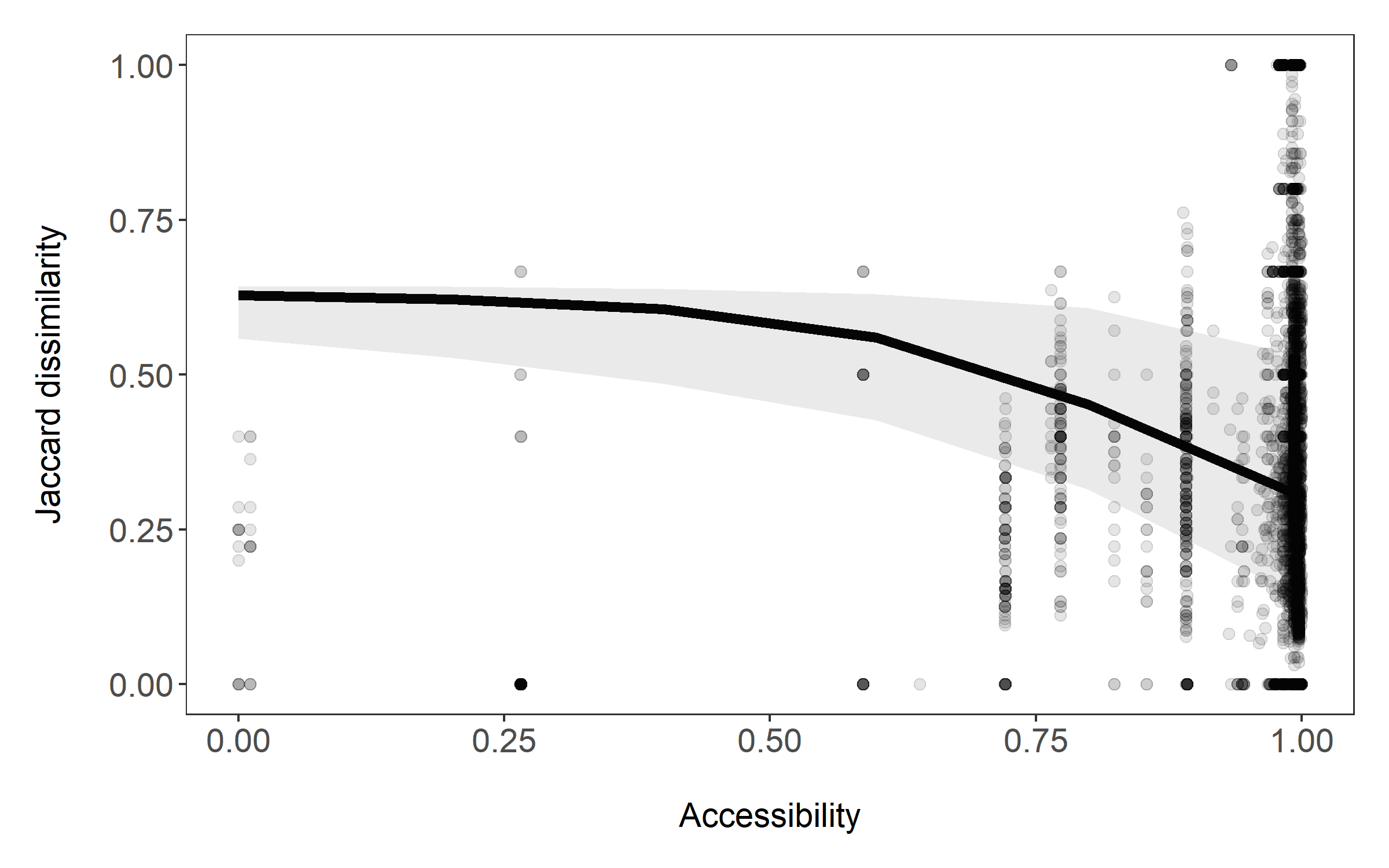
*Questions:*

* *How to put sample size*
* *Limitations of results in results section?*
* *Visualising vs modelling*
* *Include sensitivity analysis here?*

Standardized effect sizes were calculated by dividing the model slopes by the standard deviation of the dependent variable

**Temporal turnover and accessibility (Research Question 1)**

In line with my predictions (preregistration), I found that temporal turnover has increased across the 5788 time-series surveyed (slope = 0.05, CI = 0.03 to 0.07, Figure 1, see Table 1 for more model outputs). On average, temporal turnover is increasing by 10% as accessibility is increasing by 10%. In line with my predictions (see preregistration), the duration of the observation influenced the magnitude of the detected temporal turnover trends, with higher turnover increases for longer observations of sites.



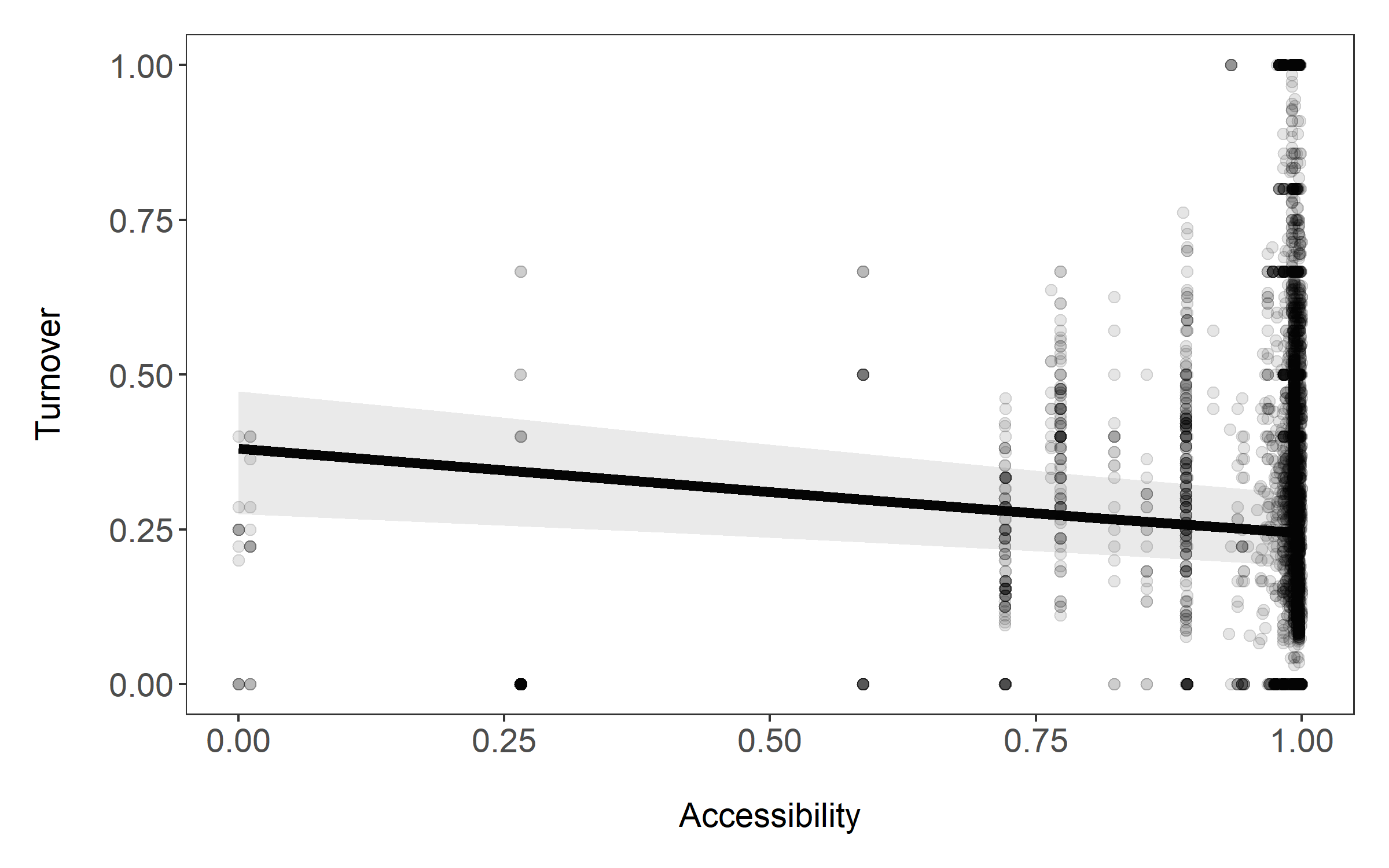
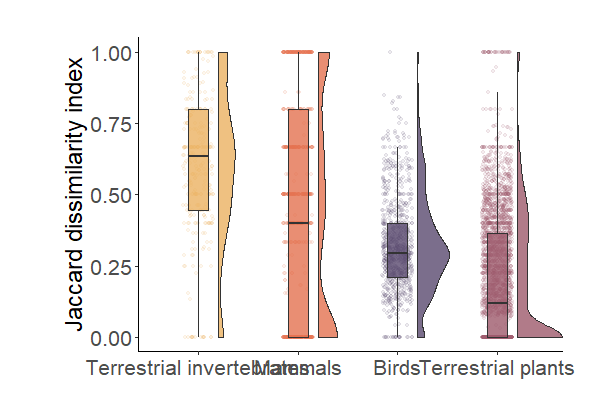


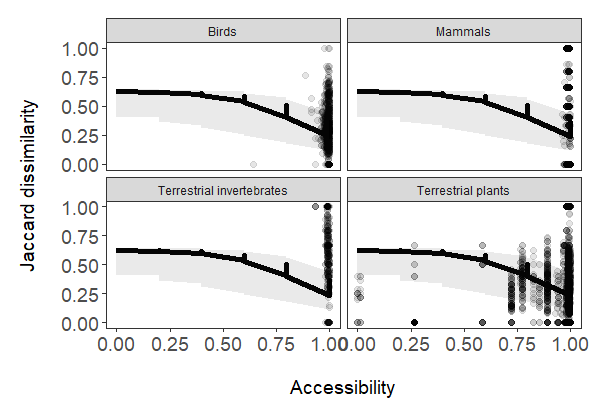
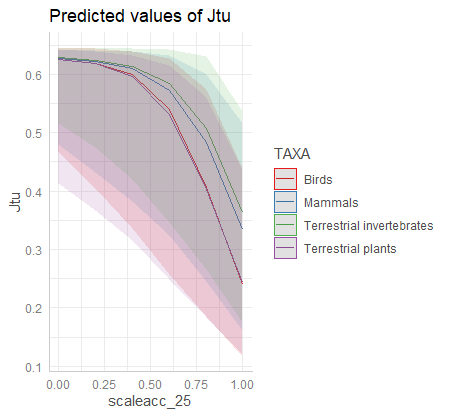
Figure 2. Jaccard turnover has increased for higher levels of accessibility across 5788 time-series globally (slope = 0.05, CI = 0.03 to 0.07, Figure 1, see Table 1 for more model outputs). Grey points represent raw data. Lines and error bands represent model predictions and 95% credible intervals, respectively. Colour coding of lines represent differing duration of monitoring. See trace plots and model Rhat values in appendix confirming model convergence.

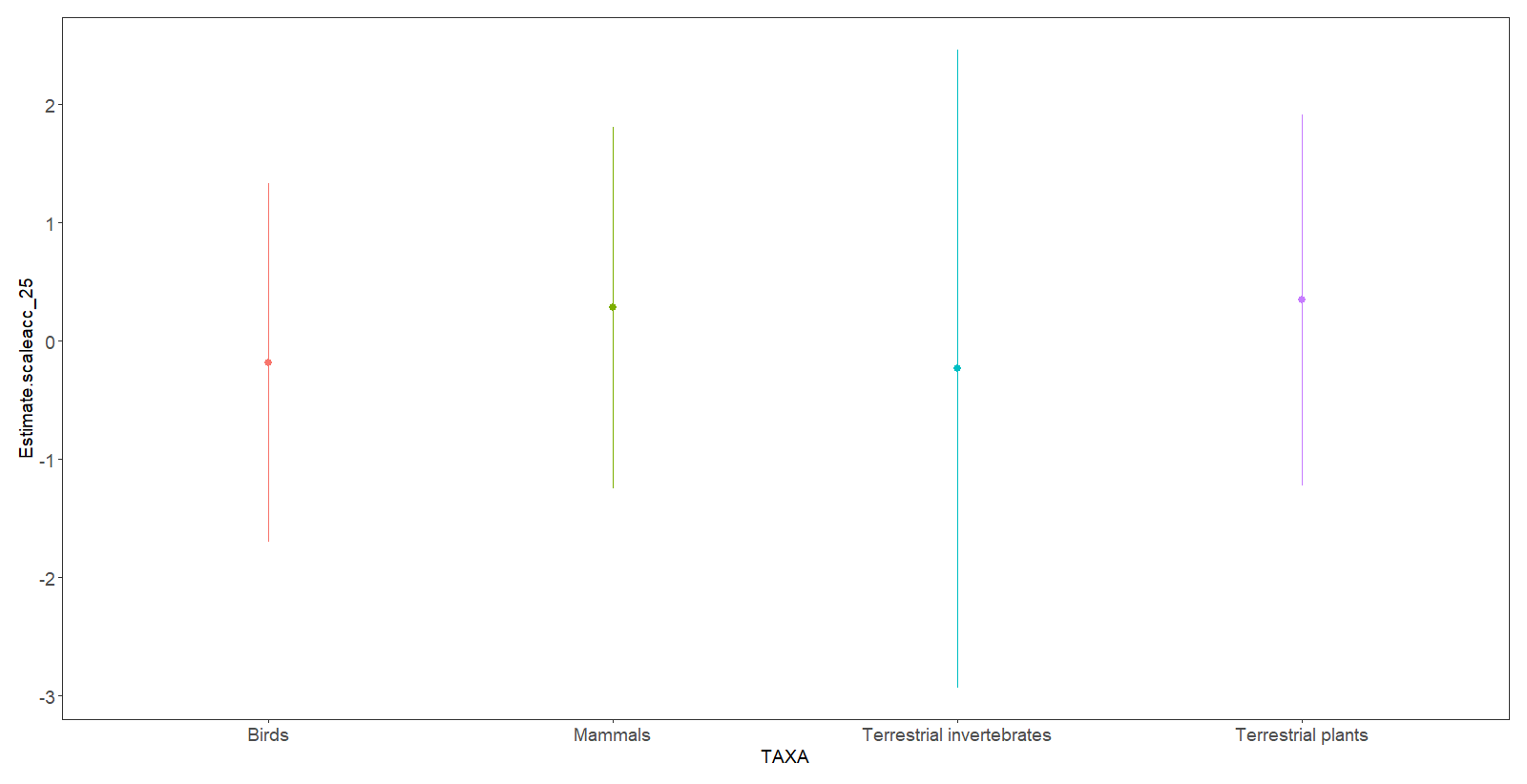
The results of the temporal turnover model revealed an increase of temporal turnover across levels of accessibility. Therefore, I found support of my initial prediction of accessibility increasing temporal turnover, and thus accept the alternative hypothesis. Study area had no significant effect on temporal turnover (slope = 0.05, CI = - 0.03 to 0.07). Latitude? Results to be taken with caution? Examining the posterior means of the random terms, study ID, taxa and broad grid cell, revealed among Study ID variation (variance = 0.4, CI 0.3 – 0.5), and little within study ID variation (variance blabla). Same for taxa and broad grid cell. Full model output can be found in Appendix X.

**Taxa-specific responses to different levels of accessibility (Research Question 2)**

Visualising raw temporal turnover data among taxa revealed no clear differences between the temporal turnover of individual taxa on different levels of accessibility (Figure 3). Terrestrial plants’ and birds’ responses, have increased turnover as accessibility is increasing. Among the 4 taxa, terrestrial plants have experiences the greatest temporal turnover increase by 23% for every 10% increase in accessibility. Mammals and terrerstrial invertebrates show no clear pattern. TALK ABOUT DISTRIBUTION OF DATA?







BAR PLOT/ BOX PLOT WITH EFFECT SIZES OF EACH TAXA

SCATTER PLOT FOR EACH TAXA?

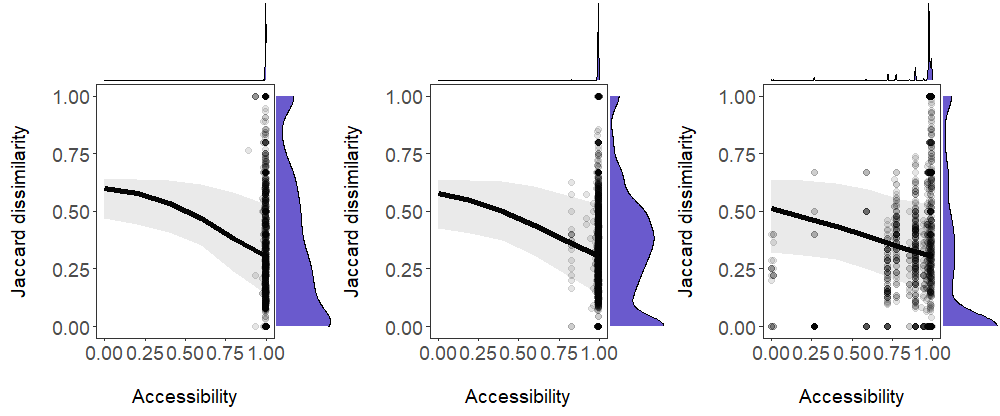
The model which compared temporal turnover among taxa revealed that there is no significant difference between taxa’s individual temporal turnover response on accessibility (slope blabla). Interaction taxa:accessibility?. 2 responede, 2 not. Caution with interpretation?

Model predictions confirmed my hypothesis of.. mention other fixed effect response tp that. + random terms

Sensitivity analysis results?

Visual examination trace plots, model convergence, shortcomings of the model

**Relationship between accessibility and human population density on temporal turnover (Research Question 3)**



# Discussion

*The object of the discussion is to summarise your major findings and place your findings in the context of previous studies current state of knowledge in the literature. When you discuss your own work and that of others, back up your opinions with evidence and citations. The first paragraph of the discussion should contain a summary of your major findings (usually 2 – 4 points) and a brief summary of the implications of your findings and should make reference to whether you found support for your hypotheses or how you answered your research questions. The following paragraphs will usually describe each of these findings in greater detail making reference to previous studies. Often the discussion will include a paragraph describing the limitations of your study and the potential for future research.*

Major findings paragraph + brief implications + refer back to hypotheses and RQs

Paragraph for each finding + past research

Limitations of study

Potential future research

Interaction of drivers

From forest paper

General discussion points

* Community self-regulation
* Ecological lags
* Land use change -> alters habitat and resource availability (make it specific to roads and urban centers!)
* Turnover independent from richness + dominant component of compositional change across BioTIME time series (geography blowes)
* Habitat fragmentation!
* Disturbance is disturbance and does not depend on magnitude of accessibility (similar to forest paper Gergana)
* Lack of magnitude of effect due to
  + Temporal lags in community responses
  + Lower influence of accessibility during monitoring period (2015) relative to historic influences accessibility
  + Influence of dirvers other than forest loss
  + Variation in species vulnerability to disturbance
  + Mismatch between assemblages monitored and localized impacts of accessibility
  + Accessibility amplified both positive and negative trends at local scales, but at larger scales favoured same species across sites (homogenization)
  + Rare species more negatively affected by land-use change
* Importance of seeing heterogeneity when scaling from local to global
* Extinction debt and immigration credits
* Temporal lags in bd change also observed in other studies
* Increasing rates of land use change in Anthropocene will alter ecosystems on both short and long term timescales
* Alien potential

### **2.5 Alien species potential**

The spread of alien species is among the greatest threats to biodiversity and ecosystem services (Blackburn, Bellard, & Ricciardi, [**2019**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0004)). Alien species are defined as species that are introduced into areas beyond their historical range, usually through human transport, accidentally or incidentally (Hulme, [**2009**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0030); Seebens et al., [**2015**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0059)). We used information on transport infrastructure related to human movement and trade that depict possible species transportation pathways and vectors (Davidson, Scianni, Minton, & Ruiz, [**2018**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0009); Hulme, [**2009**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0030)). Specifically, we used spatial datasets of transport connectivity (including data on road and rail networks and navigable rivers) in the terrestrial realm and cargo volume at ports in the marine realm (Table [**S1**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#support-information-section)). While these do not represent the only invasion pathways, they are commonly accepted proxies for human‐mediated propagule pressure, which is known to be among the most important determinant of alien species establishment (Hulme, [**2009**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0030); Seebens et al., [**2015**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0059)).

Our analysis required high‐resolution global gridded maps, but high‐resolution alien species distribution data are not available for neither realm. However, information on alien species distribution was available at a regional, subnational and national levels for some taxonomic groups, including birds (Dyer et al., [**2017**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0016)) and plants (van Kleunen et al., [**2019**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0066)). We used these datasets, representing taxa with low and high mobility, to assess the validity of our proxy by testing the correlation between alien species richness and mean connectivity at the spatial scale of the distribution data. We found a significant rank correlation for both datasets (birds, *ρ* = 0.42; plants, *ρ* = 0.46, see Figure [**S1**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#support-information-section) for more details), suggesting our proxy represents a reasonable estimate of alien species potential.

### **2.6 Human population**

We also included ‘human population density’ as a separate driver (CIESIN, [**2017**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0007)) accounting for the effects of human activities not falling into the other categories (Salafsky et al., [**2008**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0057)). Although we recognize that the relationship between local human population density and the local human activities negatively impacting on biodiversity can strongly vary among countries, for example with economy size. By including human population density, we could also test the relationship between human population density and the other drivers.

Taxa specific

* Taxa specific responses due to longer generation times
* Max change BD 6-13 years after forest loss
* But rapid change frequently after habitat change
* Longer for taxa with longer generation times (mammals and birds)
* Long lags in trees!
* Species rarity not influencing, but rather smaller pop size and larger range more likely to range
* More taxonomic than geographic patterning of pop change

 However, the realized outcome of different drivers on biodiversity will ultimately depend on a combination of both the magnitude of exposure to drivers and species' sensitivities to environmental change (Foden et al., [**2013**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0018)).

Unlike exposure, sensitivities vary among taxa according to characteristics such as their life history, traits and niche breadth (Sunday et al., [**2015**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0062)) and therefore need to be examined separately for different taxa.

Limits methods

* Spatial underrepresentation of sites modified by human activities
* Don’t have accessibility scores across spectrum
* Temporal mismatch of data hinders ability to detect causal link acc and biodiversity change
  + We don’t know impact directly after road/ city was built; species might adapt over time?
* Complexity of eco communities and temporal dynamics of them
* Taxonomic, spatial and temporal imbalances make large scale attribution analyses of bd trends and global change drivers challenging
  + Underrepresentation certain areas and species
  + Different spatial scales biodiversity monitoring and accessibility -> spatial mismatch driver and response
  + Temporal mismatches and lags
    - Improvement possible with better matched data

The resolution at which we will calculate driver intensity is larger than

the roaming ranges of small-bodied animals and less mobile species. Because of the

magnitude of different species and communities that we will be analysing, it is not possible to

have an analytical scale tailored to the traits of each species and community. Furthermore, it is

still largely unknown what is the optimal scale at which to conduct macroecological studies,

and finer resolution global driver data are not currently available for most drivers. For more

details on analytical methods, see the statistics section further down.

Future research

* Biotic homogenization
* Multiple types of anthropogenic activities are jointly influencing + whether amplification
* Both realms

Conclusions

* This finding challenges the widely-held assumption that land-use change universally leads to population declines and species richness loss ([***11***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-11), [***13***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-13), [***39***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-39)).
* Complex and variable over time
* Varied and often positive effects of habitat fragmentation on biodiversity metrics
* Incorporating the full spectrum of population and biodiversity change in response to land-use change will improve projections of future impacts of global change on biodiversity and thus contribute to the conservation of the world’s biota during the Anthropocene.

If we find greater turnover with increasing intensities of both climate and human userelated

drivers, this will mean that the two types of drivers correspond with local

extinctions and colonisations of different types of species and are acting in synergy,

thus affecting larger proportions of ecological communities58. Such patterns suggest

that species’ vulnerability to different global change drivers is negatively correlated47, in

line with evolutionary trade-off theory60.

● Conversely, a lack of increase in turnover with greater intensities of both climate and

human use-related drivers will suggest that the two types of drivers influence ecological

communities in different ways and are having antagonistic effects when acting together.

If one driver has led to the local extinction of a species, a second driver cannot cause

the local extinction of the same species again58, and some species show positive

correlation in their vulnerability to different types of threats23,61,62, as predicted by

Brown’s niche breadth hypothesis63.

HPD (isla paper)

or many drivers, it can be hypothesized that exposure patterns may be inter‐linked due to related local or regional human activities, driven by local human population density (Ellis, Goldewijk, Siebert, Lightman, & Ramankutty, [**2010**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0017); Geary et al., [**2019**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0021)).

# Conclusions

*The conclusion paragraph should put your findings into the broader context of the literature and explain how you have filled the knowledge gap that you have identified in the introduction. This is your chance to present to your reader the major take-home messages of your dissertation research. It should be similar in content to the last sentence of your summary abstract.*

# References

# Appendices