

**GLOBAL ASSESSMENT OF LOCAL BIODIVERSTIY CHANGES REVEAL SURPRISINGLY COMPLEX RESPONSES TO LARGE-SCALE HUMAN ACTIVITY**

*By*

**DANIELA GARGYA**

in partial fulfilment of the requirement for the

Degree of BSc with Honours in

Ecological and Environmental Sciences with Management

May 2020

# Abstract/ Summary

Globally, biodiversity is changing in complex ways in a time of accelerating human impact. We lack real-world data how large-scale anthropogenic activity, as a prominent contemporary global change driver, is directly and indirectly influencing the reshuffling of ecological communities over time. Here, I quantify the influence of human activity captured with the metric accessibility to cities on ecological assemblages worldwide by analysing change in 5787 time-series across birds, mammals, plants and invertebrates. Surprisingly, I found that for every 10% increase in accessibility, species replacement (turnover) decreases by 5%. Turnover was highest for invertebrates and mammals and lowest for birds and plants. My findings demonstrate the complexity of real-world biodiversity change and challenge the assumption that current conservation focus on protecting wilderness areas might not be sufficient to achieve biodiversity composition conservation goals.

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.

questions current conservation priorities focussed on protecting wilderness areas.

# Table of contents

Contents

[Abstract/ Summary 2](#_Toc38970976)

[Table of contents 3](#_Toc38970977)

[Acknowledgments 3](#_Toc38970978)

[List of abbreviations 4](#_Toc38970979)

[Introduction 5](#_Toc38970980)

[Background 5](#_Toc38970981)

[Objectives and research questions 6](#_Toc38970982)

[Research hypotheses 7](#_Toc38970983)

[Predictions 7](#_Toc38970984)

[Methods 8](#_Toc38970985)

[Databases 8](#_Toc38970986)

[Data processing 9](#_Toc38970987)

[Statistical/data analysis 9](#_Toc38970988)

[Results 11](#_Toc38970989)

[Discussion 16](#_Toc38970990)

[Conclusions 21](#_Toc38970991)

[References 21](#_Toc38970992)

[Appendices 21](#_Toc38970993)

# Acknowledgements

I would like to thank my supervisors, Dr Isla Myers-Smith and Gergana Daskalova for their constant support, shared knowledge and encouragement throughout the process of this dissertation and beyond. From finding a research question, to help with statistical analysis, coding, and writing tips, I always found open ears and patient explanations. Also, I am very grateful for the opportunity to have become part of Team Shrub, where I learned a lot during the weekly lab meetings while also having fun. The feedback Team Shrub provided me on one of my paragraphs was very useful.

I also want to acknowledge and thank my great support network. Starting with my wonderful flatmates, Anna, Larisa and Giada, for always supporting and keeping the spirits high, but also given valuable feedback and proofreading drafts.

# List of abbreviations

CI Confidence Interval

BAIC Before after impact control

RQ Research question

# Introduction

Humans have modified 75% of terrestrial land cover, leading to major pressures on the biosphere and its inhabitants (IPBES, 2019). Increasing human population and the growth of cities and road networks, which predicate the equity agenda of the UN by advancing accessibility (UN, 2015), are expected to intensify impacts on the natural environment (IPBES, 2019). Large scale human activity has altered abundance, richness and composition of ecological assemblages in complex ways (Dornelas *et al.*, 2014; Vellend *et al.*, 2017; Hillebrand *et al.*, 2018; Magurran *et al.*, 2018). The consequences for ecosystem processes and their resilience are not fully understood (Vellend *et al.*, 2017), yet biodiversity is increasingly instable. Disentangling drivers of complex biodiversity change and establishing effective conservation practices without compromising human development is an urgent issue. Currently, we only have a limited quantitative understanding of how global change drivers, such as large-scale human activity, influence local patterns of biodiversity over time. Despite calls for more encompassing tests of the effects of global change drivers on biodiversity changes, research has mostly focussed on individual types of environmental change such as forest loss and land-use change. Recent global maps of large-scale human activity such as the accessibility to cities map together with long-term biodiversity time-series, allow us to quantitatively test more encompassing global change drivers’ effects on biodiversity change. Linking large-scale human activity with biodiversity change can provide the needed information and predictions for better international policy making in the light of our rapidly changing Anthropocene.

Biodiversity changes/patterns depend on the scale and metric of observation (McGill *et al.*, 2015; Chase *et al.*, 2019). On a global scale, much research point towards a detrimental impact of human activity on the natural environment with biodiversity declining, as is reflected in increasing global extinction rates. Contrary, on a local scale, biodiversity measured with the metric richness seems to be stable or even increasing (Butchart *et al.*, 2010; Dornelas *et al.*, 2014, ISla?). A potential explanation can be found when looking at the metric species turnover (changes in the composition of ecological communities), which can reveal changes in biodiversity that are often uncoupled from richness change (Dornelas). Communities seem to undergo replacement of some species by other species with no overall change in the total number of species. This highlights that the biodiversity crisis is not about decline but rather about large-scale reorganization of communities leading to homogenization across space (Blowes *et al.*, 2019). This homogeneity leads to a decrease in biodiversity over larger scales and has serious implications on the ability of species communities to adapt to future environmental changes (Eriksson and Hillebrand, 2019). Thus, to comprehend biodiversity change across scales and make prediction for the future it is important to understand changes in communities’ compositions at the local scale.

Biodiversity change and its attribution to a specific driver can be assessed through different methods/ study designs, each coming with its own advantages and disadvantages. Based on difference in methods used, local biodiversity changes due to human activity are a topic of ongoing controversy. Research that use space-for-time and modelling approaches generally report negative trends of biodiversity change following human impact such as land-use change. Research that uses temporal trends and real-world data generally report a more complex picture of biodiversity change with both negative and positive biodiversity change present. Space-for-time models can make use of much applicable data but have been criticised for the uncertainty in the assumption that time can be substituted for space. Especially when researching biodiversity change, this approach is lacking important temporal aspects such as ecological lags and community self-regulation with the consequent risk of overestimating the effect of global change drivers. Temporal assessments based on real world data can infer driver-response relationships by observing fluctuations through time. These attributions heavily depend on long-term availability and match of data of both driver and response variables under observation. Assessing biodiversity changes and their relationship to global change driver could benefit from looking at real-world temporal data.  
  
Biodiversity change can be driven by multiple human impacts simultaneously. Humans have impacted the natural environment mainly through habitat change, exploitation, pollution, climate change and invasive species. Previous studies have focussed on individual types of human impacts such as forest loss and land-use changes/transitions, which consequently attributed a very specific driver to biodiversity change. At the same time, these studies are limited in their extent to capture potential interactions of simultaneous human activities. To implement most effective conservation measures it is not sufficient to look at one driver in isolation, but we seek to gain a more general understanding of biodiversity changes in reaction to large-scale human activities as we are dominating the planet in such way. The metric accessibility to cities which is a measure of the closest travel time to the next urban centre can be seen as a proxy for multiple human influences. An increase in accessibility, goes along with increases of road network, urbanisation and human activities linked to urbanisation such as land-use changes and agricultural activity. This metric can capture changes to the environment and its inhabitants such as habitat fragmentation, land-use change, alien species and habitat loss as a cumulative measure. It allows to observe outcomes of potential interactions between those environmental changes. Furthermore, it can be hypothesized that the impacts on biodiversity change might be amplified with higher exposure to human activities, driven by human population density. Biodiversity changes are influenced by simultaneous human activities which potential interaction effects between them and are thus captured best with a metric that accounts for a variety of human activities.

Conservation strategies require informed assessment of biodiversity change and prioritisation setting. Ultimately, biodiversity change is influenced by population dynamics which is dependent on species vulnerability. Species vulnerability varies with functional traits as the reaction to anthropogenic and environmental change differs. Species with small population sizes, high habitat specificity and restricted geographic extent are more likely to locally go extinct, thus increase the likelihood of biodiversity change. Less mobile species might struggle more to disperse and find a suitable refuge as there is more concentrated exposure to environmental change. Small population sizes are more prone to undergo stochastic fluctuations (Taylor’s power law) as well as higher occurrence of inbreeding with resulting reduced fitness. High habitat specificity means that colonization of new areas is restricted by limited habitat preferences. Species traits shared across a taxon make certain taxa more vulnerable to declines and extinctions. Studies looking at different species responses to a range of human impacts have found differing responses among taxa, related to functional traits. Understanding biodiversity changes on a taxa-specific level can increase our understanding generally and allows for more specific targeting of conservation efforts.

## Objectives and research questions

My aim is to quantify how global change drivers influence ecological communities over time. Specifically, I will focus on large-scale human activity captured in the metric accessibility to cities, and human population density and their relationship with temporal changes in ecological community composition overall and across taxa. To achieve this, I investigate the influence of accessibility to cities on ecological assemblages worldwide and across taxa (birds, mammals, plants and invertebrates) by analysing change in 5787 time series, addressing the following 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 is temporal turnover influenced by an interaction between human population density and accessibility?
3. How does temporal turnover of assemblage composition respond to levels of accessibility across taxa (birds, mammals, terrestrial invertebrates, terrestrial plants)?

## 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. The relationship between accessibility to cities and temporal turnover is steeper when human population density is higher. When looking at individual taxa, I hypothesize that taxa responses will vary for temporal turnover across levels of accessibility, with both positive and negative relationships present. Those hypotheses will be tested against the null hypotheses of no relationship between levels of accessibility and temporal turnover, no amplification of effect when human population density is higher and no difference in relationships between temporal turnover and accessibility across taxa.

## Predictions

I predict greater temporal turnover with greater magnitude of accessibility, as alterations of the natural environment caused by human activities benefit 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 the relationship between accessibility and temporal turnover to be steeper, when human population density is higher, as high human population density increases the pressures on the natural systems, leading to higher turnover. I predict both positive and negative trends to be present among taxa, as they differ in functional traits.

If I find support for my null hypotheses, this will indicate that the metric accessibility cannot sufficiently capture direct and indirect human impacts affecting biodiversity change, questioning whether the current conservation emphasis to preserve wilderness areas is enough. If the results are in line with my alternative hypotheses, this will demonstrate the importance of humanly undisturbed places for the conservation of biodiversity.

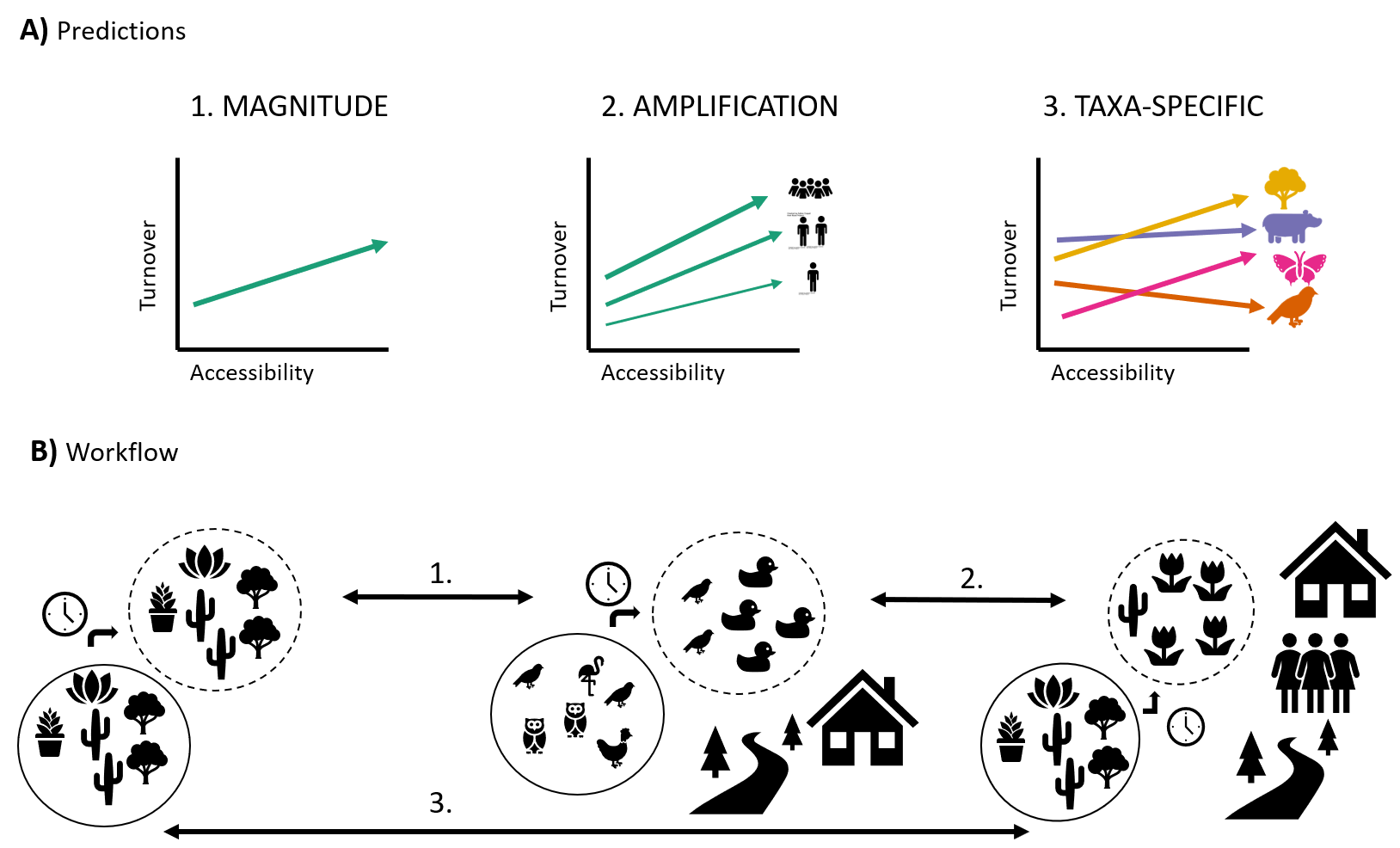


Figure 1. My study looks at three different aspects related to biodiversity change.  
**A** Conceptual diagrams of my predictions **B** Analytical workflow (Figure inspiration Daskalova, 2019).

# Methods

In this study, I ask how the magnitude of accessibility and human population density is affecting 5787 ecological assemblages over time across four taxa (birds, mammals, invertebrates and plants). To quantitively test the relationship of ecological communities and large-scale anthropogenic activity, I used 3 global databases.

## Databases

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

I analysed 5787 time series from 181 different studies from 1023 unique terrestrial locations around the world, covering a range of taxa, including birds, mammals, invertebrates and plants (Dornelas *et al.*, 2018) that make up a part of the BioTIME database as of 12/03/2020. I did not predetermine sample size but 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 5000 plots per study, plot fixed to one location and at least 2 survey points per plot. The resulting sample sizes across space, time and taxa can be found in Figure 2 and Table 1.

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.

Contrary to other studies which partitioned studies with large extent and consequently used sample-based rarefaction to standardise sampling within each time-series, 64 % of my studies were within 1km². 37 % of studies were in protected areas. Duration varied across time-series, ranging from 1923 – 2016, with a mean duration of 19 years (standard deviation of +/- 13 years).

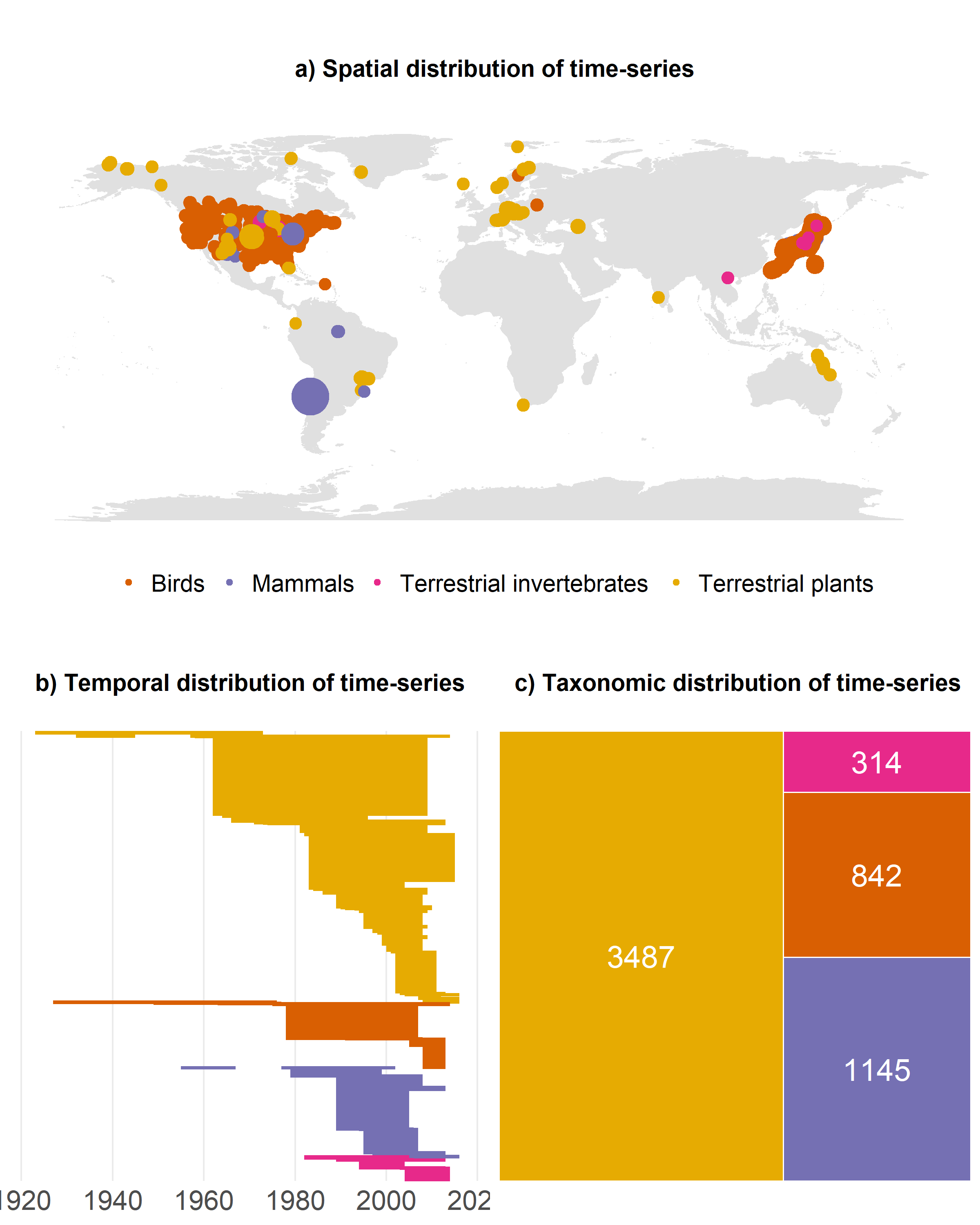


Figure 2. My study incorporates biodiversity time-series data across space, time and taxa (Figure inspiration Daskalova, 2019).

***Accessibility to cities 2015 data***

To quantify large scale human impact, 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. This dataset is available for the nominal year of 2015.

In the main figures, I used the inverses of travel time to nearest densely populated area, so that high values correspond to higher hypothesized human effect.

***Human population density dataset***  
To estimate human population density, I derived 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 at a 30 arc-second resolution. To match the timing of the accessibility dataset, I used the dataset for the nominal year of 2015.

## Data processing

All data processing was conducted in R v. 3.6.1. (REF R).

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 each time-series. Turnover as opposed to nestedness was the dominant part of biodiversity change in the BioTIME dataset (REF). For study records that were not count data, density records were converted into presence/absence, so no data needed to be excluded. Temporal turnover is bound between zero and one, where zero is no change in community composition and one indicates that all 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 when extracting the values with {raster}. I considered an area > 1km² to be more representative of the impact-influence relationship. My analyses were not sensitive to cell size over 25km² (tests from 25km² to 100km², but showed higher values with similar slope for 1km²). I bound the/scaled 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.

To account for spatial autocorrelation, I created and assigned global grid cells to each time-series using {dggridr}. The grid cells covered areas of resolution 12, which is equivalent to an area of around 100km².

## Data analysis

I conducted all statistical analysis in R v. 3.6.1. (REF R). To quantify the influences of accessibility and human population density across taxa on temporal turnover of ecological communities, I used mixed effects models in a Bayesian modelling framework based on a Stan computational framework and accessed through the {brms} package (REF). I based the models on a zero one inflated beta distribution to reflect the properties of turnover (bound between, and including, zero and one). I assumed a Bernoulli distribution for values of 0 and 1, and a beta error distribution for values between 0 and 1. I fit the model with only an intercept.

I modelled temporal turnover as my response variable. Fixed effects were accessibility and duration of the time-series (RQ 1). I did not consider centring of duration necessary as the variation was relatively little within. Model convergence could not be achieved with the interaction term between accessibility and human population density, so latter was added as a fixed effect without the interaction (RQ 2). Neither could I achieve model convergence when allowing each taxon to have a random slope (nor intercept) with accessibility, so I added taxa as a fixed effect (RQ 3). I adjusted research question 2 and 3 accordingly when presenting my results. To account for confounding effects within the same study as the methods were consistent within but not among studies, Study ID was included as a random effect. To account for spatial autocorrelation the global grid cell variable was added as a random effect. I used ggpredict to calculate the model predictions. I assumed said model set-up to be the optimal balance between requirements of the data and feasibility.

I used the default priors which are weakly informative as I had no ecological explanation to assume otherwise. The default priors can be found in the code in the appendix.I ran the models with 4000 iterations, with a warmup of 1000 iterations on 4 chains. I assessed convergence visually by examining trace plots and Rhat values (ratio of the effective sample size to the overall number of iterations. Values close to one indicate convergence.)

As I used a Bayesian framework, my inferences were based on the posterior distribution of each fixed effect. They were considered significant if the lower and upper 95% credible intervals (CI) did not overlap zero. I concluded all results, regardless of the direction or magnitude of the effect size.

**Sensitivity analysis**I conducted sensitivity analyses to test potential limitations of my data. I ran an analysis just a subset of data that only included plants. Firstly, I conducted analysis to test the sensitivity of scale, modelling accessibility and human population density extractions of 1km², 50km² and 100km². Secondly, I ran a model with data included from only 1970-2015 to better temporally match the datasets to the nominal points of accessibility and human population density of 2015. Thirdly, in a post-hoc analysis I used a subset of my data that only included plants, as this was the taxon that was most equally distributed across levels of accessibility. All model terms were kept equal to the original model outlined above; except when I modelled plants, I removed the taxa fixed effect.

The full R script, the link to the repository and to my preregistration can be found in the appendix.

# Results

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

Contrary to my predictions, I found that temporal turnover has decreased as accessibility increases across the 5787 time-series surveyed (slope = -1.20, CI = -2.09 to -0.32, Figure 1, see Table 1 for full model outputs). On average, for every 10% increase in accessibility, turnover decreases by 1.6 %. Notably, when taking the last census point as a baseline (lowest point of slope located at high accessibility), the ecological assemblages across levels of accessibility have experienced average 24% replacement of their species (as turnover is bound between 0 and 1) and more over their time-period monitored (average duration of 19 years). Only ~ 7% of time-series analysed experienced complete turnover of communities (turnover = 1) and ~ 37% experienced no turnover at all (turnover = 0). As 90.5% of data points have an accessibility score of 0.9 and above, there is high uncertainty around the main effect at lower values of accessibility, indicating the need to take the high value of temporal turnover at low accessibility with caution.   
  
In line with my predictions, the duration of the observation influenced the magnitude of the detected temporal turnover trends, with higher temporal turnover observed for longer monitoring of sites (see Figure A2 in appendix).

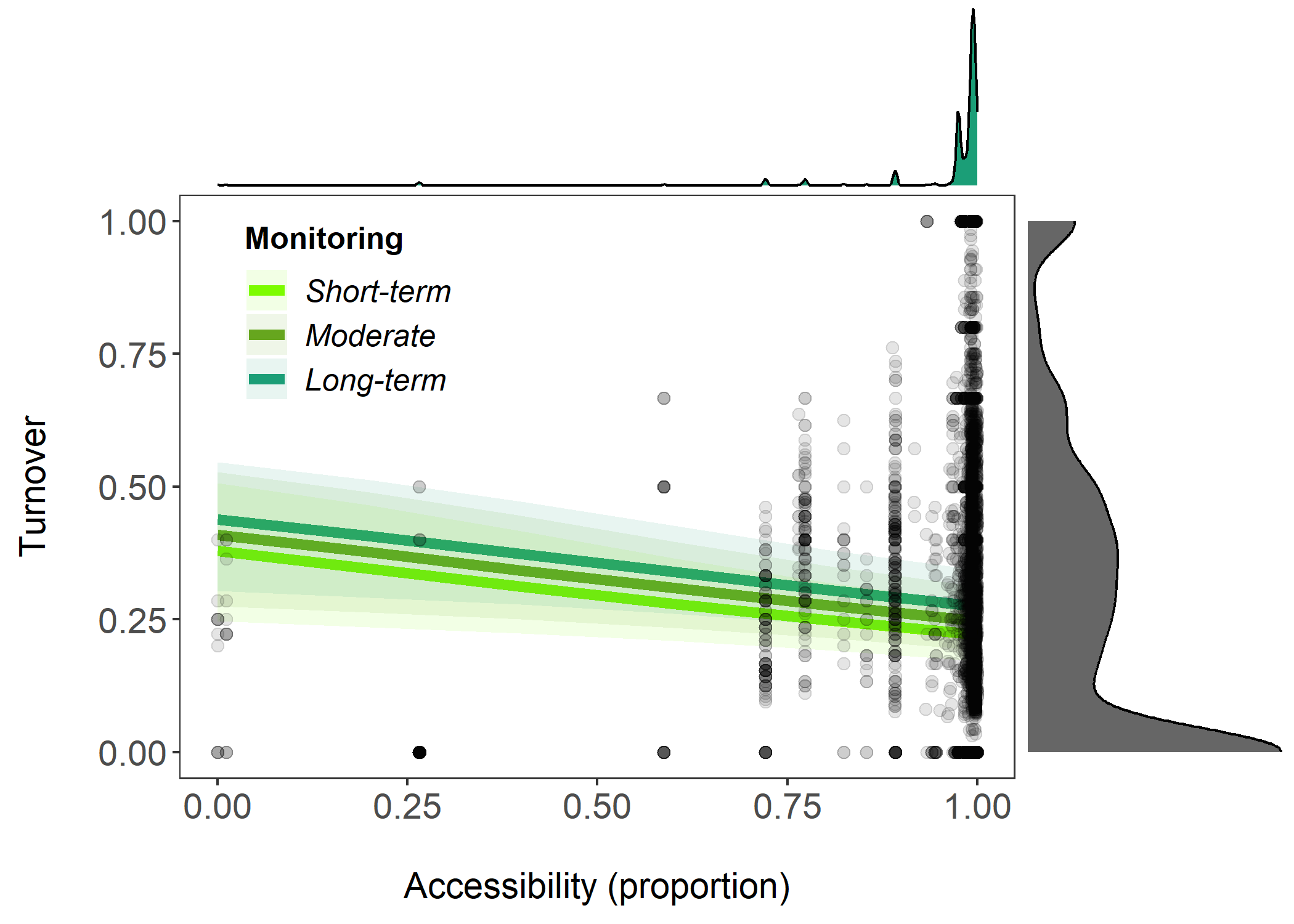


Figure 3. Temporal turnover has decreased as accessibility is increasing across the 5787 time-series surveyed (slope = -1.20, CI = -2.09 to -0.32, see Table 1 for full model outputs). Grey points represent raw data. Lines and error bands represent model predictions and 95% credible intervals, respectively. Colour coding of lines represent differing duration of monitoring of time-series. The marginal density plots represent accessibility (top density plot) and temporal turnover (right density plot) distributions across all time-series surveyed. See trace plots and model Rhat values in appendix confirming model convergence.

**Temporal turnover and human population density (Research Question 2 modified)**

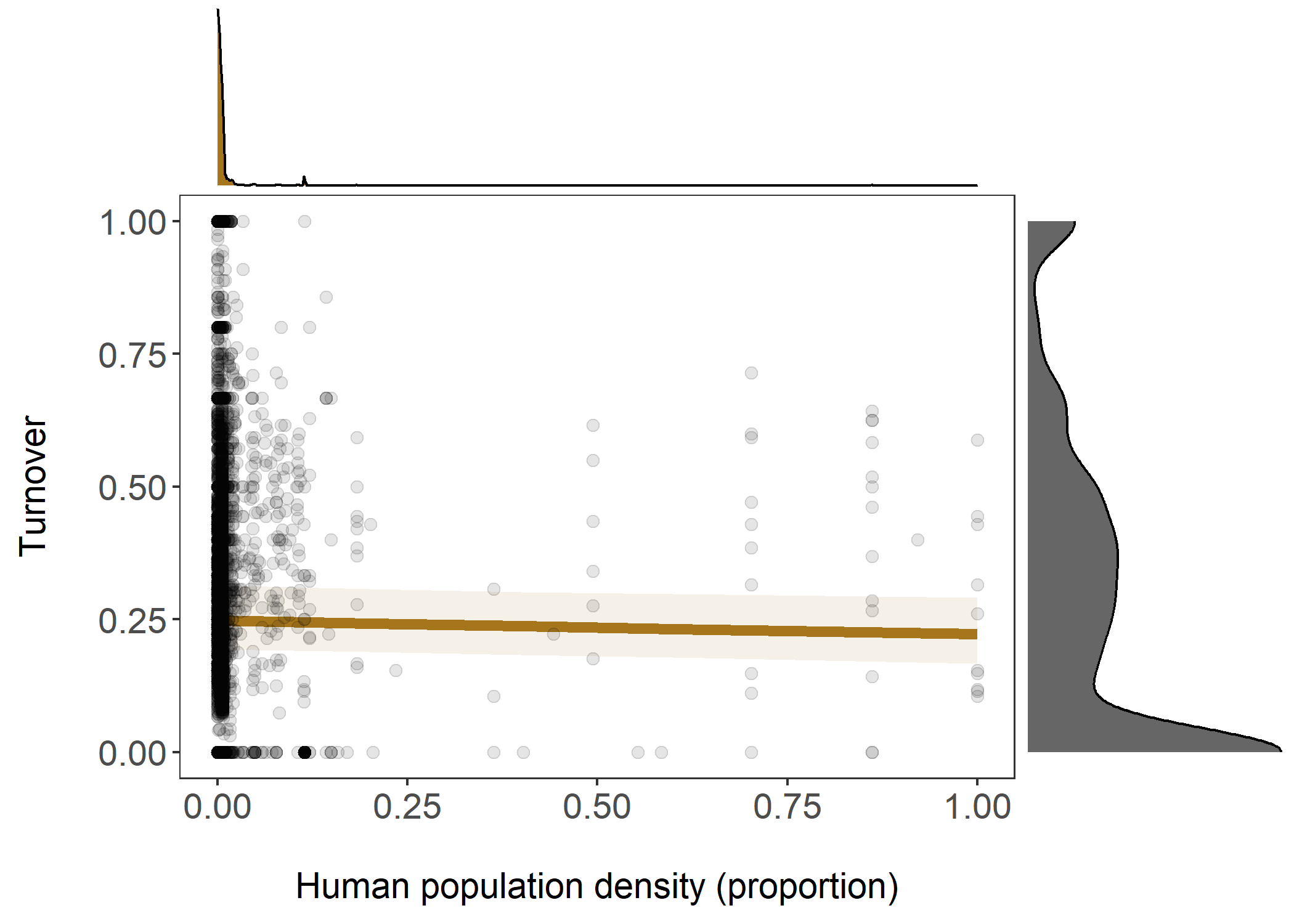
Looking at the relationship between temporal turnover and human population density (without the interaction as that model did not converge), I found that temporal turnover has neither increased nor decreased as human population density increases across the 5787 time-series surveyed (slope = -0.22, CI = -0.49 to 0.05, Figure 1, see Table 1 for more model outputs). Notably, when taking the last census point as a baseline (lowest point of slope located at high human population density), the ecological assemblages have experienced a 17 % replacement of their species (as turnover is bound between 0 and 1) over their time-period monitored (average duration of 19 years). Contrary to the distribution of accessibility falling into higher spectrum, 96.4% of data points have human population density score of 0.1 and below.   


Figure 4. Temporal turnover has showed no directional relationship with human population density across the 5787 time-series surveyed (slope = -0.22, CI = -0.49 to 0.05, see Table 1 for full model outputs). Grey points represent raw data. Lines and error bands represent model predictions and 95% credible intervals, respectively. The marginal density plots represent human population density (top density plot) and temporal turnover (right density plot) distributions across all time-series surveyed. See trace plots and model Rhat values in appendix confirming model convergence.

**Temporal turnover and taxa (Research Question 3 modified)**

Looking at the relationship between temporal turnover and taxa surveyed (not considering the relationship across levels of accessibility as that model did not converge), I found that all taxa experienced temporal turnover (see Figure 5, Table 1 for full model outputs). Mammals (slope = 0.71, CI = 0.01 – 1.42) and terrestrial invertebrates (slope = 0.99, CI = 0.31 – 1.7) experienced higher amounts of turnover relative to birds (slope = 0.11, CI = -0.87 – 1.14) and plants (slope = 0, CI = -0.56 – 0.55). Terrestrial invertebrates experienced highest amount of turnover (54% more than plants). Looking at the raw data (right side panel), demonstrated high variability of turnover experienced within mammals and lowest variability within birds. The number of time-series sampled for each taxon differed: of all time-series analysed 60% are made up of plants, followed by 20% mammals, followed by 14% birds and only 6% invertebrates. Out of the 37% time-series that showed no turnover at all, plants made up 73%.

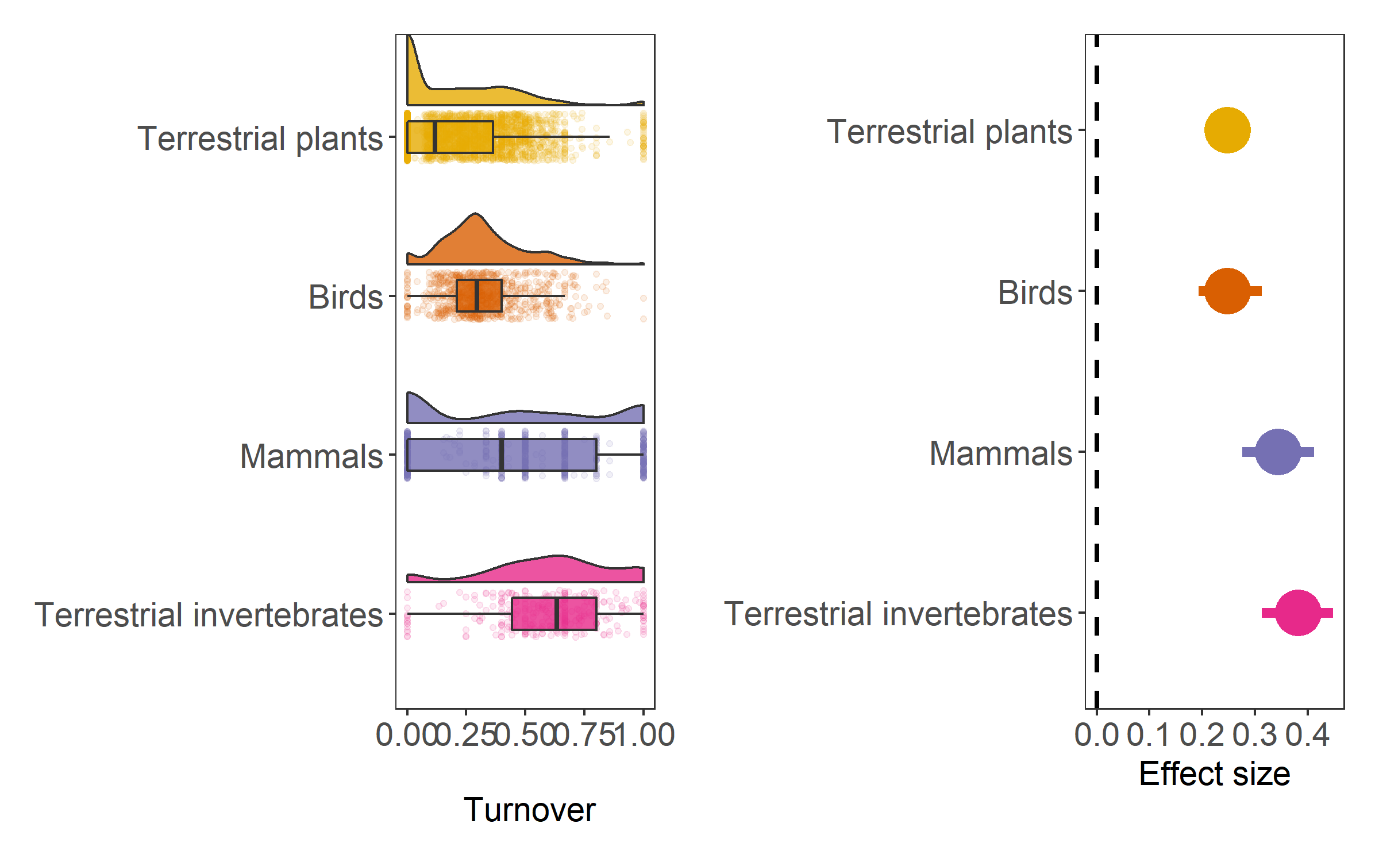


Figure 5. Temporal turnover is apparent across all taxa surveyed with variation within taxa.

**A** Model visualisation for temporal turnover and taxa. Error bars represent 95% credible intervals. Dashed line marks the zero threshold. See trace plots and model Rhat values in appendix confirming model convergence. **B** Raw data visualisations of turnover across taxa. Split violins represent data distribution, boxplots with mean values and points are raw data.

# Discussion

Combined, my global analysis of 5788 terrestrial time-series demonstrated complex heterogeneity in the relationships between biodiversity change and large-scale human activity. Contrary to my predictions, I revealed that as accessibility increases, temporal turnover has declined (Figure 3). Simultaneously, I demonstrated that even the lower range of predicted temporal turnover rates are above baseline levels, highlighting widespread temporal turnover across levels of human activity (Figure 3). I uncovered a non-directional relationship between temporal turnover and human population density, at approximately the same magnitude as accessibility (Figure 4), pointing towards the difficulty of capturing relevant human impacts with singular metrices. The lack of sufficient data prevented me to answer my original questions of an interaction between these two metrices as well as quantifying the relationship between temporal turnover and taxa across levels of accessibility and thus highlighted the need for more comprehensive sampling in the future. I uncovered distinct taxonomic signals of temporal turnover, with terrestrial invertebrates experiencing the highest amount, followed by mammals, whereas plants and birds showed relatively lower levels of turnover (Figure 5). On a global scale, human activities are causing a decline in biodiversity, but considering a more local scale I uncovered heterogenous responses to large-scale anthropogenic activity challenging the assumption that the absence of human activity is sufficient to conserve compositional biodiversity.

Global datasets have been criticised with important implications for the interpretation of results for various reasons. Firstly, critiques have denounced spatial underrepresentation of areas modified by human activities (Gonzalez), which prevents an accurate reflection of how humans have modified the environment. I found that my dataset covers a representative range of accessibility scores, as many parts of our planet are highly accessible (see appendix hist acc\_fake+real + map accessibility). My accessibility dataset suffers from the opposite as it underrepresents areas with low accessibility, causing high uncertainty of the model at low levels (Figure 3). Additionally, accessibility is a metric that captures influences beyond protected areas (which is good). It is important to note though, that 33% of the time-series monitored fall into protected areas. All protected areas have a accessibility level of 0.9 and above (see appendix coloredbyPA) which might drive the results at higher accessibility to a low amount of turnover, without those being representative of the real world. In a *post-hoc* sensitivity analysis, I looked at terrestrial plants only as they showed most variation across levels of accessibility (see appendix figure raincloudacc) and I found a similar relationship. Again though 39% of plants time-series fall into protected areas. The second criticism concerns the mismatch in timing of disturbance and monitored time-series, as only then an attribute of biodiversity change to a driver is possible. One robust method to do this is the Before-After-Control-Impact method, comparing changes both before and after disturbance. In my case, human activities related to accessibility have been mainly happening before the start of the biodiversity monitoring, plus I do not have accessibility data going back. However, when looking at the cumulative impact of human activity it is likely that not all with have negative impacts. So while I might not capture the effect of disturbance only but also recovery, the event of singular disturbance becomes less important. Overall, despite representing more or less sites modified by human activities, I cannot ultimately capture the relative contribution of each (different) driver to biodiversity change but rather have cumulative and interactive response.

**Temporal turnover and accessibility (RQ 1)**  
Contrary to my first prediction (“magnitude”), I found that temporal turnover decreases as accessibility increases (Figure 3). I also found that 63% of all time-series monitored showed some degree of turnover (<0) with the lowest model prediction at the highest level of accessibility still pointing towards a turnover level of 25% across the monitored time periods. While research that used only space-for-time and modelling projections reported a decline for human activities such as land-use change, using real-world temporal turnover data, I can provide insights into a more complex reality. Similar complexity of responses with both positive and negative reponses present after disturbance were found using the same methods. This study furthered highlighted the importance of temporal lags in the response to disturbances which on one hand were peak right after disturbance, on the other hand depended on the generation times and lasted for up to 50 years. As I did not analyse the timing of disturbance it is difficult to estimate what disturbance, lag and recovery responses are dominant in each time-series. Also influencing are variation in species vulnerability to disturbance (goes along with heterogneous reponses explored below).  
  
Accessibility is a cumulative variable, representing many different human activites and their respective environmental impacts. Most of these impacts have been assumed to be have a negative effect on species abundance and population. However, we currently only have a limited understanding how these different activites and impact interact with each other which might explain the reverse relationship found. Multiple drivers may be associated with each other, either coincidentally (due to shared causes) or causally (when one driver affects the intensity of another) (Geary, Nimmo, Doherty, Ritchie, & Tulloch, [**2019**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0021)). Moreover, when drivers co‐occur, their impacts on communities may be additive, or interact synergistically (total impact stronger when together) or antagonistically (total impact weaker when together) (Cote, Darling, & Brown, [**2016**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0008); Sirami et al., [**2017**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0060)). Nonetheless, few studies have examined the effects of multiple drivers on biodiversity (Mazor et al., [**2018**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0042); Sirami et al., [**2017**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0060)). Hence, unpacking the spatial patterns of exposure of different drivers, and assessing the extent to which they jointly act on communities, is a key area of research. More recent research has started to focus on interactive effects of human activities such as land-use changes and climate change, showing potential interactive effects there. One determing coincidence of my study could be that the very remote places I studied, coincide with areas that are in very high and low lattitudes (often not very accessible) which experience more changes due to climate change and thus might show a higher level of turnover. It is important to look at potential different interactions of effects as I join recent research in emphasizing the importance of real-world data that can uncover trends which are not detectable with space-for-time and modelling.

**Temporal turnover and human population density (modified research question 2)**I found a non-directional relationship between temporal turnover and human population density. The lowest model prediction at the highest level of human population density still pointed towards a turnover level of 22% across the monitored time periods, making it very similar to the lowest level of turnover experienced across accessibility. Human population density is another metric pointing at varying influences of human activity generally assumed to cause a negative effect. Interestingly, when looking at the coincidence of the distribution of accessibility and hpd, they lie on opposite ends (figure appendix histboth). That indicates that high accessibility does not come with high human population density but many places on earth have been modified even without the immediate or dense presence of humans. Therefore, accessibility seems to be an important measure to capture all sorts of impacts on the environment. Space-for-time approaches found decline again, but again showing importance of metric temporal turnover with real world data. The lack of model convergence emphasizes the need to collect data more comprehensively.

**Temporal turnover and taxa (modified research question 3)**

My findings highlight variation of temporal turnover among taxa, with terrestrial invertebrates experiencing the highest amount, followed by mammals, whereas plants and birds showed relatively lower levels of turnover (Figure 5). Taxon-specific traits such as life history traits, generation time, tropic levels and reproduction strategy could play a role. Traits found before to explain variation in population declines and immigrations (strongly related to turnover) such as range size and niche breadth (Newbold), could not explain variation found in my study. If we assume that birds are mobile species and plants less mobile species, I still found a similar relationship with turnover. Other study also found that rarety (standing for range, blabla) could not capture the heterogeneity of population change found. Invertebrates were least studied taxa, only represented 5% of the time-series studied. Furthermore, they very rarely coincidence with protected areas, only 4% of invertebrates studied. Furthermore, despite their importance for biodiversity monitoring, their sampling has been understudied and also perceived higher difficulties with sampling. Invertebrates normally surveyed on plot scale ; number of undescribed invertebrates large. (Andersen). Despite there being no relationship with traits in this study, phylogenetic relatedness predicts extinction, occurring over longer time-scales. Shorter time-scales might be influenced by other processes as the interactive effects and lags. Importance of relating traits and biodiversity change to inform policies?

**Study limitations and future directions**

Analysis of biodiversity change can be limited by imbalances in taxonomic, spatial and temporal patterns. Tropical locations and thus species are underrepresented in the biodiversity dataset (see figure 2), in the dataset I analysed invertebrates were undersampled and I could not include amphibians because too little studies. Spatial scales are difficult to set and the relationship between human activies acting on that scale and the potential impacts they can cause on species-relevant scale. In a sensitivity analysis I found that turnover trends only differed in their magnitude but not in the direction of the relationship and only between very small scales (1km²) but not across bigger scales. Lastly, it is difficult to ultimately attribute changes to one particular driver, especially in the presence of potential interacting effects. Biodiversity changes and attribution it to global change drivers will be enhanced by more comprehensive spatial and temporal data collection of environmental impact and biodiversity data.

**Complexity of real-world biodiversity changes in particular of temporal turnover**Although I did not detect an increase of turnover as accessibility increases, 63% of all time-series monitored showed some degree of temporal turnover. Even at low accessibility, turnover seemed to average of 25%. High accessibility should be treated with caution due to the little data availability of time-series with low accessibility scores. The high uncertainty around the main effect at lower values of accessibility, is due to that and will be explored further in the section of limitations. I demonstrated turnover across the whole spectrum of accessibility, that goes beyond a hypothetical baseline rate (Dornelas), emphasizing the importance of assessing temporal turnover for understanding local biodiversity changes.

Turnover (as compared to nestedness) is the dominant contributor to biodiversity change for the BioTime dataset (Dornelas). Species replacement can be broken down to local extinction and local immigration. On the other hand, exact same human activities have been shown to increase local diversity. Success of anthrophilic species (Aronsonn), increases in local diversity following disturbance and spread of exotic species. Especially through transportation and enhanced connectivity which is key to the metric of accessibility , alien species potential and thus immigration risk increases. Generally, human activities are assumed to increase rates of local extinction (Davies, 2006). Accessibility captures a range of human activities that have also been assumed to reduce rates of extinction. Accessibility can be seen as a metric capturing influences ranging from urbanisation, roads and transport network to land-use dominated by agriculture and pollution. Such human impact alters habitat and resource availability and increases habitat fragmentation. Evidence for losses mostly comes from space-for time subsitutions which have been critised for not accounting for ecological lags and community self-regualtion. Potentially either immigration or extinction rates are not for highly accessible places and might therefore not be reflected in the metric of turnover. Other study looking at forest loss has also found very varied reponses of turnover. This study also used Before-after-control-impact which could then attribute driver to change. However, there was no significant effect of magnitude of forest loss on turnover. This might indicate that a disturbance is a disturbance and changes in biodiversity can only be assessed in presence/ absence but not through magnitude. Therefore, either our current understanding of temporal turnover and its relation to environmental disturbnace is limited so far and more complex than thought and/ or there are inherent limitations in the methodology of temporal turnover. More difficult in my situation as accessibility is cumulative metric. I am accounting for both disturbance and recovery on top of the heterogenous effects of disturbance itself. However, it is true that it is difficult to match as most human activity has happened before first half of 20th century but most monitoring studies after. I guess I am capturing both recovery, disturbances, lags.

**Interaction different effects**

The coincidence between the presence of other drivers and/or their potential interaction with impacts captured in accessibility might explain higher turnover in less accessible sites. As explored above, the same impact can have different effects. But also relationships among interaction of different effects of accessibility can create heterogenous patterns. Trade-off between cumulative metric and understanding underlying patterns.  
Multiple drivers may be associated with each other, either coincidentally (due to shared causes) or causally (when one driver affects the intensity of another) (Geary, Nimmo, Doherty, Ritchie, & Tulloch, [**2019**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0021)). Moreover, when drivers co‐occur, their impacts on communities may be additive, or interact synergistically (total impact stronger when together) or antagonistically (total impact weaker when together) (Cote, Darling, & Brown, [**2016**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0008); Sirami et al., [**2017**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0060)). Nonetheless, few studies have examined the effects of multiple drivers on biodiversity (Mazor et al., [**2018**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0042); Sirami et al., [**2017**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0060)). Hence, unpacking the spatial patterns of exposure of different drivers, and assessing the extent to which they jointly act on communities, is a key area of research.

On top of relationships among impacts associated with accessibility, other drivers also play important role. One very prominent is climate change; climate change second biggeset threat to biodiversity after land-use change? Ongoing research for interactions anthropogenic threat complexes. But research ahs shown how climate change can lead to turnover as well. Climate change displays geographic heterogenous patterns. Recent studies have created maps of global anthropogenic threats including climate change and other large scale human impacts, joining effects of multiple drivers. Less accessible sites might coincide with regions that are experiencing more extreme climate change, which can lead to biodiversity change (Isla paper?).

**Indirect large-scale human impact**

Both scale of disturbance and scale of monitoring plays a role. UltimatelyHowever, these findings might implicate that we do not understand temporal biodiversity dynamics at low human impact sides yet compared to better studied large scale human impacts.

Other studies have focussed on more direct environmental changes (forest, land-use change) but I look at broader human impact (EXPLORED BEFORE). Studies with focus on low human impact areas, often titled wilderness, have found that such areas reduce extinciotn risk of species by 50%. Again, those studies were conducted with modelling approaches and did not use real-world temporal data. In order to put the most effective conservation measurements in place, we need to understand what is going on both in areas with low human impact and with high human impact using real-world data.

Many landscapes are mosaics of habitats that have been subjected to both direct and indirect human influences. Farm fields or urban areas have experienced direct human influence where much plant and animal life have been destroyed and replaced with lower diversity land cover. While such areas can harbor populations of functionally important species (Wolters et al. [**2000**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0061)), the direct effects that people have on local biodiversity through habitat destruction or conversion are typically negative. In contrast, adjacent habitat fragments have not been destroyed, and represent areas where humans may increase species richness (e.g., species introductions) or decrease richness (e.g., fragmentation, pollution; see Haddad et al. [**2015**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0025)) and alter community composition (Wardle et al. [**2011**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0059)). Future efforts to quantify changes in local biodiversity must simultaneously account for the direct effects that people have on biodiversity through habitat destruction, or conversion, and the indirect effects (both positive and negative) humans have on remaining or recovering habitats. Only by simultaneously considering both the direct and indirect causes of biodiversity change on a landscape will we be able to provide accurate estimates of local biodiversity change.

Relation accessibility and wilderness?

Exploration accessibility as a metric to capture human impact  
Cumulative vs single driver  
Most places seem highly accessible, despite being often in protected areas -> challenges what we define as protected and to what scale  
Proxy after all  
It cannot capture direct impact and consequences of direct impact  
human population density didne seem to have positive relationship with turnover either (but most places with quite low human population density) -> shows relevance of accessibility ( as it seems to matter somehow), but more interesting to see high accessibility and low human population density coinciding? -> is this metric better for capturing indirect impact than direct impact?   
limited in representation of full spectrum of accessibility and hpd

**Complex interactions of species vulnerability to environmental change (TAXA)**

INTRO?

Temporal turnover is also influenced by population dynamics which is dependant on species vulnerability. Species vulnerability varies with species traits as the reaction to anthropogenic and environmental change differs. Species traits shared across a taxon makes certain taxa more vulnerable to declines and extinctions.

INTRO?

Species with small population sizes, high habitat specificity and restricted geographic extent are more likely to locally go extinct, thus increase the likelihood of turnover. Less mobile species might struggle more to disperse and find a suitable refuge as there is more concentrated exposure to environmental change. Small population sizes are more prone to undergo stochastic fluctuations (Taylor’s power law) as well as increased inbreeding with resulting reduced fitness. Thirdly, high habitat specificity means that colonization of new areas is restricted by limited habitat preferences.

Heterogeneity of effects of mobility as highlighted by ongoing habitat fragmentation discussion. In general, for habitat loss and fragmentation caused by land-use changes more mobile species are better able to move among distant habitat fragments, than less mobile species. Contrary research suggests that more mobile species, having larger home ranges rely on larger habitat patches and therefore might be more sensitive to habitat fragmentation. Additionally, the impact at larger scale is more important for mobile organisms. Interactions between these two processes further play a role as with increased specialisation (narrow niche width) rely more on mobility to succeed than generalist species.

Although I found differences in the relationship between turnover and different taxa, I found no distinct taxonomic signal differing between more or less mobile species. Generally, plants can be seen as less mobile and birds as more mobile. However, both taxa experiences similar rates of turnover.   
Study using space-for-time method again, found general decline of specialist and narrow range species compared to generalist and wide-range species pronounced in more urban areas. Difficult to compare because I have full-range of impacts (although most at high accessibility).   
Especially, birds are vulnerable to urban environments, mammals show mixed responses with high sensitivity to high population density but then intermediate disturbance up. Could explain high turnover?  
Invertebrates highly sensitive to human pressures; could explain high turnover?.   
plants showed no local richness change but not sufficient to link to temporal turnover?

Study looking at population trends and fluctuations rather than temporal turnover (but it is related anyways) found that mammals and birds population increased making them less likely to go extinct as per having larger population sizes (Gergana). However, when looking at specific traits such as the range size, population size and habitat specificity, all populations monitored experienced increases, declines and fluctuations (common vs rare). That goes along with my results that there are very heterogenous responses to environmental change caused by anthropogenic activity. Population size was most associated with fluctuations (which would be reflected in turnover), but that cannot be matched with one taxa?

Ecological lags and interacitons different effects.

Again importance of looking at real-world temporal data and responses are not as simple as thought.

OLD PART

Recent advances in our understanding of biodiversity started to question the narrative of universal declines in biodiversity measured through richness and abundance caused by human impact. Global assessments which have found diversity declines with land-use changes to more human dominated landscapes (Newbold), have been criticised for using space-for-time approaches (Gergana) which don’t account for ecological lags and community self-regulation (Temporal baselines). Instead the use of temporal trends was suggested, ideally with a before-impact-after-control approach as this has been suggested to better reveal complexity of real-world changes.

As richness and abundance cannot capture complex biodiversity changes, the question remains how large-scale human impact captured in the metric accessibility relates to temporal turnover. Accessibility can be seen as a metric capturing influences ranging from urbanisation, roads and transport network to land-use dominated by agriculture and pollution. Such human impact alters habitat and resource availability and increases alien species potential and habitat fragmentation, all indicating to an expected higher turnover, as extinction and immigration risks increase accordingly.

Temporal turnover seems to be even more complex than that as changes in the environment do not always respond to higher temporal turnover. Recent studies (Gergana and human impacts one?) that also assessed temporal turnover also found highly complex changing biodiversity. In line with the narrative of increasing environmental change causing increasing turnover, Daskalova et al found increase of temporal turnover after forest loss and the turnover of habitat conversions were highest when converted to agriculture and urban areas. However, there was no significant effect of magnitude of forest loss on turnover. This might indicate that a disturbance is a disturbance and changes in biodiversity can only be assessed in presence/ absence but not through magnitude. Therefore, either our current understanding of temporal turnover and its relation to environmental disturbnace is limited so far and more complex than thought and/ or there are inherent limitations in the methodology of temporal turnover.

**Potential shortcomings of temporal turnover**

Shortcomings of using time-series (Gonzalez, de palma) could be due to mismatches between the record of the potential negative impact of human activity and the response of the ecological community. Large-scale human impact such as land-conversion, road building etc could have occurred outside of biodiversity monitoring period. This is further enhanced by accessibility being an accumulated variable. Most human impacts related to accessibility such as roads and urban centres have been present before the monitoring period of the time-series (early 20th century) as time-series span an average duration of 12 years only. Forest cover change has been found to peak biodiversity change 6-13 years after. Further complicating is the presence of ecological lags which can last up to 50 years (Gergana), making it even more difficult to record and evaluate biodiversity change in relation to human impact.

Mismatch assemblages monitored and localised impacts of accessibility; but I want to capture large scale changes?

**Limitations**

**Data availability and methodology**

Taxonomic, spatial and temporal imbalances  
results sensitivity analysis here?

he vast majority of the papers considered implied that the authors attempted to sample all species found within specified taxonomic groups. As with any meta-analysis or synthetic analysis of this kind, not all species will have been sampled during the original surveys. It is likely that undetected species tended to be the rarer species; if the rarer species are also the most sensitive to land-use change, our results will be conservative. 

**Direction for future studies**Interesting further studies include the interaction effects between different global drivers. More temporal studies in less accessible areas. Biotic homogenisation.

# Conclusions

This study advances our understanding of how local biodiversity patterns respond to global change drivers, such as large-scale human activity across taxa. First, I demonstrated that large-scale human activity captured in the metric accessibility has not led to increases in temporal turnover across the 5787 time-series surveyed. Second, I demonstrated that human population density did not have a significant effect on turnover. Thirdly, I provided evidence for individualistic, yet complex turnover-taxa relationships. Lack of effect could be due to blabla.

My findings indicate the importance of using real-world data complementary to space-for-time and model study designs as biodiversity is complex. Higher turnover associated with lower accessibility challenges the assumption that wilderness is sufficient to achieve conservation goals. Incorporating a more complex spectrum of biodiversity change in response to large-scale human impact will improve our understanding of future impacts of global change drivers and thus can inform the most effective conservation strategies during this time of accelerating human impact.

In summary, our analysis reveals an intensification of both increases and decreases of populations and biodiversity by up to 48% at local scales after forest loss at sites around the planet. 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)). A current assumption underlying existing projections of biodiversity responses to land-use change ([***11***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-11), [***13***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-13)) is that space-for-time approaches accurately reflect longer-term population and biodiversity dynamics ([***45***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-45)). In contrast, we found up to half of a century of temporal lags in population and biodiversity change following forest loss that varied by taxon and generation time. Our analyses highlight that real-world responses of population and assemblage to forest cover loss and gain are complex and variable over time. Forest loss was concurrent with both declines and increases in populations and ecological assemblages, similarly to the varied and often positive effects of habitat fragmentation on biodiversity metrics such as species richness ([***18***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-18)). Our finding that forest cover gain does not correspond to gains in population abundance and species richness contribute to a growing body of literature indicating that afforestation efforts might have unintended biodiversity consequences ([***47***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-47)), warranting caution with recent calls for global afforestation as a climate change mitigation tool ([***21***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-21)). 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.

# References

# Appendices