

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

*By*

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# 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.

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# List of abbreviations

CI Confidence Interval

BAIC Before after impact control

# Introduction

Importance my analysis: real world data; direct and indirect influences  
link every conclusing sentence to bigger picture? Conservation?

## Background

Globally, 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 profoundly 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, such as their resilience are not fully understood (Vellend *et al.*, 2017). 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.

Importance link local and global BD  
Human alterations to the environment have been widely viewed as a main contributor to the global-scale biodiversity crisis, with elevating rates of species extinction (REF 6th mass extinction?). However, studies reveal a more complex picture that is very dependent on the scales and biodiversity metrices used (McGill *et al.*, 2015; Chase *et al.*, 2019). While local alpha diversity seems to show no decrease in species richness, global biodiversity seems to decline (Butchart *et al.*, 2010; Dornelas *et al.*, 2014, ISla?). At the same time, local communities show high species turnover (changes in the composition of ecological communities), potentially indicating a different type of biodiversity change; 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, it is very important to understand local biodiversity and its relations to global biodiversity changes to be able to predict how biodiversity will change on a global scale.

Importance temporal trends and real-world data; check gonazalez  
Local biodiversity’s changes due to human activity are a topic of ongoing controversy. While some research reports a general negative trend of richness and population abundance following human impact such as land-use change, other studies reveal both increases and decreases at the local level. The controversy can be linked back to difference in methods used – the spatiotemporal design of the study. While former relies on space-for-time and modelling study designs, latter directly observes change over time with real-world data. Real world data heavily depends on long-term data availability, whereas space-for-time approaches have been criticised for missing out important temporal aspects such as ecological lags and community self-regulation. Given existing compilations of real-world biodiversity records, understanding real-world changes and the complexity of it is essential to advance our understanding.

How to capture human impact// Importance broader scale direct and indirect influences  
Humans have driven biodiversity change mainly through habitat change, exploitation, pollution, climate change and invasive species. It is difficult to capture the difference aspects of human influences (and their interactions). Previous studies have focussed on individual types of environmental change such as forest loss and land-use changes/transitions. However, we know little about the effect of multiple types of human activities acting together and how they influence the reshuffling of ecological communities. The metric accessibility 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 this metric goes along with increase of road network, urbanisation and human activities linked to urbanisation such as land-use changes and agricultural activity. Therefore, it can capture changes to the environment and its inhabitants such as habitat fragmentation, land-use change, alien species, habitat loss as a cumulative measure. For many of the human influences mentioned above, it can be hypothesized that effects are further enhanced/driven by local human population density.

Importance to understand functional biodiversity and traits -> Taxa  
Influence of humans have returned mixed results, with some studies reporting increases of biodiversity due to human influence, whilst other found strong declines (or general finding). Demonstrating a general pattern has been hindered by species-specific interaction between land-use change and biodiversity dynamics, as well as the influence of other drivers on biodiversity change. Other drivers include climate change etc. The interaction of taxa-specific can add to understanding overall and allows 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 on temporal changes in ecological community composition overall and across taxa. 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 (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 ecological communities respond to levels of accessibility across taxa (birds, mammals, terrestrial invertebrates, terrestrial plants)?

## Research hypotheses

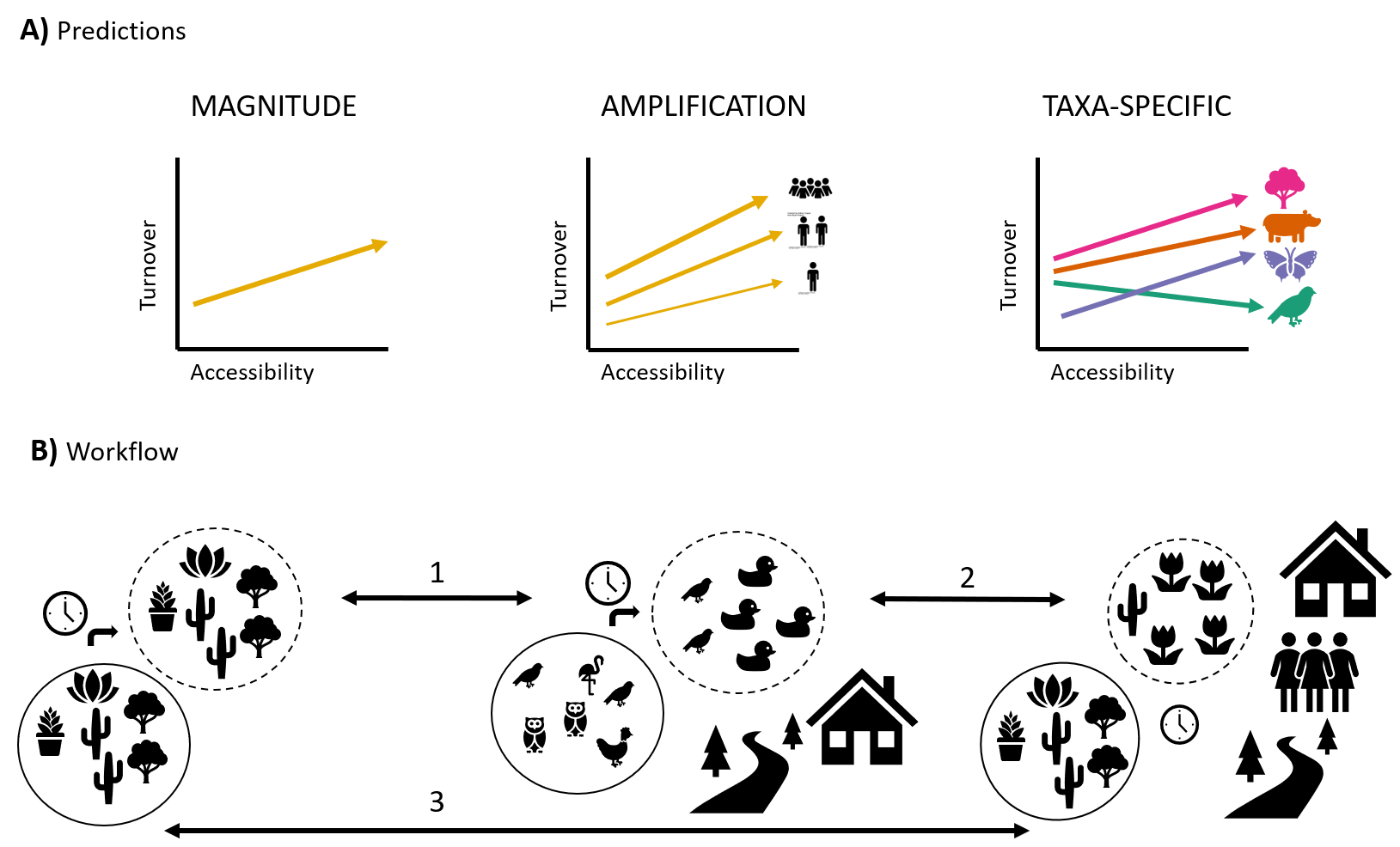
I hypothesize that there will be a positive relationship between higher accessibility to cities and greater temporal turnover. The magnitude of temporal turnover increases for sites which have been monitored over longer durations. The relationship between accessibility to cities and temporal turnover is steeper, when human population density is higher (all positive). 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. 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 and taxa.

## Predictions

Preregistration? https://osf.io/pua5m/?view\_only=575f6a48587245f3b6971235bcf32b3f

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 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. I predict both positive and negative trends to be present among taxa, as they have differences in ecological requirements.

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.



# Methods

In this study, I ask how the magnitude of accessibility and its interaction with human population density is affecting 5787 ecological assemblages over time across four taxa (birds, mammals, invertebrates and plants). 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?  
REASON WHY NO RAREFACTION

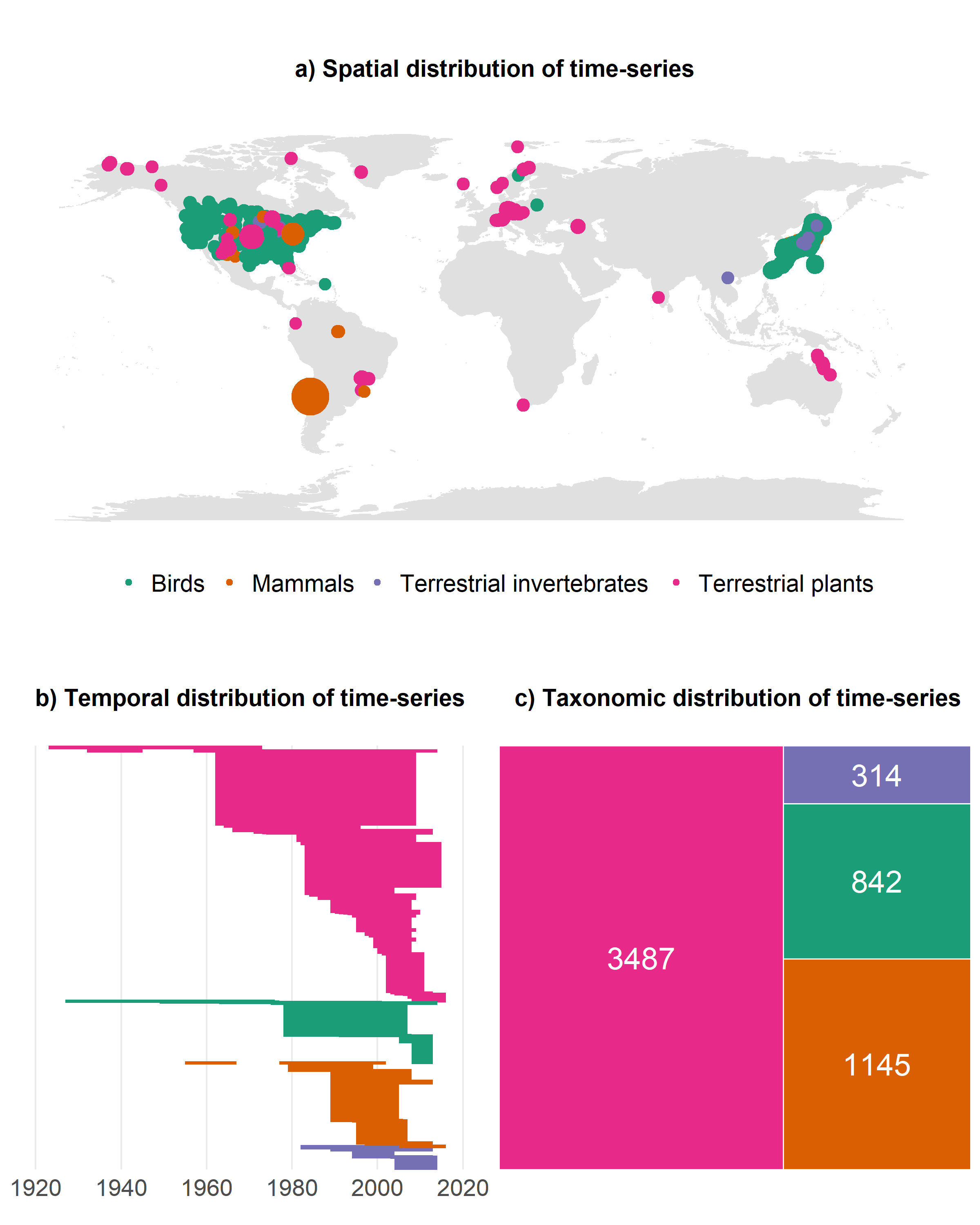
***BioTIME Database – biodiversity time series data***

The currently largest database of temporal community time series spans 4,970,128 (UPDATE) records of abundances and numbers of species globally, covering a range of taxa, including birds, mammals, invertebrates and plants (Dornelas *et al.*, 2018). I analysed 5787 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 resulting sample sizes across space, time and taxa can be found in Figure 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 portioned studies with large extent and consequently used sample-based rarefaction to standardise sampling within each time-series, XX% of my studies were within 1km². X% of studies were in protected areas. Duration varied across time-series, ranging from 1900 – 2020, with a mean duration of XX.

*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).*



*PUT SAMPLE SIZES IN FIGURE CAPTION? MENTION UNIQUE LOCATIONS SOMEWHERE*

***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.

In the main figures, the inverses of distance to roads and travel time to major population centre (proximity to roads and accessibility) were presented so that high values corresponded to higher hypothesized human effect

***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?

All data processing and statistical analysis 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 the time period outlined above. This 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.

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 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.

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

## Statistical/data analysis

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 on a zero one inflated beta distribution to reflect the properties of turnover (bound between, and including, zero and one). Because only X% of time series had experienced complete species replacement (turnover =1) and only X% had experienced no species replacement at all (turnover =0), I assumed a Bernoulli distribution.

**Explanation models response variables, fixed effects, random effects**  
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. Similarly, 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. As model convergence could not be achieved with a taxa random effect allowing for each taxa to have its own slope with accessibility, it was added as a fixed effect. To account for autocorrelation of the method applied, Study ID was included as a random effect. To account for spatial autocorrelation the global grid cell variable was added as a random effect.

Centering of duration was not necessary as the variation was relatively little.

Due to the inclusion of several model variables, model predictions were calculated using the tidybayes package and ggpredict for predicting the taxa fixed effect.

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

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

I used the default priors as they are weakly informative and I have no ecological backup to assume otherwise. The default priors are/ can be found in the code in the appendix.

I ran the models with 4000 iterations, with a warmup of 1000 iterations; 4 chains?. Adapt alpha was set to 0.85. 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 (CI) don’t overlap zero. I concluded all results, regardless of the direction or magnitude of the effect size.

**Alternatives to measuring variables?**

**Sensitivity analysis**I conducted sensitivity analysis to test the validity of limitations of my data. I ran an analysis just with plants, as this taxa displayed was most equally distributed across levels of accessibility. Furthermore, I conducted analysis to test the sensitivity of scale, modelling accessibility and hpd extractions of 1km², 50km² and 100km². Thirdly, I ran a model with data included from only 1970-2015 to better temporally match the datasets to the nominal points of accessibility and hpd of 2015. All other model terms were kept equal to the model outline above; except when modelling plants, the taxa fixed effect was removed.

Richness change?

Full R script in appendix, preregistration link

# Results

*Questions:*

* *How to put sample size*
* *Put distribution of variables?*

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

Contrary to my predictions, I found that temporal turnover has not increased as accessibility is increasing across the 5787 time-series surveyed (slope = -1.05, CI = -1.59 to -0.51, Figure 1, see Table 1 for more model outputs). On average, for every 10% increase in accessibility, turnover decreases by 1.6 %. 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. Quantification. Only ~ 7% experienced complete turnover of communities (turnover = 1) and ~ 37% experienced no turnover at all (turnover = 0). There is high uncertainty around the main effect at lower values of accessibility. As can be seen from the distribution 90.5 % of data points have accessibility score of 0.9 and above.

 and that your relationship is driven by random effect things like certain studies really driving the overall relationship with really high accessibility? and there is a lot of uncertainty around the main effect at lower values of accessibility?

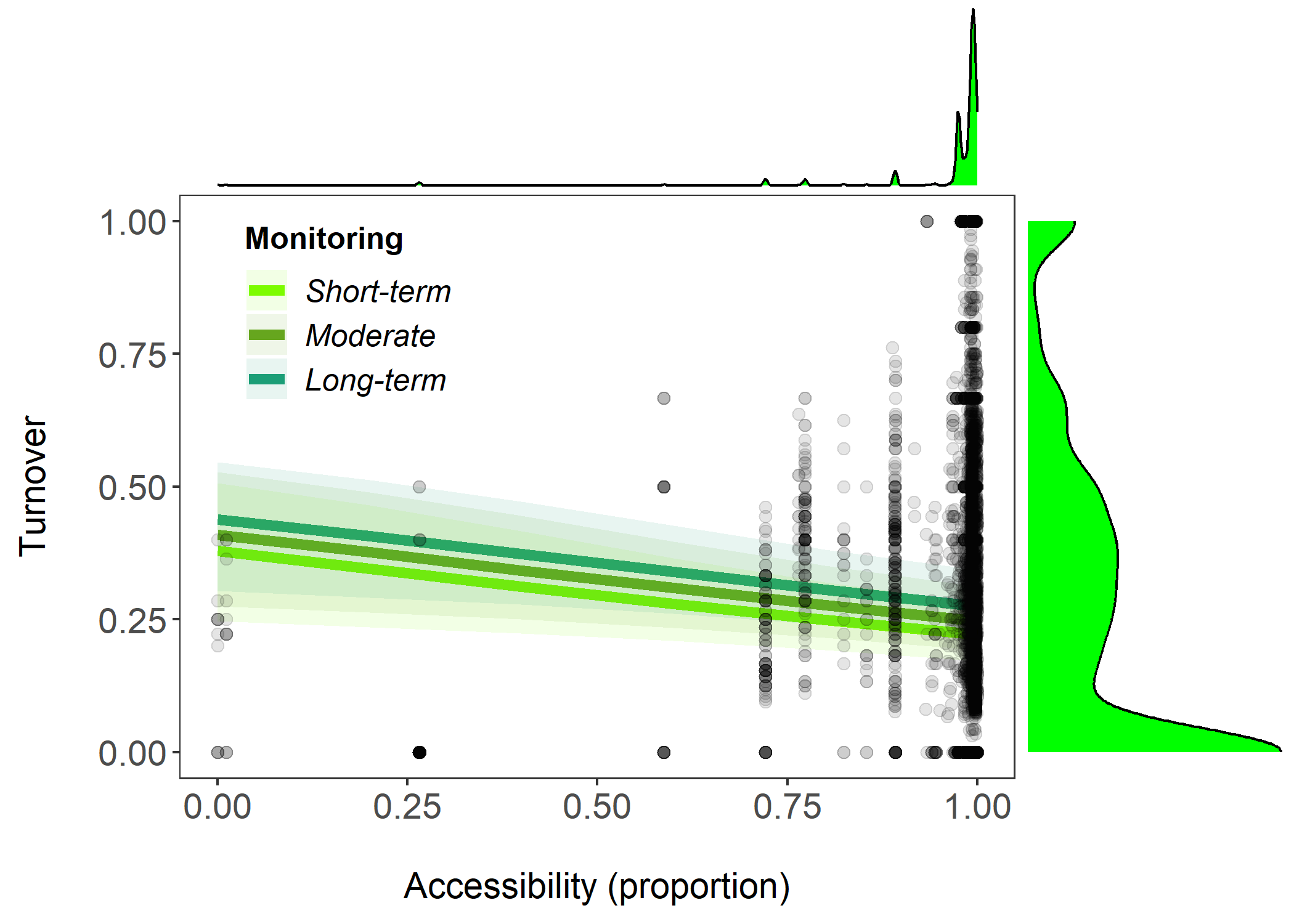


Figure 2. Jaccard turnover has increased for higher levels of accessibility across 5788 time-series globally (slope = 0.05, CI = 0.03 to 0.07, Figure 1, see Table 1 for more model outputs). Grey points represent raw data. Lines and error bands represent model predictions and 95% credible intervals, respectively.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

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

Looking at the relationship between turnover and human population density, I found that temporal turnover has not increased as human population density increased across the 5787 time-series surveyed (slope = -1.05, CI = -1.59 to -0.51, Figure 1, see Table 1 for more model outputs). the duration of the observation influenced the magnitude of the detected temporal turnover trends, with higher temporal turnover observed for longer monitoring of sites. Quantification. Uncertainty of main effect is more similar throughout levels of human population density. As can be seen from the distribution 96.4 % of data points have human population density score of 0.1 and below.

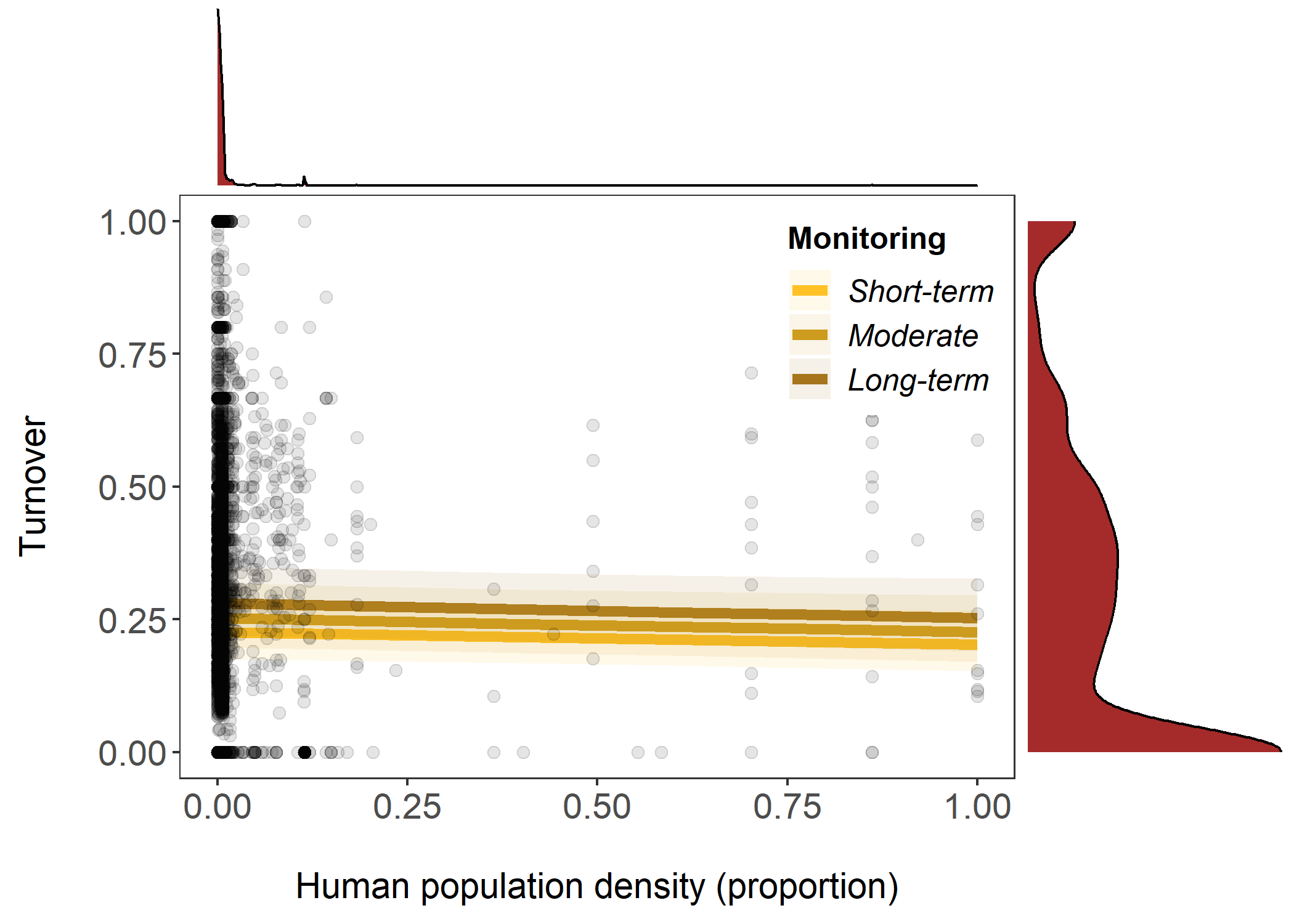
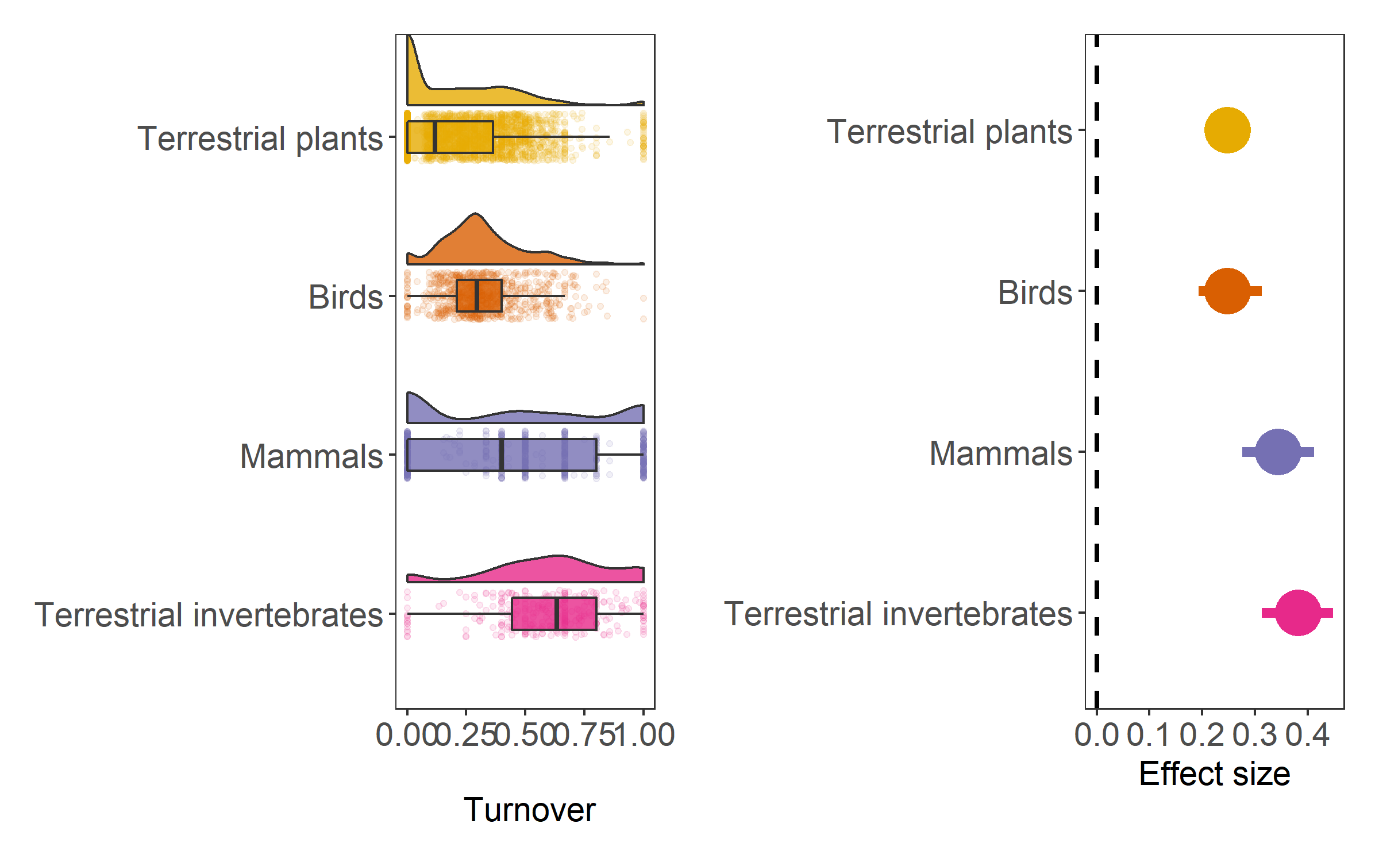


Figure 2. Jaccard turnover has increased for higher levels of accessibility across 5788 time-series globally (slope = 0.05, CI = 0.03 to 0.07, Figure 1, see Table 1 for more model outputs). Grey points represent raw data. Lines and error bands represent model predictions and 95% credible intervals, respectively.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

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

Looking at the relationship between temporal turnover and each taxa, I found that temporal turnover showed positive relationships across the four taxa surveyed (across the 5787 time-series surveyed) (slope = -1.05, CI = -1.59 to -0.51, Figure 1, see Table 1 for more model outputs). mammals and invertebrates have higher amounts of turnover relative to birds and plants and that invertebrates have the highest turnover**.** Also plants made up 73% of time-series that showed no turnover (turnover = 0). Raw data shows high variability for mammals, low for birds and plants. But also unequal sampling: 60% of data set is made up of plants, followed by 20% mammals, followed by 14% birds and only 6% invertebrates. Also interesting to see is different distribution of coincidence with PA: Plants and mammals show high coincidence; 39% and 45% respectively and below 5 for both invertebrates and birds.



# Discussion

*PUT SENSTIVITY ANALYSIS RESULTS IN HERE?*

My analysis of 5788 time-series in 1023 unique locations globally did not show an increase of turnover with an increase of accessibility. Contrary to my prediction, turnover was higher in less accessible sites, suggesting a rejection of my hypothesis of a positive relationship between turnover and increasing accessibility. The lack of positive responses/ negative relationship of turnover to accessibility could be due to the complexity of real-world biodiversity change, interactions between different effects of human impacts and uncaptured indirect effects of large-scale human impact; further enhanced by data and analysis limitations (high uncertainty of main effect at low accessibility). My modified second research questions revealed no directional relationship between human population density and turnover. The taxa-specific relationships between accessibility and turnover (modified research question 3) demonstrate that all studied taxa experienced turnover. My findings of negative responses to low accessibility highlight the complexity of real-world communities both in terms of heterogeneity of effect as well as heterogeneity of response. My study points out the importance for considering temporal dynamics and interactive effects of large-scale human activity when planning and implementing conservation schemes (refer back to possible reasons) and challenges the current focus of protecting wilderness areas as a primary conservation strategy.

**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)**

Biodiversity change is coupled to species vulnerability to disturbances. The vulnerability might differ depending on both the type of disturbance, which are a ranging because nature of accessibility; but also depending on characteristica of the species themselves. As turnover is affected by dispersal processes and metacommunity dynamics, species mobility plays an important role (Vellend, 2010), as does the degree of specialisation in the use of resources (niche width). These processes apply both within taxonomic groups and among. 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. This would indicate higher initial temporal turnover, but then long-term might also allow more mobile species to persist.

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. This would indicate more long-term turnover for mobile species.

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.

Again, my results reflect the complexity of dynamics of the interaction between scales and vulnerabilities. (Due to problems with model convergence, I can only present results that evaluate the relationship between temporal turnover and taxa and not taxa’s different responses to turnover across levels of accessibility.) I presented taxa-specific relationships between temporal turnover and taxa (Figure 4), in particular showing that terrestrial invertebrates followed by mammals show higher temporal turnover than birds and plants (QUANTIFICATION). All taxa show some degree of temporal turnover (QUANTIFICATION). However, generally birds can be considered highly mobile and plants less mobile (reference HI paper), but that was not reflected in the amount of turnover experienced.

Contradicting temporal lags with mammals and birds

s we predicted, the period between peak forest loss and peak change in populations and biodiversity was longer for taxa with longer generation times (e.g., large mammals and birds, [**Fig. 5**](https://www.biorxiv.org/content/10.1101/473645v4.full#F5) and S14, Table S1). Population declines and increases occurred on similar timescales (Fig. S14). Losses in species richness lagged behind richness gains by only approximately half a year (slope = 0.5, CI = 0.1 – 1.05), indicating that extinction debts and immigration credits accumulated at roughly the same speed across taxa.

No richness change and no turnover for plants? Global meta-analysis

Coincidence of observed change because of ease of detection?

Importance of looking at real-world communities, understanding biodiversity better when looking at compositional changes and considering scale: both at level of impact and observation. Implications for conservation?

Species with a smaller geographic range might have more concentrated exposure to environmental change, with less opportunities to find refugia or disperse, thus increasing the likelihood of declines[**1**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-1),[**9**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-9)

As per population dynamics theory[**22**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-22),[**23**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-23) and Taylor’s power law[**24**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-24), species with small populations are more likely to undergo stochastic fluctuations that could lead to pronounced declines, local extinction and eventually global species extinction[**5**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-5). Small populations are also more likely to decline due to inbreeding[**25**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-25),[**26**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-26). Allee effects, the relationship between individual fitness and population density, further increase the likelihood of declines due to lack of potential mates and low reproductive output once populations reach a critically low density[**27**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-27),[**28**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-28).

Amphibians experienced net declines over time (slope = -0.01, CI = -0.02 to -0.005), whereas birds, mammals and reptiles experienced net increases (slope = 0.004, CI = 0.003 to 0.01; slope = 0.01, CI = 0.01 to 0.01; slope = 0.02, CI = 0.01 to 0.02), with birds having a bimodal trend distribution (Hartigans’ dip test, D = 0.04, p < 0.01, [**Figure 1a**](https://www.biorxiv.org/content/10.1101/272898v5.full#F1)).

Across monitored vertebrate populations globally, species with smaller ranges, smaller population sizes, or narrower habitat specificity (i.e., rare species) were not more prone to population declines than common species ([**Figure 3**](https://www.biorxiv.org/content/10.1101/272898v5.full#F3), Table S2).

Such taxonomic patterns could be driven by different taxon-specific factors including reproductive strategy, trophic level, generation time and life history traits[**43**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-43),[**44**](https://www.biorxiv.org/content/10.1101/272898v5.full#ref-44).

As human activities continue to accelerate, the next key step is to determine how intrinsic factors, such as rarity attributes and threats, interact with extrinsic global change drivers and together influence the persistence of Earth’s biota.

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?  
spatial under/overrepresentation of sites modified by human activities? No points at low accessibility

**Statistical analysis**

The BioTime data compilation was not big enough (yet) to allow for an interaction effect between accessibility and human population density neither to include random slopes and intercepts for taxa as model convergence was not achieved. Talk about priors?

**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