**Dissertation notes**

# Title

# Intro

First paragraph

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

Middle paragraphs

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

## Hypotheses and Predictions

# Methods

## Statistical analysis

We tested the question/hypothesis that [richness has increased over time] at the Tulik lake field station , Alaska. We used a hierachical linear model with year as a fixed and site as a random effect, to account for variation among sites.

Data checks

* Data points from BioTIME which don’t have accessibility score?
* Distribution Histrogram
* Center latitude and year data?
* Sites coincidence with protected areas
* Spatial extent of studies
* Is there effect of amount of data points in time series on outcomes?

Ideas for sensitivity analysis of models

* Sensitivity to cell size
* Reaction rare species vs common species
* Differences in latitude (eg tropics)
* Taxonomic differences (if not included as research question)
* Preference of urban-adapted species?

Choice of biodiversity metric?

**turnover will vary across latitudinal bands due**

**to known latitudinal gradients in climate change, human use and biodiversity.**

# Discussion

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

Paragraph for each finding + past research

Limitations of study

Potential future research

RQ1:

Turnover is lower when accessibility is higher

* Biological conclusion
  + Meaning higher and lower accessibility (relating back to urbanisation and roads etc)
  + Importance to match BD record to what is actually happening (most transformation beforehand)

Human impact alters habitat and resource availability (ref sax, Newbold) and is a global threat for terrestrial species.

The decoupling between magnitude of accessibility as an indicator of human impact could be due to those facts:

Accounting for heterogeneity in the effects of forest cover change over time is key when scaling from localized impacts of human activities to global-scale biodiversity patterns and attribution of change ([***1***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-1)).

* Findings relation to other papers

* Possible biological explanation why different from expected
  + Temporal lags in community responses
  + Lower influence of accessibility during monitoring period (2015) relative to historic influences accessibility
  + Influence of dirvers other than forest loss
  + Variation in species vulnerability to disturbance
  + Mismatch between assemblages monitored and localized impacts of accessibility
  + Accessibility amplified both positive and negative trends at local scales, but at larger scales favoured same species across sites (homogenization)
  + Rare species more negatively affected by land-use change
  + Potential antagonistic effects of suite of drivers explained by the metric accessibility (see prereg gergana)
* Possible methodological findings why different
* Relate back to bigger picture; statement X
  + Complexity of BD?
  + Accounting for heterogeneity in the effects of forest cover change over time is key when scaling from localized impacts of human activities to global-scale biodiversity patterns and attribution of change

Net changes in diversity provide an incomplete view of the effects of human activities on biodiversity because they ignore the replacement of original species by newcomers[8](https://www.nature.com/articles/nature14324#ref-CR8).

From forest paper

General discussion points

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

### **2.5 Alien species potential**

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

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

### **2.6 Human population**

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

RQ3:

Taxa specific

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

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

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

Anthropogenic pressures can affect ecosystem functions and services more strongly than changes in species diversity would imply, if species' responses depend on their traits

* Biological conclusion
  + Meaning if one taxa higher/lower than the other
* Findings relation to other papers
* Possible biological explanation why outcomes as they are
  + Species more sensitive to other drivers eg warming?
* Possible methodological limitations

Limits methods

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

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

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

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

have an analytical scale tailored to the traits of each species and community. Furthermore, it is still largely unknown what is the optimal scale at which to conduct macroecological studies, and finer resolution global driver data are not currently available for most drivers. For more details on analytical methods, see the statistics section further down.

Future research

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

Conclusions

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

My finding add to the growing body of research that real-world biodiversity change is complex and does not always follow the decline narrative of human impact causes biodiversity change.

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

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

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

thus affecting larger proportions of ecological communities58. Such patterns suggest

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

line with evolutionary trade-off theory60.

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

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

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

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

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

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

Brown’s niche breadth hypothesis63.

58. D. Vinebrooke, R. *et al.* Impacts of multiple stressors on biodiversity and ecosystem

functioning: the role of species co-tolerance. *Oikos* **104**, 451–457 (2004).

47. Isaac, N. J. B. & Cowlishaw, G. How species respond to multiple extinction threats.

*Proceedings of the Royal Society of London. Series B: Biological Sciences* **271**, 1135–1141

(2004).

60. Futuyma, D. J. & Moreno, G. The evolution of ecological specialization. 29

63. Brown, J. H. On the Relationship between Abundance and Distribution of Species. *The*

*American Naturalist* **124**, 255–279 (1984).

HPD (isla paper)

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

Prereg Gergana

We predict greater declines in population abundance and species richness with greater

exposure to human use activities, denser human population and higher pollution due to niche constraints and fitness reductions caused by this suite of anthropogenic threats9,36–39. We expect greater declines in population abundance with higher exposure to invasions because species’ invasion can limit the resources available for native species40,41.

Hölker, F., Wolter, C., Perkin, E. K. & Tockner, K. Light pollution as a biodiversity threat.

*Trends in Ecology & Evolution* **25**, 681–682 (2010).

37. McNeely, J. A. The sinking ark: pollution and the worldwide loss of biodiversity. *Biodiversity*

*and Conservation* **1**, 2–18 (1992).

38. Vörösmarty, C. J. *et al.* Global threats to human water security and river biodiversity. *Nature*

**467**, 555–561 (2010).

39. Didham, R., Tylianakis, J., Gemmell, N., Rand, T. & Ewers, R. Interactive effects of habitat

modification and species invasion on native species decline. *Trends in Ecology & Evolution*

**22**, 489–496 (2007).

40. Simberloff, D. *et al.* Impacts of biological invasions: what’s what and the way forward.

*Trends in Ecology & Evolution* **28**, 58–66 (2013).

41. Gaertner, M., Den Breeyen, A., Cang Hui & Richardson, D. M. Impacts of alien plant

invasions on species richness in Mediterranean-type ecosystems: a meta-analysis.

*Progress in Physical Geography: Earth and Environment* **33**, 319–338 (2009).

As global change drivers increasingly alter ecosystems26,53,54, the resulting environmental

change facilitates colonisations by new species55,56, but also leads to local extinctions and

changes in relative abundance43,57. When multiple drivers are present and species vary in their

vulnerability to threats47, larger proportions of the community might be affected compared to

when only one driver is in place58, leading to an accelerated reshuffling of ecological

communities. Thus, we predict synergistic effects of global change drivers on community

composition, with turnover increasing with greater exposure to human exploitation, climate

change, pollution and invasion pressure.

# Divergent biodiversity change within ecosystems

<https://www.pnas.org/content/115/8/1843>

Notwithstanding the above, the noncorrelated pattern of assemblage turnover observed here sheds little light on whether community resilience (as shown by nontrending α-diversity) occurs because of temporal β-diversity, or despite it. As noted by Darwin [and inherent in MacArthur and Wilson ([**57**](https://www.pnas.org/content/115/8/1843#ref-57)) and similar ecological theory], some degree of turnover is essential to promote community persistence. However, we also know that contemporary rates of temporal turnover exceed the theoretical expectations of existing ecological models ([**7**](https://www.pnas.org/content/115/8/1843#ref-7), [**13**](https://www.pnas.org/content/115/8/1843#ref-13)). It is likely that anthropogenic impacts, including climate change and translocations of exotic species, are contributing to the temporal turnover that we observe in this and other studies. Moreover, while the functional consequences of biodiversity change within the ecosystem as a whole remain unclear, research suggests that ecosystem function will be prejudiced if diversity is reduced in any taxonomic or functional groups ([**21**](https://www.pnas.org/content/115/8/1843#ref-21)). A pressing research question, then, is, at what point does elevated temporal β-diversity jeopardize community integrity?

Monitoring schemes are not evenly distributed across the Earth’s surface ([**28**](https://www.pnas.org/content/115/8/1843#ref-28)), and data gaps from tropical ecosystems and the freshwater realm mean that these systems are under-represented in appraisals of biodiversity change ([**7**](https://www.pnas.org/content/115/8/1843#ref-7), [**8**](https://www.pnas.org/content/115/8/1843#ref-8)). Compositional shifts are particularly difficult to generalize as rates of temporal turnover can vary across localities and groups ([**34**](https://www.pnas.org/content/115/8/1843#ref-34), [**59**](https://www.pnas.org/content/115/8/1843#ref-59), [**60**](https://www.pnas.org/content/115/8/1843#ref-60)), yet it is becoming clear that evaluating temporal β-diversity is essential not just to safeguard the world’s ecosystems, but also to answer fundamental questions about the resilience of ecological communities and the maintenance of biodiversity.

Pitch

Plant phenology is advancing in the Arctic and we need to know if longer growing seasons translate to more plant growth to understand the links between climate change, vegetation productivity and ecosystem function.

Human impact is reshaping natural systems including biodiversity and we need to know the drivers of this change to understand the links between human activity, biodiversity change and conservation efforts better.

We would assume that longer growing seasons and warmer temperatures would both increase growth of tundra shrubs, yet the different influences on growth have yet to be tested together.

Write the discussion, which should present only additional information (e.g., literature) that modifies, extends, confirms, or contradicts the conclusions based on your results.

Conclusions each section Gergana

Predictions  
Overall, our analyses provide real-world estimates of the magnitude of landscape-scale forest loss impacts and the pace at which they are altering terrestrial ecosystems around the planet.

Contrary to our first prediction (“timing”), we found that forest loss led to both increases and decreases in populations and biodiversity over time ([**Figs. 3**](https://www.biorxiv.org/content/10.1101/473645v4.full#F3)-[**4**](https://www.biorxiv.org/content/10.1101/473645v4.full#F4) and S8-S9).  
Our findings of a full spectrum of population and biodiversity responses to forest loss highlight the complexity of real-world communities that might be overlooked in analyses that use a space-for-time substitution and thus do not capture the temporal dynamics of ecological responses to land-use change ([***11***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-11), [***12***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-12), [***14***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-14), [***39***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-39)).

Contrary to our second prediction (“magnitude”), we did not detect an effect of the magnitude of forest change on population and biodiversity losses.  
Accounting for heterogeneity in the effects of forest cover change over time is key when scaling from localized impacts of human activities to global-scale biodiversity patterns and attribution of change ([***1***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-1)).

In line with our third prediction (“lags”), we found evidence for up to half-century ecological lags in local-scale changes in population abundance, species richness and turnover following forest loss ([**Fig. 5**](https://www.biorxiv.org/content/10.1101/473645v4.full#F5)).   
Overall, our results indicate that increasing rates of land-use change in the Anthropocene ([***45***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-45), [***46***](https://www.biorxiv.org/content/10.1101/473645v4.full#ref-46)) will alter ecosystems on both short- and long-term timescales that need to be captured in ongoing and future biodiversity monitoring.

Taxonomic, spatial and temporal imbalances in sampling can make large-scale attribution analyses of biodiversity trends and global change drivers challenging.  
Biodiversity monitoring and global change attribution analyses will be improved by better spatial and temporal matching of biodiversity and environmental impact data.

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.  
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)).  
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.

[file:///C:/Users/DanielaG/Downloads/DePalmaetal\_Preprint.pdf](file:///C:\Users\DanielaG\Downloads\DePalmaetal_Preprint.pdf)

However, while time series can provide estimates of net change, this approach is not well suited to understanding how disturbances and other pressures influence biodiversity, unless data on pressures are available for the sampling locations and dates, ideally according to a design such as one of those considered above. Without such data, the average trend across a set of time series will only correctly estimate the average trend across the entire region of interest if the sites sampled are fully representative, in terms of the disturbances or other pressure changes that they show

SCALES  
Patterns of biodiversity frequently depend on the spatial and temporal scales of observations. Although it is possible for patterns and processes to interact across scales (e.g., local diversity can depend on regional diversity; [**83**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**110**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)), changes in species diversity are not necessarily correlated across scales ([**65**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). For example, [**nonnative species**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949#dl1) introductions across continents can cause large increases in regional species richness at the same time that extinctions cause a global decrease.

**TAXA**

* Species difference in vulnerability to impacts of accessibility; but can’t actually relate that back to outcomes as no random slopes
* Risk of invasion differs between taxa (jeschke ref)
  + Alien species can be directly related to turnover
  + Important because affecting ecosystem functioning
  + High rates related to expanding trade networks, human mobility and environmental change (land degradation -> varied among taxa)
  + Taxa specific
    - Birds intro via pet brid trade
    - Highest alien species for invertebrates in recent years
* Mobility
* Invasion
* Relate back to several influences acting on each taxa (eg climate)
* Ecological lags
* Species rarity not influencing, but rather smaller pop size and larger range more likely to range

Unlike exposure, sensitivities vary among taxa according to characteristics such as their life history, traits and niche breadth (Sunday et al., [**2015**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0062)) and therefore need to be examined separately for different taxa. Hence, despite similar exposure patterns, we can expect a diversity of biodiversity responses within each ATC due to variation in species' sensitivities.  
However, the realized outcome of different drivers on biodiversity will ultimately depend on a combination of both the magnitude of exposure to drivers and species' sensitivities to environmental change (Foden et al., [**2013**](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10071#pan310071-bib-0018)). 

Sensitivity and responsiveness   
More mobile species easier to response (faster range extensions)

MOBILITY  
<https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6>

Besides the degree of specialisation in the use of resources (i.e. niche width), mobility has been proposed as a relevant trait in disturbed environments like urban areas (Büchi et al. [**2009**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0005), Öckinger et al. [**2010**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0038), Schleicher et al. [**2011**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0043)). Species composition of biological communities is greatly affected by dispersal processes and metacommunity dynamics, such as source–sink dynamics, in which species mobility plays a prominent role (Dunning et al. [**1992**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0015), Leibold et al. [**2004**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0028), Vellend [**2010**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0053)). In the case of plants, highly mobile species able to rapidly colonize open sites after disturbances, usually proliferate in urban areas (Kühn and Klotz [**2006**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0024), Lososová et al. [**2012**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0029)). Typically, these are pioneer species associated with early successional stages. Mobility is also very important for animals, with highly mobile species being supposed to better cope with urban disturbances (Devictor et al. [**2007**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0012)). The maintenance of urban communities may actually rely on the immigration of individuals from nearby populations from more natural habitats, in which case species dispersal is even more relevant (Stefanescu et al. [**2004**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0048), Shochat et al. [**2006**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0045)). This is generally the case in systems that suffer recurrent disturbances, such as agricultural land, where biodiversity levels greatly depend on the species pool hosted by (semi‐)natural habitats in their surroundings (Duelli and Obrist [**2003**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0014), Tscharntke et al. [**2005**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0051)).

Overall, poorly mobile species are assumed to be more intensively affected by habitat loss and fragmentation caused by land‐use changes, while more mobile species, able to move among distant habitat fragments, are expected to be less sensitive to this process (Öckinger et al. [**2010**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0038), Schleicher et al. [**2011**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0043)). However, more mobile animals usually have larger home ranges and rely on larger habitat patches as well, and, as a result, they may be more sensitive to habitat fragmentation (Thomas [**2000**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0050), Chace and Walsh [**2006**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0007), Slade et al. [**2013**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0046)). In addition, more mobile organisms tend to be affected by processes acting at larger scales than those influencing poorly mobile or sessile organisms (Merckx et al. [**2009**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0033), Concepción and Díaz [**2011**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0009), Braaker et al. [**2014**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0003)). Despite the relevance of selecting a proper range of spatial scales to analyse ecological processes affecting diversity patterns for distinct organism types (Tews et al. [**2004**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0049), Merckx et al. [**2012**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0034), Raebel et al. [**2012**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0040)), only a few studies have addressed this question in relation to urbanisation impacts on biodiversity (Braaker et al. [**2014**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0003)).

The relevance of spatial dynamics in biological communities greatly varies depending on organisms’ degree of specialisation and mobility (Leibold et al. [**2004**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0028)). Every organism may experience the environment in a different way, and the same landscape can hence be perceived as heterogeneous by one species and as fragmented by another. Likewise, a resource‐rich patch for one species can be a barrier for another, and this, in addition, depends on the spatial scale we consider (Tews et al. [**2004**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0049)). For instance, specialist species – with narrow ranges of resource and habitat requirements (i.e. niche width) – would typically perceive their habitat as more fragmented than generalists, and would consequently rely more on their mobility to succeed (Öckinger et al. [**2010**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0038)). Responses to ecological processes that shape community assembly also depend on species’ degree of specialisation and mobility. This can prevent some species from occurring in certain places, where, for instance, their resource requirements are not fulfilled (i.e., environmental filtering), they are excluded by stronger competitors (i.e. biotic filtering or limiting similarity), or they are not able to reach because of dispersal limitations (Mason et al. [**2005**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0031), Grime [**2006**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0019)). Moreover, these assembly processes are also expected to be scale‐dependent and to act more intensively in disturbed environments, such as managed grasslands (Mason et al. [**2011**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0032), de Bello et al. [**2013**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0011)). However, studies on how urbanisation affects community assembly patterns have appeared only recently (Le Viol et al. [**2012**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0027), Knapp et al. [**2012**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0023)).

Here, we investigate urbanisation impacts on two species characteristics, namely mobility and the degree of specialisation in resource use, which are primarily involved in metacommunity dynamics and community assembly processes, and then supposed to be greatly affected by urbanisation. We explore such impacts for distinct taxonomic groups and across several spatial scales to address the following research questions: 1) Do the degree of specialisation and mobility of species assemblages of different taxonomic groups change along the urbanisation gradient? 2) Which ecological processes are driving these changes? And 3) at which spatial scale are organisms with different degrees of specialisation and mobility affected by urbanisation?

These results partially (i.e. except for birds) confirm our expectations of highly mobile organisms (i.e. butterflies) being affected by factors acting at larger spatial scales than poorly mobile or sessile organisms (i.e. plants; Concepción and Díaz [**2011**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0009), Braaker et al. [**2014**](https://onlinelibrary.wiley.com/doi/full/10.1111/oik.02166?casa_token=fhWgGzDEsqwAAAAA%3ADNkUGBoEi6hMzlPVhzXsMHEe-dKJIzMvTWp-d0XTfzzlxmQX5vc7R8cbyTUZIdwHsOJ_jqOxGCi6#bib-0003)). Furthermore, differences in the spatial scale at which highly and poorly mobile species within taxonomic groups responded to urbanisation also became evident for plants and butterflies and, in addition, varied with species degree of specialisation.

I showed taxa-specific relationships between turnover and taxa (Figure 4). In particular, I presented that terrestrial invertebrates, followed by mammals show higher turnover than birds and mammals. (All show negative relationship of turnover across levels of accessibility). Inferences about species vulnerability due to their mobility (REF) have suggested that less mobile species are more vulnerable to habitat change. Vulnerability can lead to extinction/immigration dynamics, explored above. While species are undoubtly negatively affected by human impacts (REFS), I found that the relationship between turnover and taxa does not only depend on the mobility of the species.   
Species different vulnerability to different suite of impacts. Vulnerability might cancel effects out, so overall trend is misleading.

Plants are found to be more vulnerable to alien species and thus we would expect to find higher turnover than more mobile species eg plants.

<https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1002/fee.2020> Have higher vulnerability to invasion pressure where as birds are still being pressured because of anthropogenic activity but not to the same extent.

My findings suggest that complexity of species-indivual responses

Another explanation is the mismatch of reaction to event. Normally maximum change in biodiversity shortly after heavy land-use change event (Gergana), but we cannot quantify rate of change of accessibility. On top, ecological lags play important role, as taxa (trees can have lag of up to 30 years). So, we need to be aware what about future changes as well.

# The Global Distribution and Drivers of Alien Bird Species Richness

<https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.2000942>

Our findings suggest that small-ranging species are in double jeopardy, with limited ability to escape warming and greater intrinsic vulnerability to stochastic disturbances

# A global model of the response of tropical and sub-tropical forest biodiversity to anthropogenic pressures

<https://royalsocietypublishing.org/doi/full/10.1098/rspb.2014.1371#d3e944>  
narrow-ranged species were less likely than widespread species to occur in all land uses, with the largest differences between narrow- and wide-ranged species seen in urban environments, croplands and plantation

Narrow-ranged species tended to be less abundant than widespread species in all land-use types but especially in urban environments, croplands and plantation forests (ΔAIC = −47.3; best-fitting model, AIC = 38145; [figure 3](https://royalsocietypublishing.org/doi/full/10.1098/rspb.2014.1371#RSPB20141371F3)*a*). Similarly, among mammals and birds, habitat specialists tended to be less abundant than habitat generalists, especially in urban habitats, croplands and plantation forests (ΔAIC = −15.4; [figure 3](https://royalsocietypublishing.org/doi/full/10.1098/rspb.2014.1371#RSPB20141371F3)*a*).

Overall, the results demonstrate that transformation of habitats for human land use is causing consistent reductions in species richness and changes in abundance, altering ecological communities in tropical and sub-tropical forests around the world. Human-dominated habitats have fewer species than natural habitats. The results add to a growing body of evidence that humans are causing fundamental changes to community structure. Collating published data on species occurrence and abundance opens new opportunities for assessing biodiversity state, and analyses like ours can be expanded to other biomes for which data are available. Using land-use information that follows a widely used classification scheme, as well as globally consistent environmental data, makes these models a strong basis for extrapolating community responses across space and through time, which will be essential for predicting the biodiversity impacts of future changes.

# Effects of Urbanization on Native Bird Species in Three Southwestern US Cities

No spatial homogenization -> less relevant?

The loss of biodiversity and ecosystem services due to urbanization has been well-documented across multiple taxa ([Lockwood and McKinney, 2001](https://www.frontiersin.org/articles/10.3389/fevo.2019.00071/full#B36)). This decline in biodiversity is especially the case for native species ([Aronson et al., 2014](https://www.frontiersin.org/articles/10.3389/fevo.2019.00071/full#B1)), making improved understanding of how native species respond to urbanization an urgent priority for the protection of biodiversity in urban landscapes.

Mammals

<https://academic.oup.com/jmammal/article/100/3/1087/5498021#136038415>

These problems are particularly acute for larger-bodied species, which have been demonstrated to have higher extinction risk, at least in the anthropogenic era (e.g., Cardillo et al. 2005, 2008; Davidson et al. 2009; Fritz et al. 2009; Dirzo et al. 2014; Ripple et al. 2015). Many large-bodied species have already been extirpated from natural ecosystems due to activities by hominins (e.g., Alroy 1999b, 2001; Barnosky et al. 2004; Lyons et al. 2004a; Burney and Flannery 2005). For example, the majority of extant large-bodied herbivores (> 100 kg) are found in Africa (n = 32) or southeast Asia (n = 19), with Europe and North and South America harboring only seven, five, and five species, respectively (Ripple et al. 2015).

The loss of large-bodied mammals is likely leading to rapid loss of ecological functions within communities (e.g., Estes et al. 2011; Dirzo et al. 2014; Ripple et al. 2015; Smith et al. 2016a).

Implicated factors include taxonomic identity, geographic distribution, home range, population density, group size, activity period, fecundity, inter-birth interval, and trophic affiliation. Whether a particular characteristic is important depends on the underlying cause of extinction, with different mechanisms driving deep-time, Holocene, and current extinctions (Lyons et al. 2004a; Turvey 2009; Turvey and Fritz 2011; Lyons et al. 2016b). For example, for much of the Cenozoic, the body size of a mammal did not influence its extinction risk (Casanovas-Vilar et al. 2010; Tomiya 2013; Smits 2015; Smith et al. 2018, but see Liow et al. 2008). This is an unexpected result given the dire conservation status of contemporary large-bodied mammals and the many studies that demonstrate size selectivity (Cardillo 2003; Cardillo et al. 2005, 2008; Davidson et al. 2009; Fritz et al. 2009). Although the allometric scaling of life history characteristics means that large-bodied mammals tend to have long generation times and reduced fecundity (Peters 1983; Calder III 1984; Ernest 2003), they also necessarily have large home ranges and wide geographic distributions (Gaston and Blackburn 1996; Jetz et al. 2004; Lyons et al. 2010; Lyons and Smith 2013), factors that buffer against extinction risk (Jablonski and Raup 1995; Payne and Finnegan 2007). In contrast, human activities lead to highly size-selective extinctions (Cardillo 2003; Lyons et al. 2004a; Zuo et al. 2013; Lyons et al. 2016b). Indeed, interaction between lifestyle, range size, and body size determines vulnerability among contemporary mammals; extinction risk generally rises sharply above ~5 kg (Davidson et al. 2009).

Knowing that large mammals are more vulnerable to extinction only in light of human activities provides information that is critical to understanding and mitigating the extinction risk of large mammals today (e.g., Davidson et al. 2009). Other effects of humans documented using a macroecological approach include weakening patterns such as Bergmann’s Rule (Faurby and Araujo 2017; Santini et al. 2017), changing species geographic ranges through fragmentation of habitats (Crooks et al. 2017), and affecting body-size distributions and hence the flow of energy through communities (Lyons and Smith 2013; Rapacciuolo et al. 2017).

# PLANTS Plant Biodiversity Change Across Scales During the Anthropocene

# Vellend

# Human domination of the biosphere in recent centuries—a period of time often referred to as the [Anthropocene](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949#dl1) ([96](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949))—is widely considered to have elevated species’ extinction rates to the point of a global-scale biodiversity crisis ([6](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [70](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). However, for plants, extinction-rate estimates are highly uncertain, and human activities, such as species introductions that bring close relatives into geographic proximity, may have actually increased the rate of plant speciation ([103](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). At subglobal scales of observation—from local study plots of a few square meters to entire continents—recent research points to immense variability in temporal biodiversity trends ([24](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [69](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [87](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [111](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). For example, [nonnative species](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949#dl1) have caused declines in some [native species](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949#dl1) at the same time that they have greatly enriched regional floras ([87](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [124](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). By understanding how and why plant biodiversity has changed in recent centuries, we can improve predictions of how it will change in the future.

A huge literature concerns patterns of plant species diversity and the factors that influence these patterns over space and time. Studies range from those addressing how factors such as productivity or land use influence diversity at small spatial scales ([**69**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**117**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)) to those addressing the effects of nonnative species on regional-scale diversity ([**87**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**124**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)) and the quantification of global extinction and speciation rates ([**45**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**78**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**103**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Here, we review this literature and present a synthesis of knowledge of patterns and causes of plant biodiversity change during the Anthropocene across spatial scales.

### Global-Scale Conclusions

▪Both extinction and speciation rates have likely increased owing to human activities during the Anthropocene.  
▪We cannot conclude definitively that the number of plant species on earth has decreased or increased since the onset of the Anthropocene.  
▪Extinctions during the coming centuries have the potential to greatly outnumber speciation events, causing a decline in global plant species richness.

### Underlying Causes and the Future of Regional-Scale Plant Diversity

The dominant cause of regional-scale plant diversity changes is clearly the establishment of nonnative species, which in turn depends on both introduction pressure and the suitability of biotic and abiotic conditions ([**59**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Net increases in diversity may be due in part to increased environmental heterogeneity, with a mix of disturbed and undisturbed habitats permitting the persistence of nonnative and native species alike ([**19**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**102**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Interestingly, the same economic activities that prompt introductions (agriculture, horticulture, and urbanization) also result in the creation of suitable habitats for many nonnative species and the modification of habitats to the detriment of many native species ([**38**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**79**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). It is thus difficult to predict future net changes in plant diversity at the regional scale, especially in tropical areas, where increasing international trade and habitat disturbance should promote both nonnative species invasions and native extinctions.

### From a theoretical point of view, an elevated rate of immigration via nonnative introductions is expected to increase diversity ([**84**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**110**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)), and for places that have been repeatedly surveyed over time, there is no sign of a recent decline in the rate of new species establishment ([**88**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). In general, increasing human activity and anthropogenic habitat modification should accelerate the establishment of nonnative species ([**57**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)), a process that might be especially important in developing tropical nations. Shifting geographic ranges resulting from climate warming are also expected to bring new species to particular regions ([**72**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**94**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)), and time lags involved in such range shifts create an “[**immigration credit**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949#dl1)” for future regional diversity ([**43**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Regional-Scale Conclusions

▪So far, the number of nonnative plant species established in a given region is typically far greater than the number of species that have gone regionally extinct.

▪The resulting net increase in regional richness has been greater on islands than in mainland regions.

▪Very little is known about net plant biodiversity changes during the Anthropocene in tropical continental areas, particularly with respect to extinctions.

▪Continued regional increases in plant species richness seem likely, but the magnitude is highly uncertain, especially for tropical continental areas.

the data set (later updated to the end of 2014; 113) includes studies from all continents except Antarctica, but with an underrepresentation of tropical regions. The main result across 212 studies is that the distribution of temporal trends is centered on zero, regardless of habitat type or geographic region ([**Figure 2**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Some individual studies reported substantial increases in plant richness over time (e.g., +38% in forests and grasslands of Vancouver Island between 1968 and 2009; [**64**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)), whereas other studies reported substantial decreases in richness over time (e.g., −70% in the Siskiyou Mountains of Oregon between 1950 and 2007; [**17**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Most studies reported very little temporal change in either direction (<10%).

### Effects of Land Use

Large areas of the earth's surface have been converted from primary vegetation to anthropogenic habitats. Newbold et al. ([**69**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)) compiled data from >250 space-for-time studies to assess the local-scale consequences of land use for biodiversity in a range of animal and plant taxa. Here, we focus on results that apply to plants (T. Newbold, personal communication), of which the clearest was that local species richness was ∼30% lower on agricultural lands (by far the dominant human land use) than it was in minimally disturbed primary vegetation.

Urban areas occupy a very small portion of the earth's surface, but roughly half of the human population lives in them. Suburban yards or urban areas devoid of green spaces typically have a lower species richness than primary vegetation, but larger, managed urban green spaces have an average species richness similar to that in primary vegetation ([**69**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Consistent with these results, a negative correlation between the magnitude of human presence in cities (e.g., population density) and plant species richness has been observed for small study plots, but in units of observation larger than 1 km2, species richness actually increases as a function of human impact ([**75**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). The latter result could be due to the tendency of humans to settle in areas already high in biodiversity or to positive effects of human-caused environmental heterogeneity and species introductions. The latter conclusion is supported by increases in city-wide plant species richness in recent centuries caused specifically by introduced neophytes ([**48**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)).

In sum, when people destroy primary vegetation to make way for agriculture and urbanization, local-scale plant biodiversity declines. Less intensive land uses, such as logging, might have positive or negative effects in any given case. When land is no longer used for agriculture, local biodiversity tends to increase, often to levels similar to those observed in primary vegetation.

The most famous study of habitat fragmentation involved the experimental creation of forest fragments of 1 ha, 10 ha, and 100 ha in the Amazon rain forest and the measurement of many ecological variables over the subsequent >30 years ([**53**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). When the investigators ensured equal sample effort or plot area, small fragment size led to sharp declines in the diversity of several taxa—most dramatically birds ([**100**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949))—but not generally for plants. The smallest fragments showed greatly increased tree mortality and rapid community turnover, but the species richness of trees in 1-ha plots was not influenced by fragment size ([**54**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). There was also no significant decline in the diversity of palms ([**90**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)) or ant-dispersed understory plants ([**11**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)), but there was a significant decline for epiphyllous bryophytes ([**129**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Other studies of tropical forest fragments have focused on functional or phylogenetic plant diversity, finding increases, decreases, or no change with fragment size, depending on the metric used or the specific context ([**1**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**61**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**85**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). Given that the generation time of most trees exceeds the duration of these studies, the longer-term consequences of tropical forest fragmentation remain uncertain.

### Local-Scale Conclusions

▪Conversion of primary vegetation to intense agricultural or urban use tends to cause a decline in local plant biodiversity.

▪The effects of other major drivers of plant community change—resource extraction, habitat fragmentation, climate warming, and N deposition—are all highly context dependent.

▪Outside of wholesale agricultural or urban habitat conversion, high context dependence and potentially counteracting forces create massive variation from place to place in temporal plant biodiversity trends, with many places showing increases, decreases, or little or no change.

▪Substantial uncertainty about long-term changes of diversity at local scales remains because of a lack of local-scale studies that span the Anthropocene.

The issue of species composition versus species diversity as targets of conservation comes into clear focus in the case of anthropogenic disturbances, such as logging and [**habitat fragmentation**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949#dl1), both of which are widely considered to be threats to biodiversity. Conservation efforts often focus on preserving or restoring the conditions found in undisturbed habitats, such as old-growth forests, but not typically because such forests harbor greater local plant biodiversity. The only general observation one can make is that disturbances such as logging favor early successional species (e.g., those that require perturbed soil to germinate or high light to grow) over late successional species (e.g., shade-tolerant, slow-growing trees), thus prompting a shift in species composition. However, a large number of early successional species can sometimes increase local plant diversity relative to undisturbed sites in just a few years after logging ([**36**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949), [**76**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)), while in other cases local plant diversity remains lower in successional forests for many decades ([**35**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). More generally, both natural and anthropogenic disturbances can have positive, negative, hump-shaped, or nonsignificant effects on the biodiversity of many different taxa ([**60**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). In short, factors such as logging or fragmentation might decrease the conservation value ascribed to a given site by people, but this is not necessarily accompanied by a decline in plant biodiversity.

BIRDS  
Taken together, our results suggest that land cover change in this agricultural landscape had little impact on temporal beta diversity of bird assemblages. Although other unmeasured deterministic process could be driving the observed patterns, it is also possible that the observed changes in presence/absence species composition of local bird assemblages might be the consequence of stochastic processes in which species populations appeared and disappeared from specific localities in a random-like way. Our results might be case-specific, but if stochastic dynamics are generally dominant, the ability of correlative and mechanistic models to predict land cover change effects on species composition would be compromised.

**Temporal, scales methods**

**Ecological lags**

BOX 1 Biotic lag

Although land-use change, habitat loss and fragmentation often have some

immediate effect on assemblage composition, the full biotic response may take

many years to unfold, a phenomenon that can be termed biotic lag. Biotic lag has

two components. The extinction debt (Tilman et al., 1994) is the number of species

that will be lost from the assemblage but whose extinction is not immediate. In a

study of forest fragments that had become isolated in Thailand, Gibson et al.

(2013) estimated that on average it would take 13.9 years for 50% of resident

small mammal species to disappear after fragmentation, while Vellend et al.

(2006) found that forest plants in the United Kingdom and Belgium still showed

evidence of an extinction debt more than a century after habitat fragmentation.

Immigration credit (Jackson and Sax, 2010) arises because arrival of new species

into the assemblage is likewise not immediate. For instance, dispersal limitation

slows the arrival of plant species into patches of relatively young forest in introduction

experiments (Flinn and Vellend, 2005). Mechanisms for biotic lag have

been reviewed recently by Kuussaari et al. (2009) and Essl et al. (2015). The probability

of a long lag time is lessened at the species level by shorter generation

times and high dispersal ability (Essl et al., 2015; Hylander and Ehrl\_en, 2013)

and at the landscape level through greater site connectivity and availability of

large, stable habitat patches (Kuussaari et al., 2009).

Studies that assume space-for-time substitution cannot fully appreciate

lagged responses, although some have tested for biotic lag by assessing whether

the variation in biodiversity among sites is best explained by current or past pressures

(e.g. Dullinger et al., 2013). Such efforts may be biased if the quality of pressure

data has changed over time, and anyway provide limited insight into the

dynamics of local biodiversity change over time

However, while time series can

provide estimates of net change, this approach is not well suited to understanding

how disturbances and other pressures influence biodiversity, unless

data on pressures are available for the sampling locations and dates, ideally

according to a design such as one of those considered above. Without such

data, the average trend across a set of time series will only correctly estimate

the average trend across the entire region of interest if the sites sampled are

fully representative, in terms of the disturbances or other pressure changes that

they show (Section 3.3). Few data sets if any meet this demanding criterion

(Gonzalez et al., 2016; Vellend et al., 2017).  
Even so, attributing

population changes to a specific impact can be difficult if there are other processes

and drivers that can influence biodiversity (Pechmann and Wilbur,

1994), and/or significant time lags in responses (Box 1).

Gonzalez critique

Alongside evidence of local biodiversity loss, however, a number of papers have shown that human impacts can also increase diversity at sub‐global scales (Stohlgren et al. [**1999**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0053), Sax et al. [**2002**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0050), McKinney [**2008**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0038), Ellis et al. [**2012**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0018), Elahi et al. [**2015**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0016)). The success of some species in human‐dominated landscapes (Aronson et al. [**2014**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0001)), increases in local diversity due to disturbance (DeVictor and Robert [**2009**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0013)), and the spread of exotic species (e.g., Bruno et al. [**2004**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0006)) are all examples. When these additions match or outpace the rate of local species extinctions, then diversity in any particular location can stay the same (Byrnes et al. [**2007**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0008)), increase (Sax et al. [**2002**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0050), Elahi et al. [**2015**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0016)), or show high rates of species turnover (Dornelas et al. [**2014**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0014)).

Here we challenge the conclusions of these two syntheses on three grounds: (1) we present new analyses showing the datasets assembled for these syntheses exhibit extreme spatial bias, and are not globally representative of species richness or human impacts on ecosystems that influence biodiversity; (2) we reanalyze these data and detect a signal of study duration on biodiversity change, indicating net biodiversity loss is most apparent in studies of longer duration. Ancillary simulations show that trends estimated with short time series can be biased; (3) we show why a lack of appropriate historical baselines or spatial references precludes these studies from accurately characterizing species richness change due to humans. After laying out our critique, we reflect on some lessons learned from these syntheses, and describe new challenges in accurately quantifying changes in biodiversity on this planet.

The observational data reported by Vellend et al. ([**111**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)) provide limited scope for assessing underlying causes and cover almost exclusively the twentieth and twenty-first centuries. All of the individual studies concerned sites that had not undergone major land-use transitions during the period of study. However, many studies were conducted in anthropogenically altered habitats (e.g., pastures or urban areas) or had been subject to disturbances of various kinds—climate change, species invasions, etc. In other words, although this was not a sample of pristine sites, the sites remained the same habitat type during the period of study, consistent with the original motivation to combine the results with experimental studies of how biodiversity influences [**ecosystem functions**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949#dl1), essentially all of which share this feature ([**39**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). As described below, major land-use transitions often cause major losses to local-scale plant diversity ([**69**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)). What the results of Vellend et al. ([**111**](https://www.annualreviews.org/doi/10.1146/annurev-arplant-042916-040949)) suggest is that in the absence of major land-use transitions, local-scale plant diversity in any given ecosystem has been just as likely to increase as it has been to decrease over the past century or so, with many places showing no significant temporal trend at all. Exceedingly few local-scale data are available to assess changes prior to the twentieth century, with relatively few for even the first part of the twentieth century.

Lack of before after disturbance comparison

Lastly, the Vellend et al. ([**2013**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0058)) and Dornelas et al. ([**2014**](https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/15-1759.1#ecy1427-bib-0014)) data syntheses point to a challenge we must meet if we are to accurately quantify diversity change on the planet. 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.

The timing, magnitude and order of stresses can cause different responses by populations.

 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.

Community self regulation

Current theory seems inadequate to explain the observed phenomenon of widespread community regulation. A better understanding of why communities are regulated is important to discern and predict whether communities can persist in the face of large anthropogenic impacts ([**33**](https://advances.sciencemag.org/content/3/7/e1700315#ref-33), [**45**](https://advances.sciencemag.org/content/3/7/e1700315#ref-45)) or whether they are about to collapse or disassemble. Better understanding of which aspects of communities are regulated (abundance and richness in this paper) and not regulated [species composition in Dornelas et al. ([**35**](https://advances.sciencemag.org/content/3/7/e1700315#ref-35))] is also important in predicting how the ecosystem functions that humans depend on will be altered. Finally, the existence of regulation at the community level highlights the need to study human impacts on whole communities, not just on selected species or populations. Long-term measurements of key shared resources and physiological tolerances of the species that appear and disappear through time should provide new insights into the details of community regulation and may guide strategies for managing assemblages in the face of strong environmental change.

Habitat conversions corresponded with both gains and losses in population and biodiversity change, with turnover being highest when primary forests were converted to agricultural and urban areas

Visual inspection of the distributions of population and 608 biodiversity change does not suggest directional patterns for any specific land-use transition 609 types

Outline discussion

* Complexity real world changes
* Interactions between different effects of human impacts
* Indirect large-scale human impact
* Limitations
* Further studies

Complexity real world changes of biodiversity and in particular of temporal turnover

* Narrative so far: human impact leads to biodiversity decline
* Global assessments have found declines with land-use changes, but used space-for time which has been criticised (Gergana)
* Importance temporal turnover -> reveal complexity of real world changes
* Expected high accessibility leads to more temporal turnover, because human impacts associated with accessibility have been found to increase extinction and immigration -> Explanation temporal turnover: extinction, immigration
* Recent studies that have looked at temporal turnover as well (Gergana) have also found high complexity
  + increase turnover after forest loss
  + lower turnover with increasing forest gain
  + but no significant effect of magnitude of forest loss on turnover
  + turnover of habitat conversions being highest when converted to agriculture and urban areas
* Temporal turnover not as straight forward because
  + Mismatch
  + Ecological lags
  + Not full spectrum of accessibility captured

Potential interactions of drivers associated with acc and other drivers (combine with taxa?)

* Possible antagonistis effects between different kind of human impacts captured with the metric accessibility and at what scales they influence species
* Ongoing debate about habitat fragmentation and their impact on species
* Taxa mobility, specialisation paragraph
* Important consideration when scaling from local to global
* But then also other drivers such as climate change and how they interact, potential confounding effects in this study

Indirect large-scale human impact

* Despite all shortcomings mentioned, it still seems that turnover is higher at lower accessibility
* That could indicate higher basline of temporal turnover and reduction of it through human activity (but baseline supposedly lower + exploration of potential interactions mentioned before)
* Or that we don’t really understand temporal dynamics at low impact areas compared to large scale human impacted areas
* Other studies have focussed on direct changes such as land-use transition or forest loss, but I look at more general large scale human impact
* Studies focussing on wilderness say reduces extinction risk, but also only use modelling approaches
* Indicates we need to obtain better understanding of whats going on in wilderness areas as well with real world data

Limitations

* Uneven sampling blabla
* Validity of accessibility but better than HPD?

Notes Intro

So far richness and population, but importance turnover as it relates to immigration and extinction; importance real world data