Using museum records to infer changes in insect communities over time

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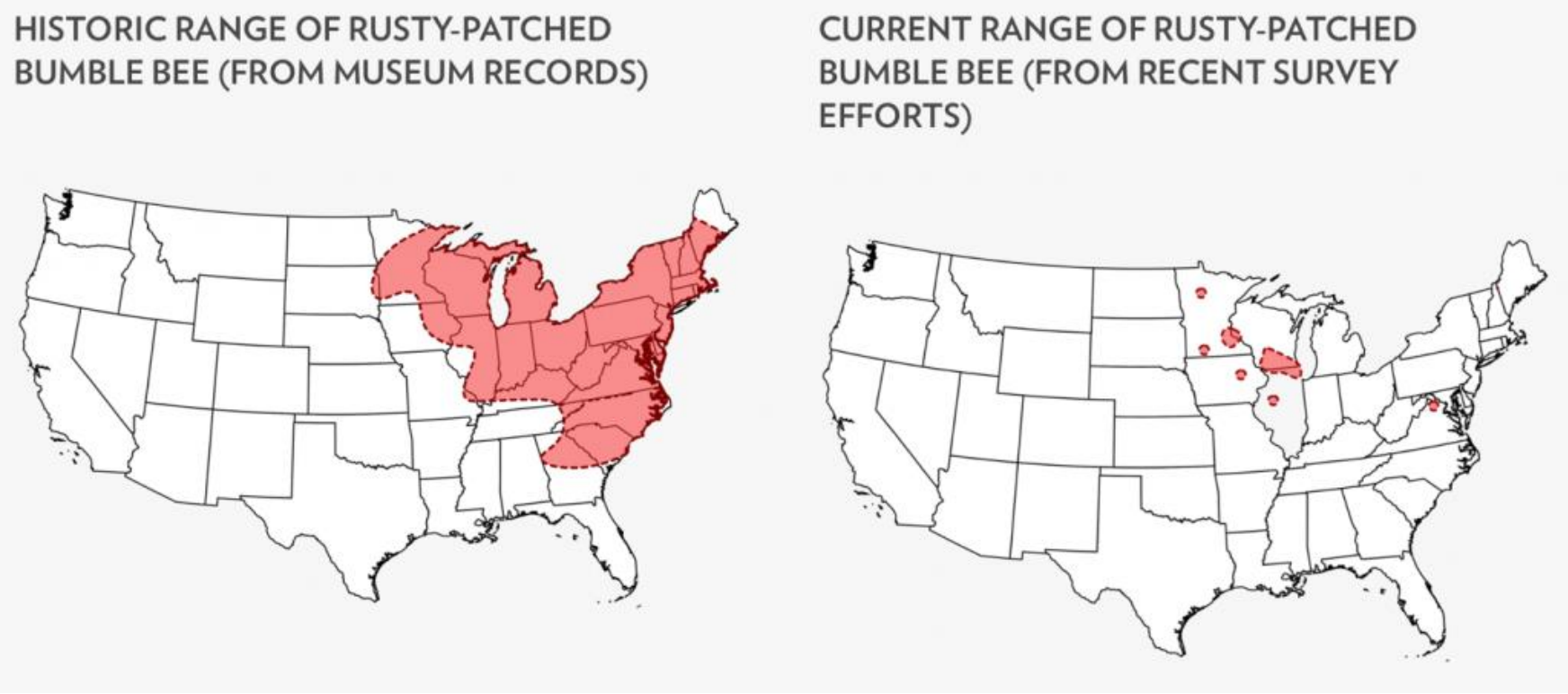
Global declines in insect populations

Reported declines in abundance, richness, and biomass of insects
(Hallmann et al. 2017; Seibold et al. 2019; Grixti et al. 2009; Potts et al. 2010)

- Rusty-patch bumble bee (Colla and Packer 2008)



Bombus affinis Cresson

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(Hallmann et al. 2017; Seibold et al. 2019; Grixti et al. 2009; Potts et al. 2010)

- Rusty-patch bumble bee (Colla and Packer 2008)

Stable or increasing populations of insects also reported
(Shortall et al. 2009; Fox et al. 2014; Crossley et al. 2020; Schowalter et al. 2021)

Bombus impatiens Cresson

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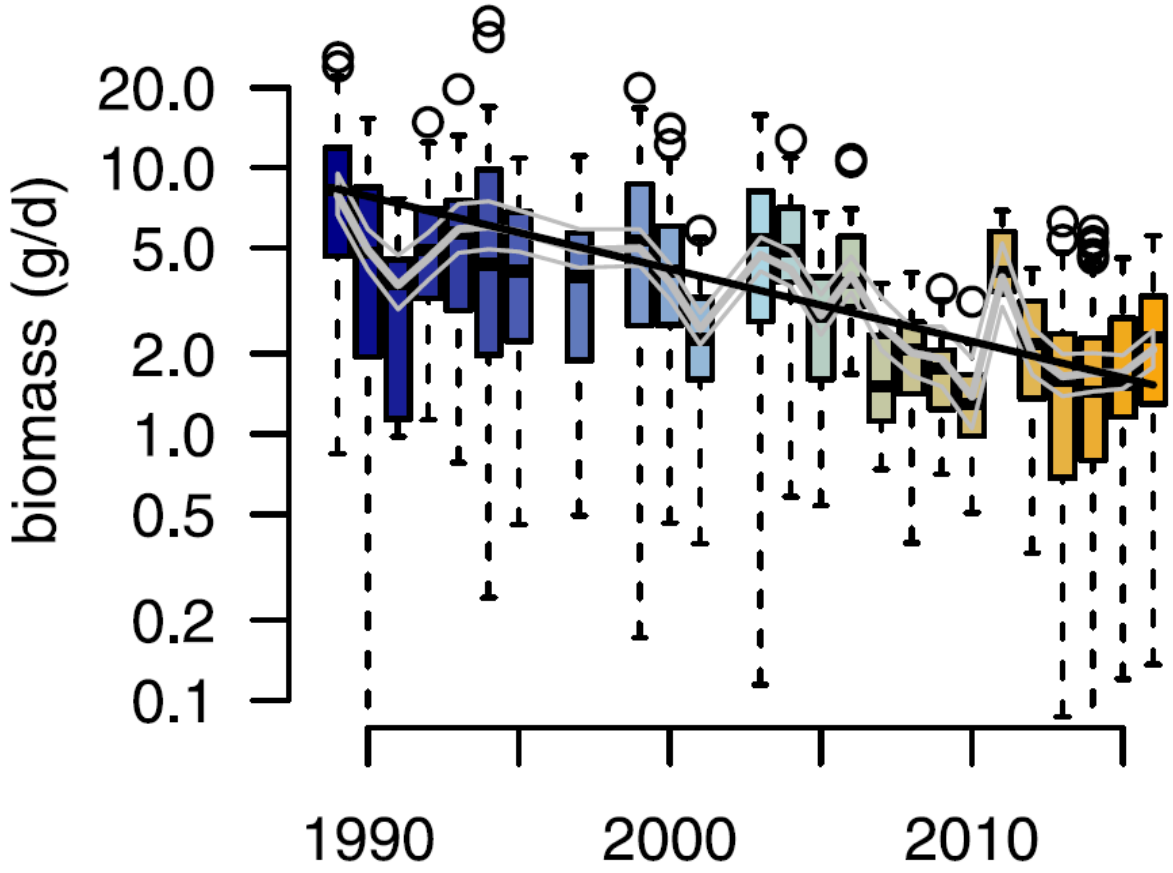
Are observed declines generalizable across space or insect taxa?

Bombus impatiens Cresson

Long-term studies reporting declines in insect populations

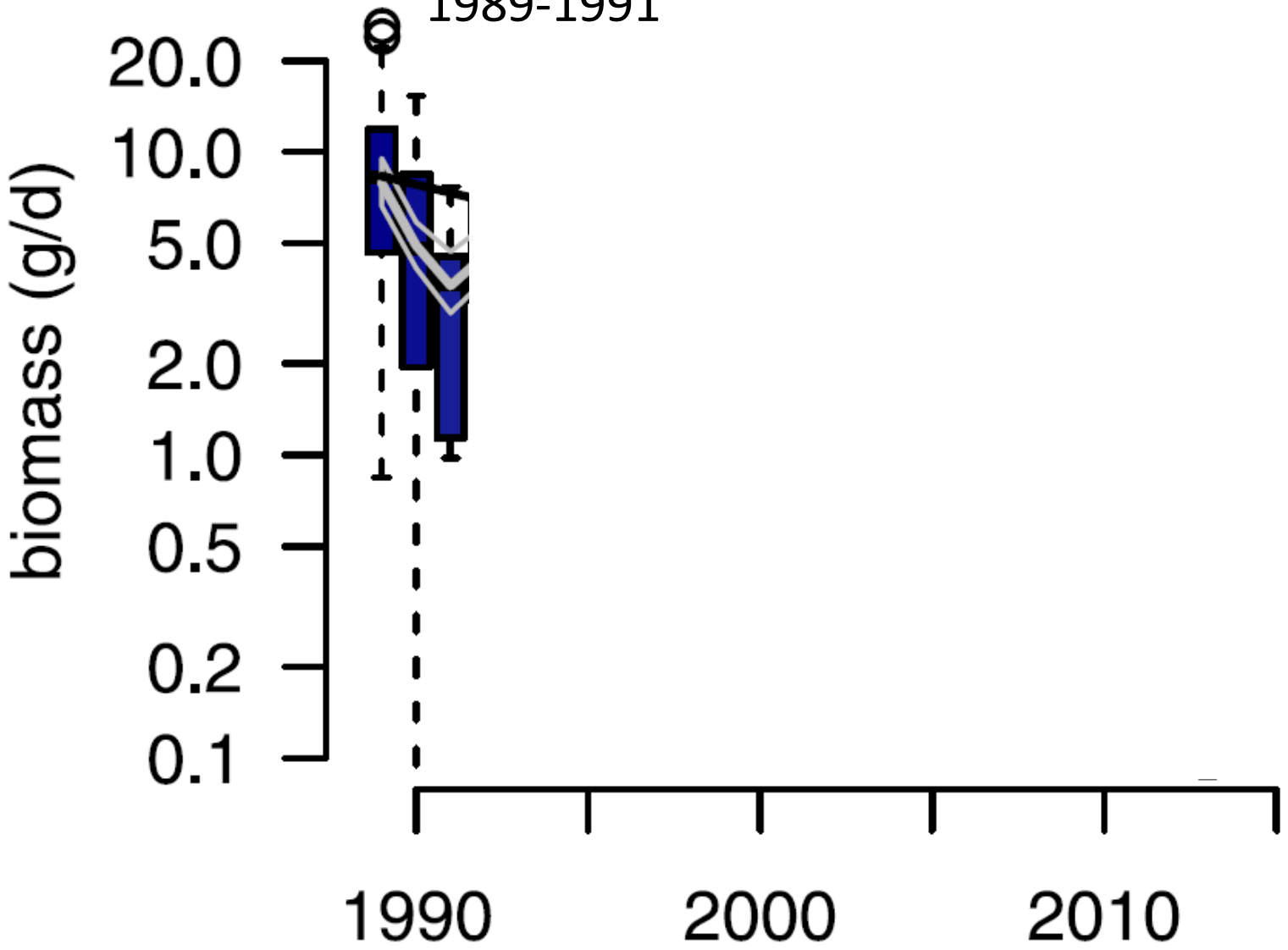
Flying insect biomass in nature reserves in Germany



Hallmann et al. 2017

Malaise trap

Long-term studies reporting declines in insect populations



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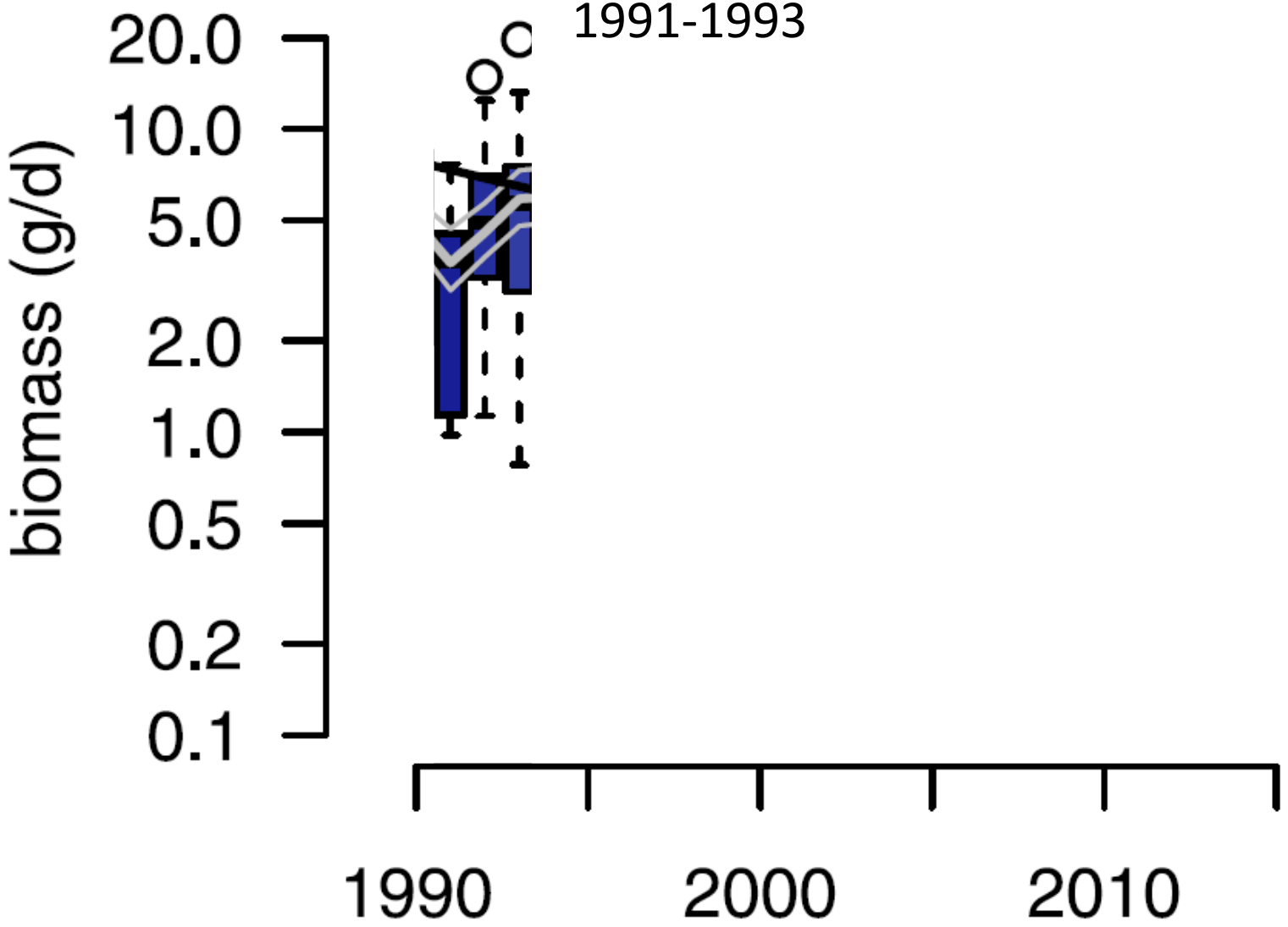
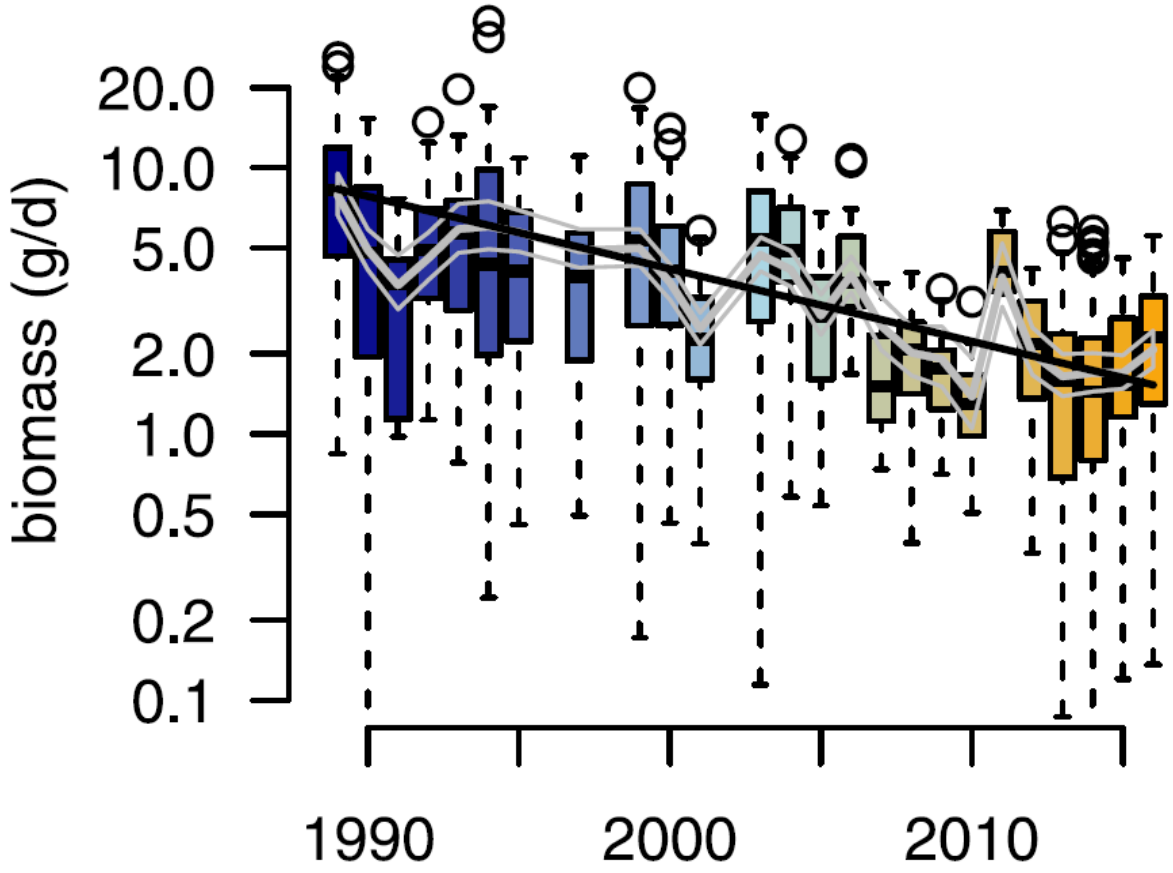


Hallmann et al. 2017

Need long-term data to separate yearly variation from multi-year trends

Flying insect biomass in nature reserves in Germany



Hallmann et al. 2017

Malaise trap

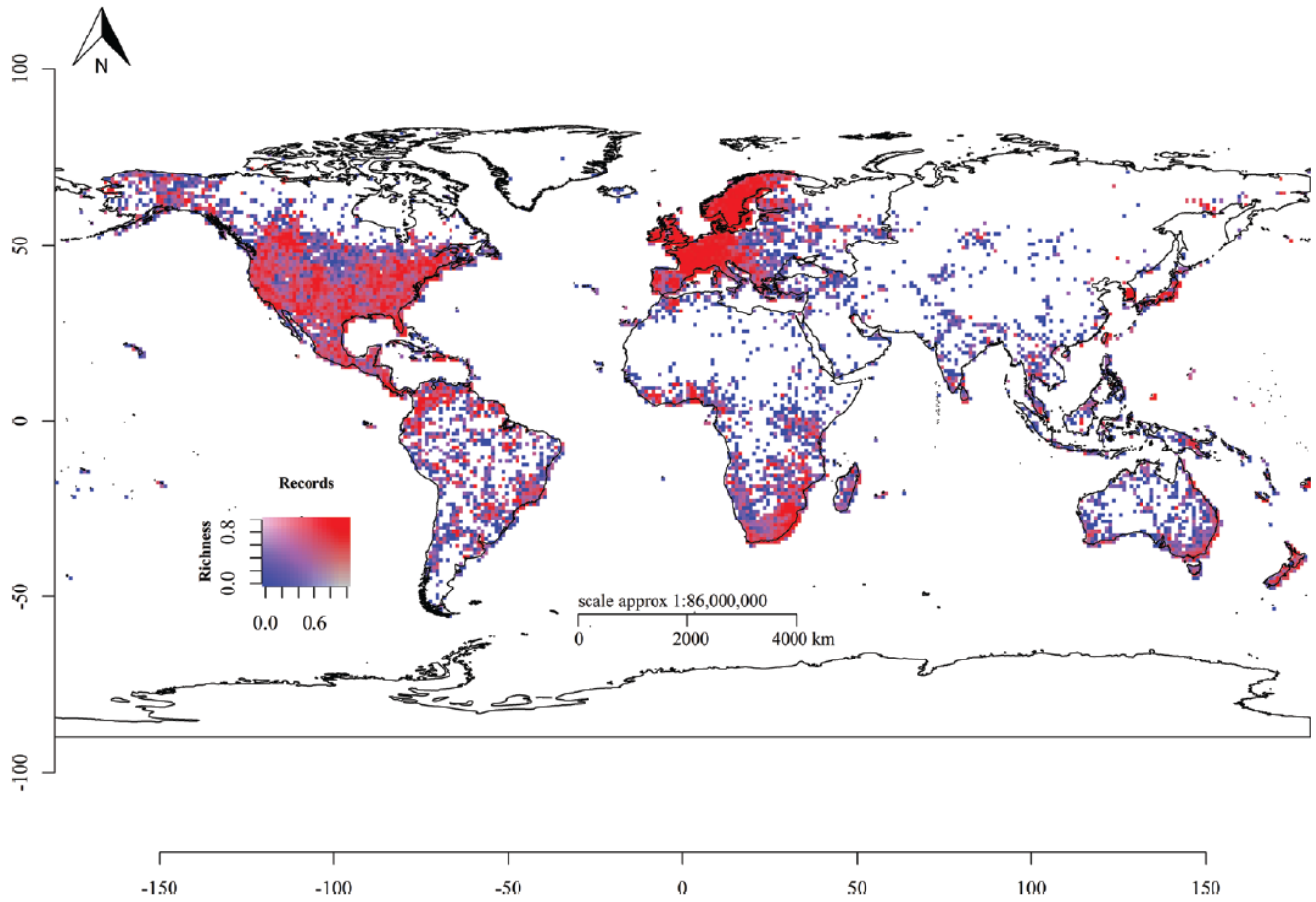
Challenges to understanding insect populations and detecting decline

Length of the study (short vs long)

Geographic and habitat biases

Taxonomic biases

Taxonomic resolution
(Order, family, species)



Rocha-Ortega 2021

Use of museum specimens to study shifts in communities over time

Data deficiencies: low taxonomic resolution, geographic restrictions, short time series (Sánchez-Bayo & Wyckhuys 2019; Thomas et al. 2019; Didham et al. 2020)

Biological collections represent unique source of historical data
(Sánchez-Bayo & Wyckhuys 2019; Thomas et al. 2019; Didham et al. 2020)

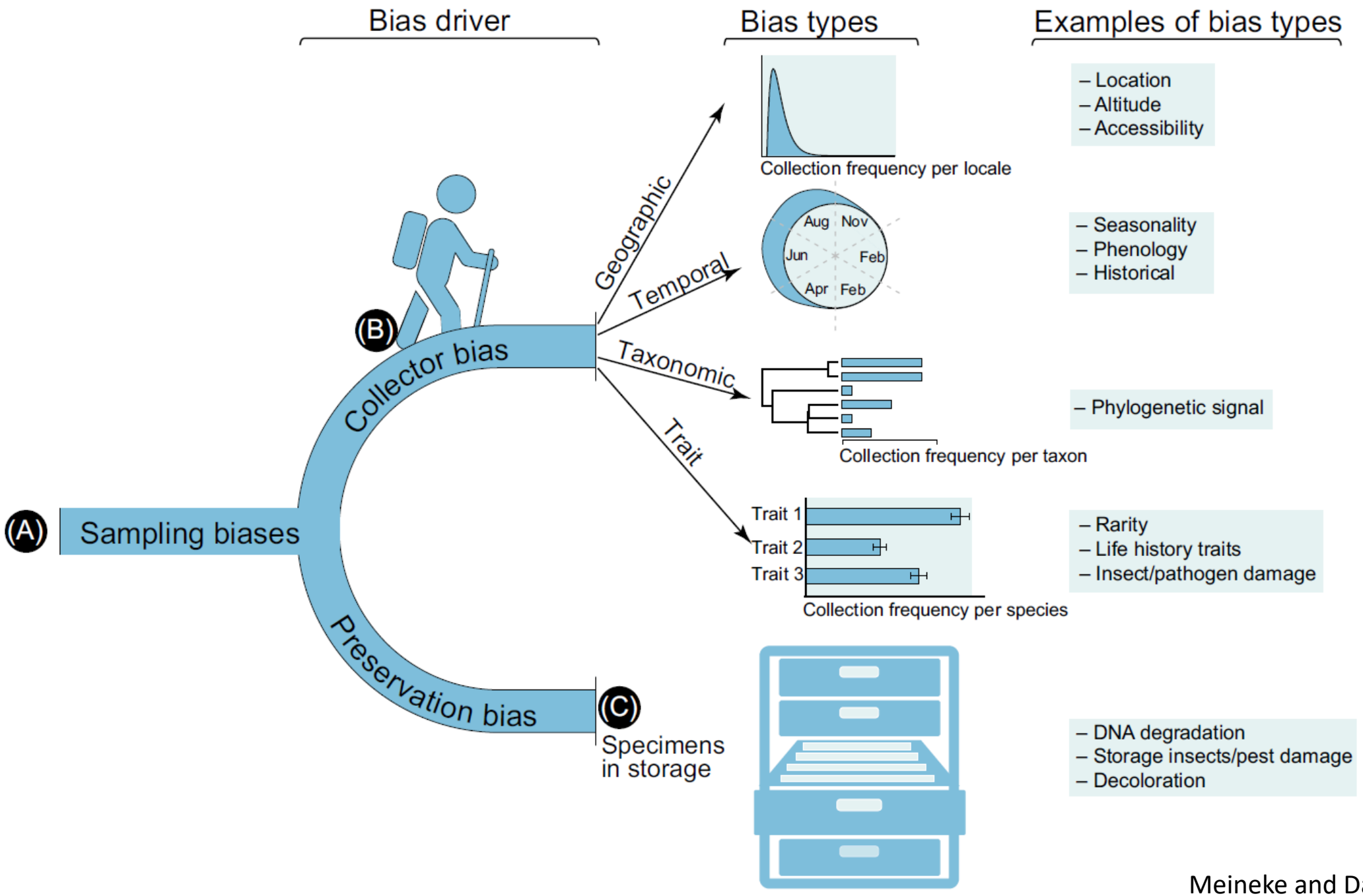
- Greater spatial and temporal scales (Lister 2011; Kharouba et al. 2019)

Baseline to investigate anthropogenic drivers
(Suarez & Tsutsui, 2004)

© Luciana Musetti, Triplehorn Insect Collection

Challenges to using specimen record-based data

Geographic, taxonomic, and temporal biases that result in nonrandom collections
(Boakes et al. 2010; Meineke & Daru 2021)



Meineke and Daru 2021

Challenges to using specimen record-based data

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(Boakes et al. 2010; Meineke & Daru 2021)

Collections data cannot track the absolute abundance of insects over time
(Ries et al. 2019)

Collections data can assess changes in captures of insects over time

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Collections data can assess changes in captures of insects over time

Use historical records to compare relative captures (or observations) among species over time

- Directional change (increase vs decrease) in captures

Native lady beetle decline

Predators of aphids, scales, psyllids, mites, fungi, and other pests
(Evans 2009; Hodek & Honěk 2009; Weber & Lundgren 2009)

Biological control in agroecosystems
(Caltagirone & Doutt 1989; Obrycki & Kring 1998; Rondoni et al. 2021)

Declines of native species across US and Europe
(Alyokhin & Sewell 2004; Harmon et al. 2007; Roy et al. 2012; Brown & Roy 2018)

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1) Exotic lady beetles

2) Landscape change

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High year-to-year variation in lady beetle abundance
(Elliott et al. 1996; Honěk et al. 2014)

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OBJ: Investigate relative importance of exotic species and landscape change as drivers contributing to changes in lady beetle communities

Evaluate long-term patterns in native lady beetle species occurrence in Ohio

(1) Characterize changes in lady beetle communities and land cover over time

(2) Evaluate responses of native lady beetle species

Landscape change and alien invasions drive shifts in native lady beetle communities over a century

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Infer changes in lady beetle communities using museum specimens

Broad search for lady beetle records from Ohio

- Contacted 59 institutions based within the United States

Historic occurrence records collected from 1900-2018

- Records from 25 institutions across the US
- Native and exotic species

Tribe Coccinellini and four commonly collected species within Hyperaspidini, Chilocorini, and Psylloborini

ECN

Entomological Collections Network

Compiled lady beetle records from Ohio

For unidentified lady beetle specimens, requested loans to make identifications

Lady beetle specimens that were unaccounted for within the collections were not included in our data set

Lady beetle records included in analyses:

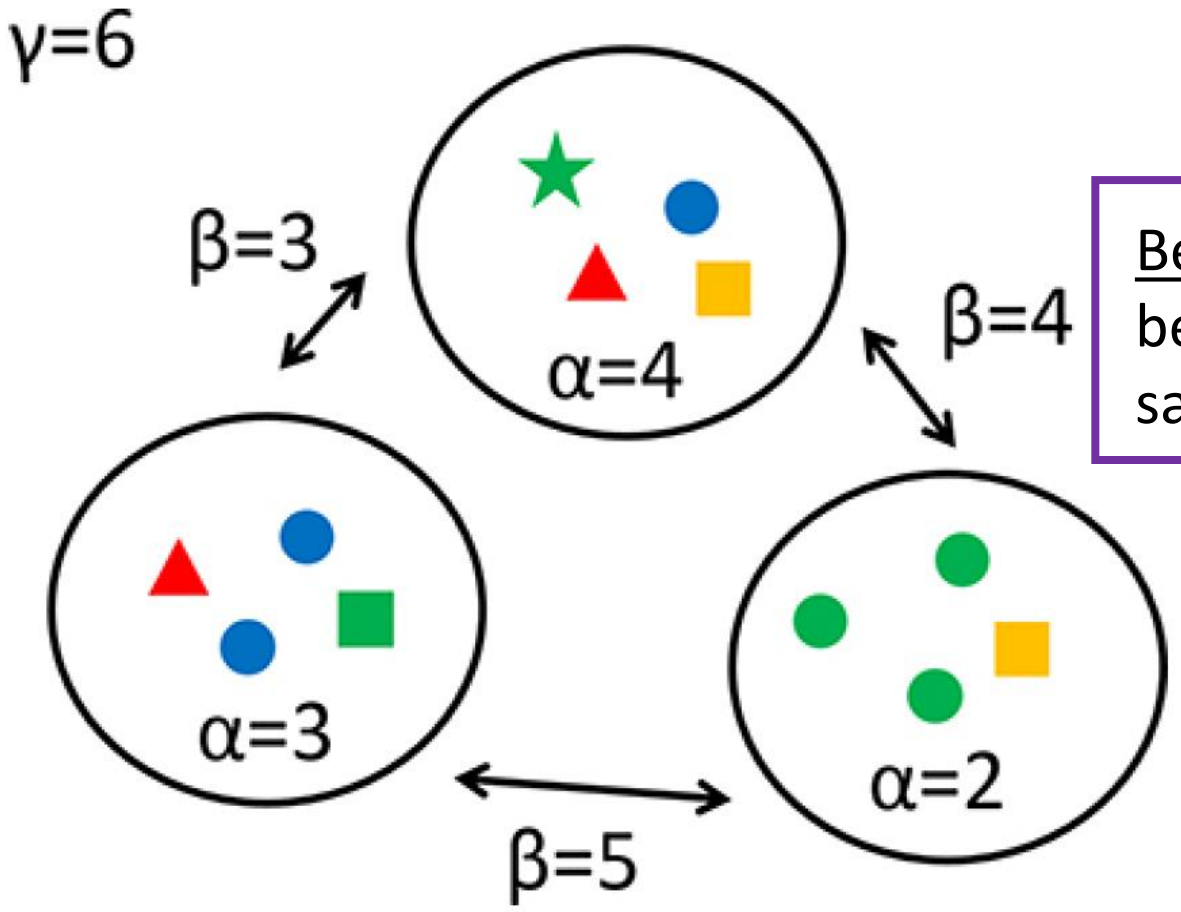
- Collected within Ohio
- County-level location
- Year of collection

ECN

Entomological Collections Network

(1) Characterize changes in lady beetle communities over time

Gamma diversity (γ) = total number of species across all habitats within a landscape



Beta diversity (β) = diversity between habitat patches, samples, or sites.

Alpha diversity (α) = diversity within a particular habitat patch, sample, or site.

Figure 5. Illustration of the concept of alpha, beta, and gamma diversity. Colored symbols represent species, circles represent habitat patches, and the large rectangle represents the landscape.

Sirami 2016

Nonmetric multidimensional scaling (NMDS) analyses

Used to assess differences in species composition among sites, treatments, etc.

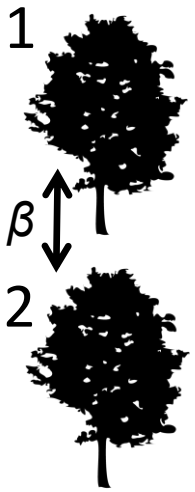
Based on a distance (dissimilarity) matrix as a measure of **beta-diversity**

Represents (as well as possible) the ordering relationships among sites in species space

Iterative method that maximizes the rank order correlations between the distances in the dissimilarity matrix and the distances in low-dimensional space

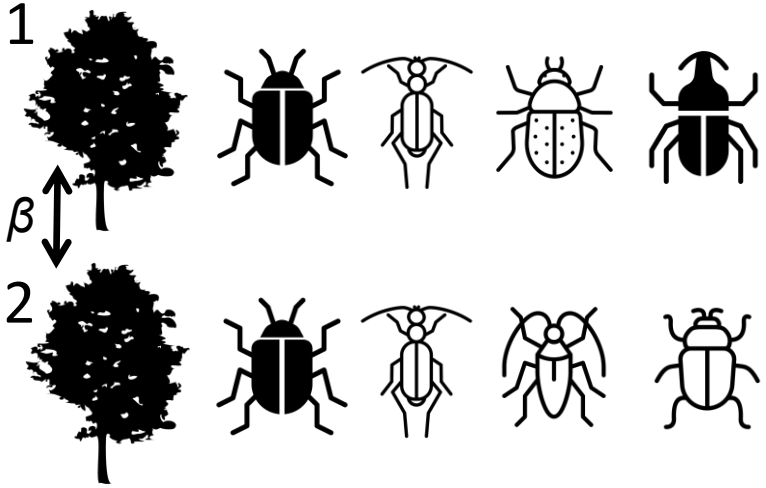
Robust technique – no assumptions of normality or linear relationships among variables

Changes in beta-diversity can be driven by turnover or nestedness



Changes in beta-diversity can be driven by turnover or nestedness

Turnover: Species Replacement



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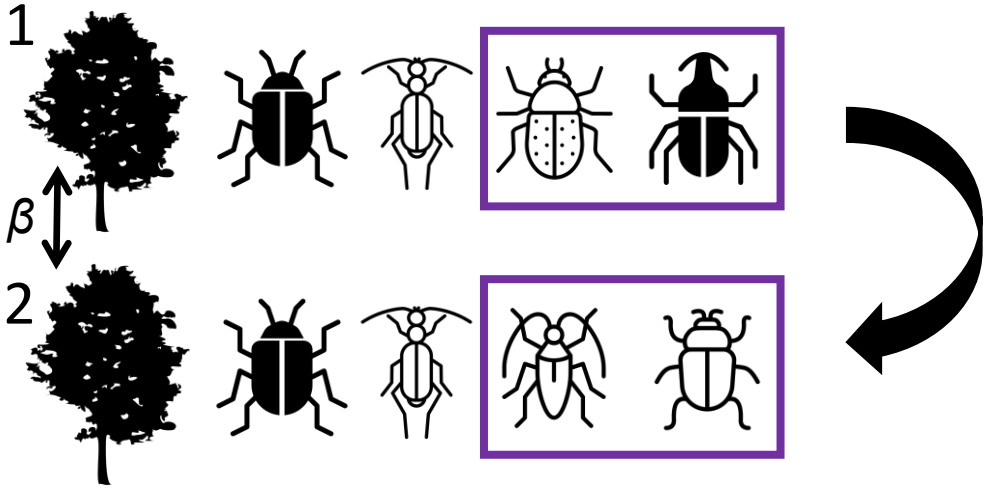
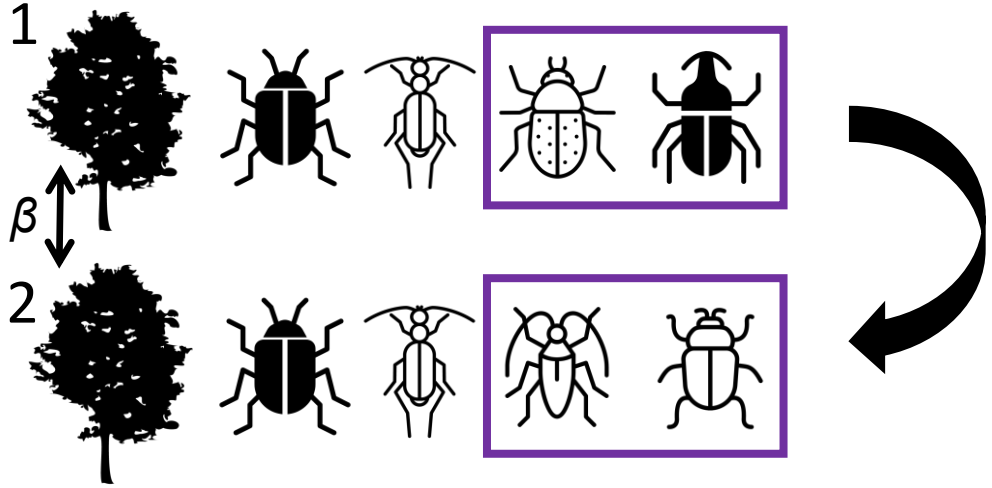


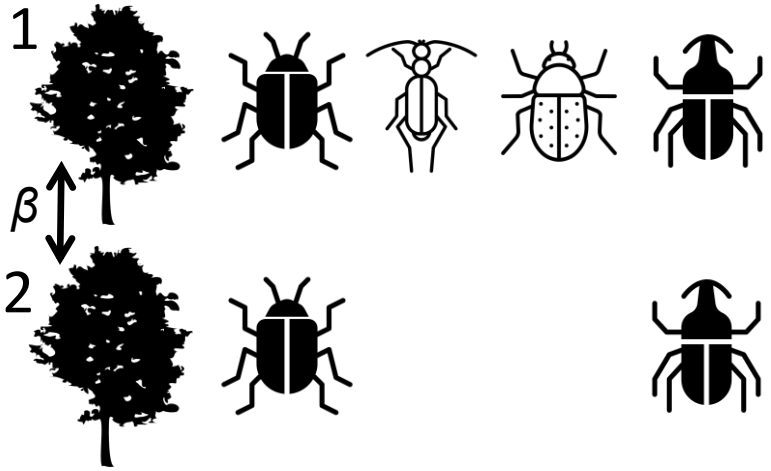
Similar number of beetle species were collected on each tree, but a low number of these species were shared among trees

Changes in beta-diversity can be driven by turnover or nestedness

Turnover: Species Replacement



Nestedness: Species Loss/Gain



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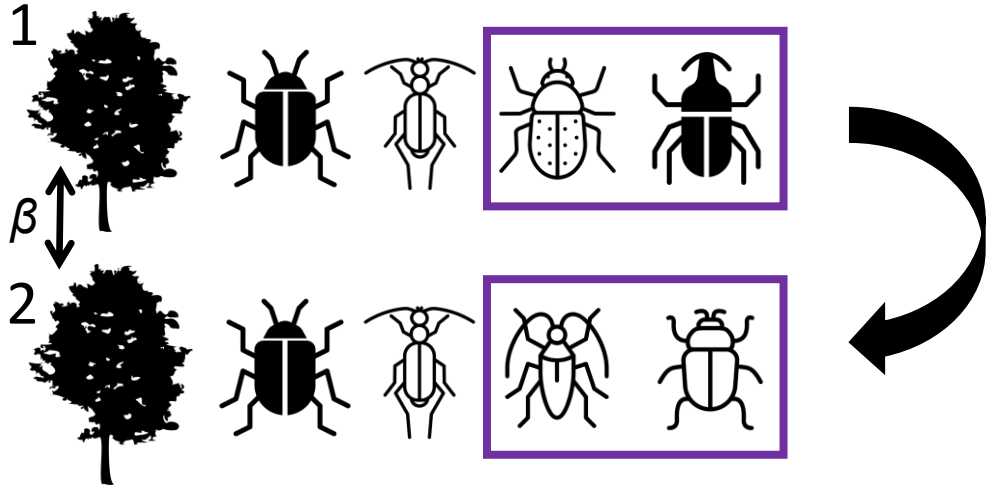

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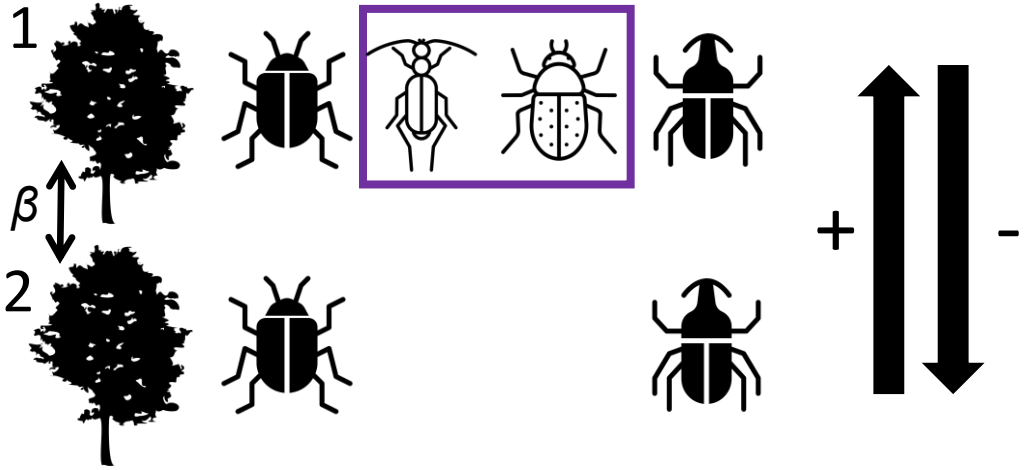

More beetle species were collected on tree 1 such that tree 2 is a subset of the species collected on tree 1

(1) Characterize changes in lady beetle communities over time

Changes in lady beetle community composition over time were visualized by nonmetric multidimensional scaling (NMDS) analyses

- Data were compiled at the county level and pooled across decades
- R package ‘vegan’ (Oksanen et al. 2011)

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- R package ‘vegan’ (Oksanen et al. 2011)

Partitioned community composition to investigate turnover and nestedness

- Data pooled across counties and across 10-yr intervals
- R package ‘betapart’ (Baselga and Orme 2012)

(2) Evaluate responses of native lady beetles to exotic species and landscape change

Negative binomial generalized additive models (GAMs)

- Assess relative influence of drivers: temporal, spatial, landscape, and exotic species

Fit global model for each species with all variables, then determined best-fit model via model selection procedures

- R package ‘mgcv’ (Wood 2011)

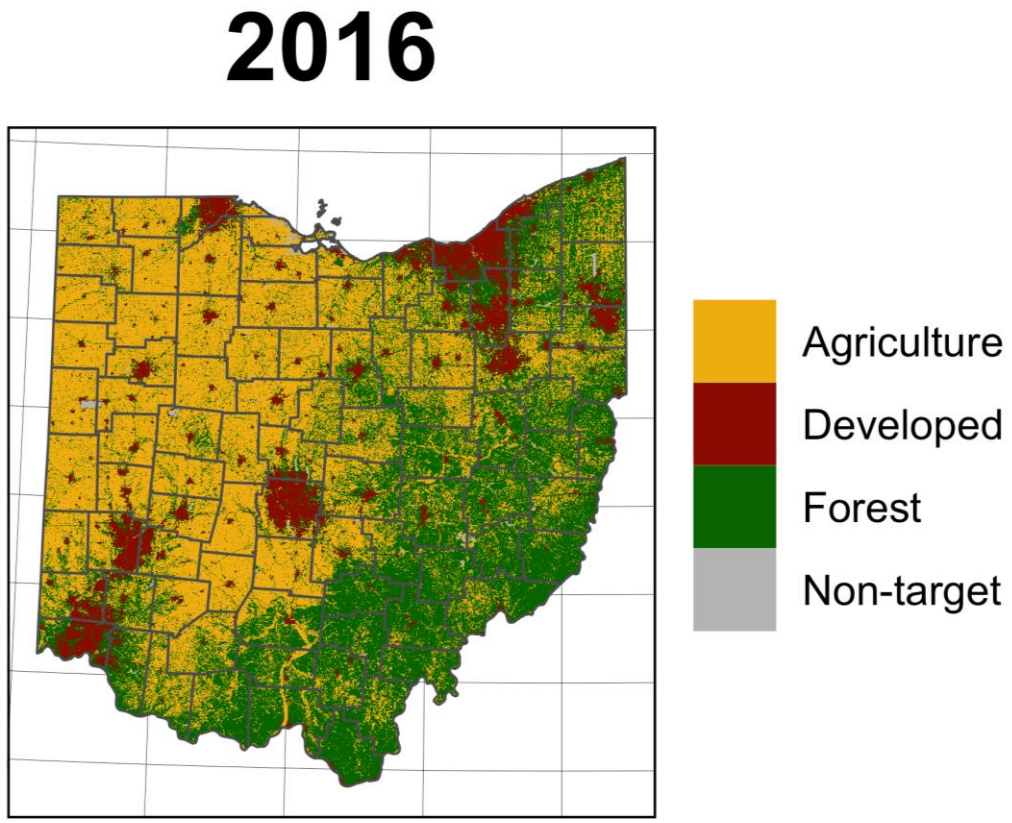
Benefits to using a GAM framework:

- Handle non-linear relationships
- Account for dependence in data (spatial & temporal autocorrelation, hierarchical structure

OBJ: Investigate relative importance of exotic species and landscape change as drivers contributing to changes in lady beetle communities

Land use land cover data obtained from US Geological Survey and National Land Cover Database (1938, 1970, 1992, 2016)

- Total cover of agriculture, developed, and forest
- Compiled at county and decade resolution



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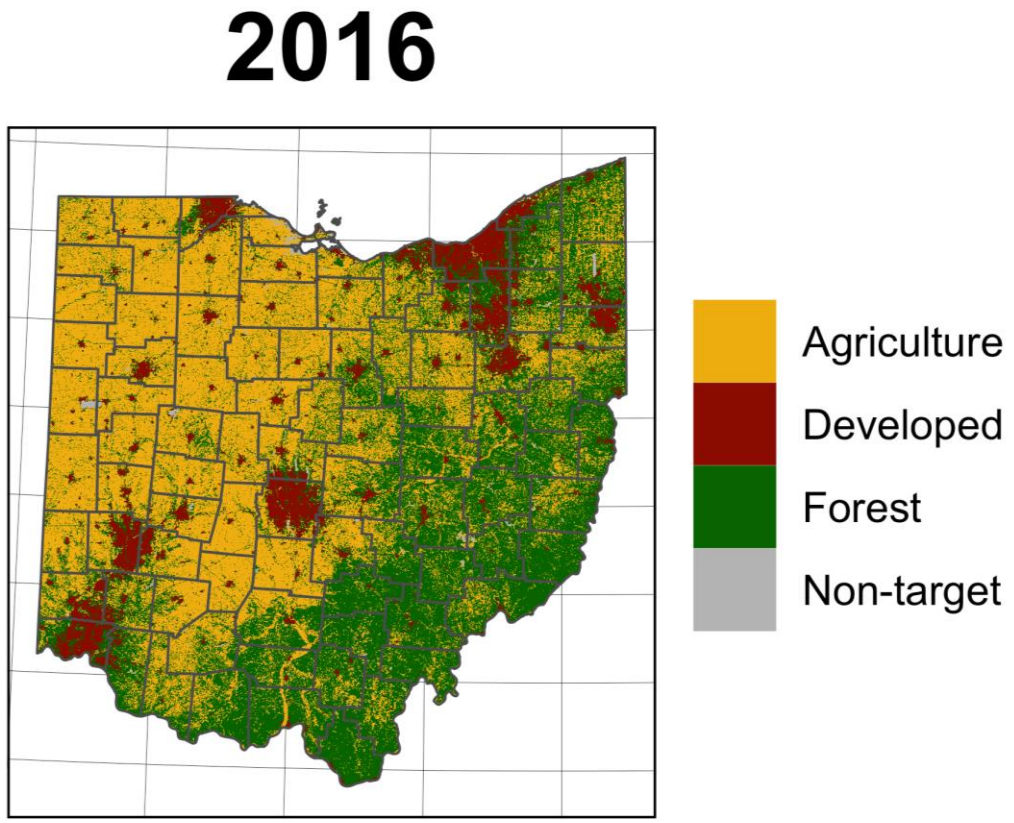
Exotic lady beetle captures represented within specimen records

- Proportion exotic captures
- *Harmonia axyridis* & *Coccinella septempunctata*



4,194 Ohio records from 25 institutions across the US

23 native lady beetle species recorded in Ohio from 1900 - 2018

Hippodamia convergens
400

©Mike Quinn, TexasEnto.net

Adalia bipunctata
218

©Mardon Erbland, Bugguide

Coccinella novemnotata
169

©Mike Quinn, TexasEnto.net

5 exotic species recorded in Ohio

Coccinella septempunctata
1978

©Mike Quinn, TexasEnto.net

Harmonia axyridis
1993

©Mike Quinn, TexasEnto.net

Propylea quatuordecimpunctata
2003

©Tom Murray, Bugguide

Hippodamia variegata
2000

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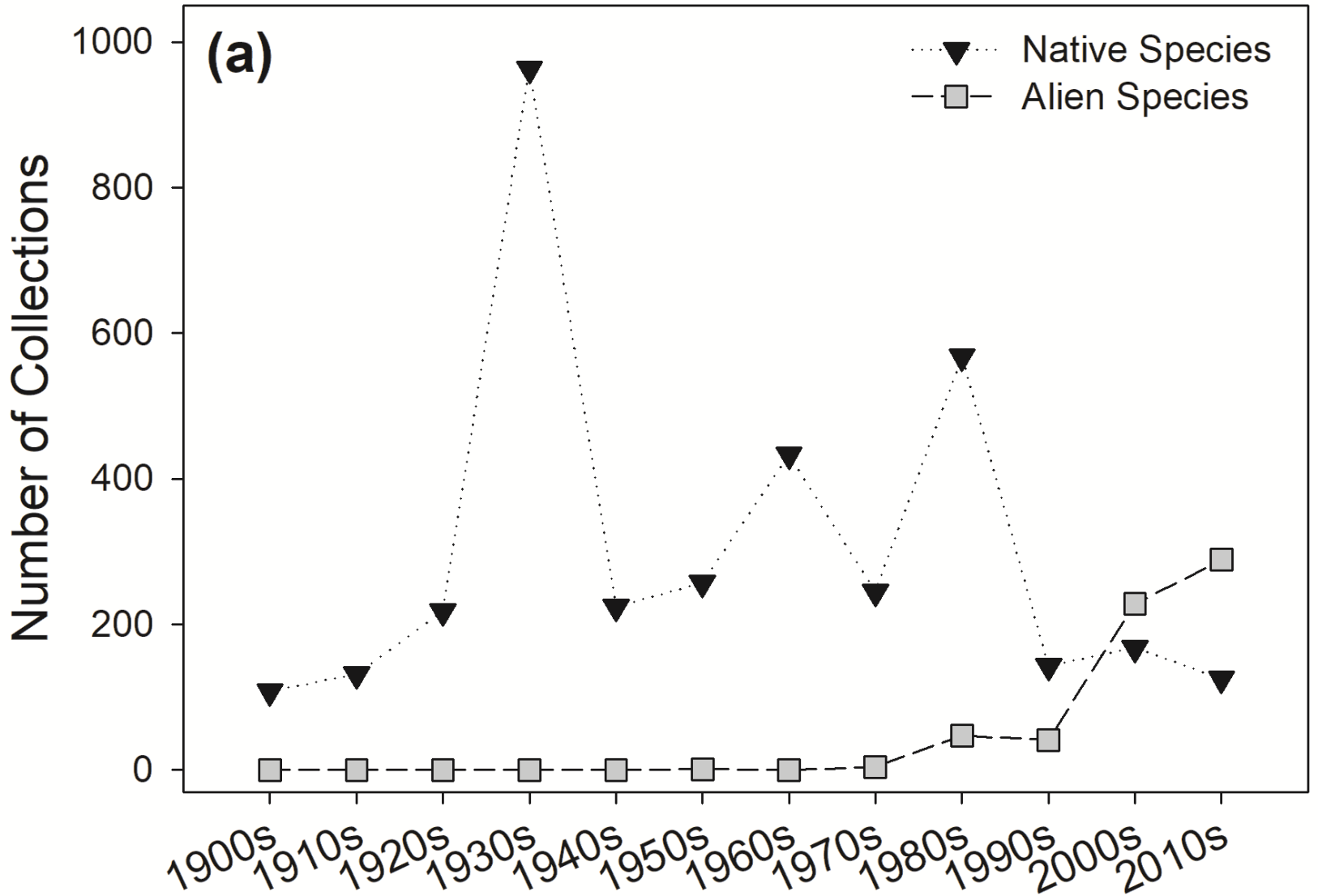
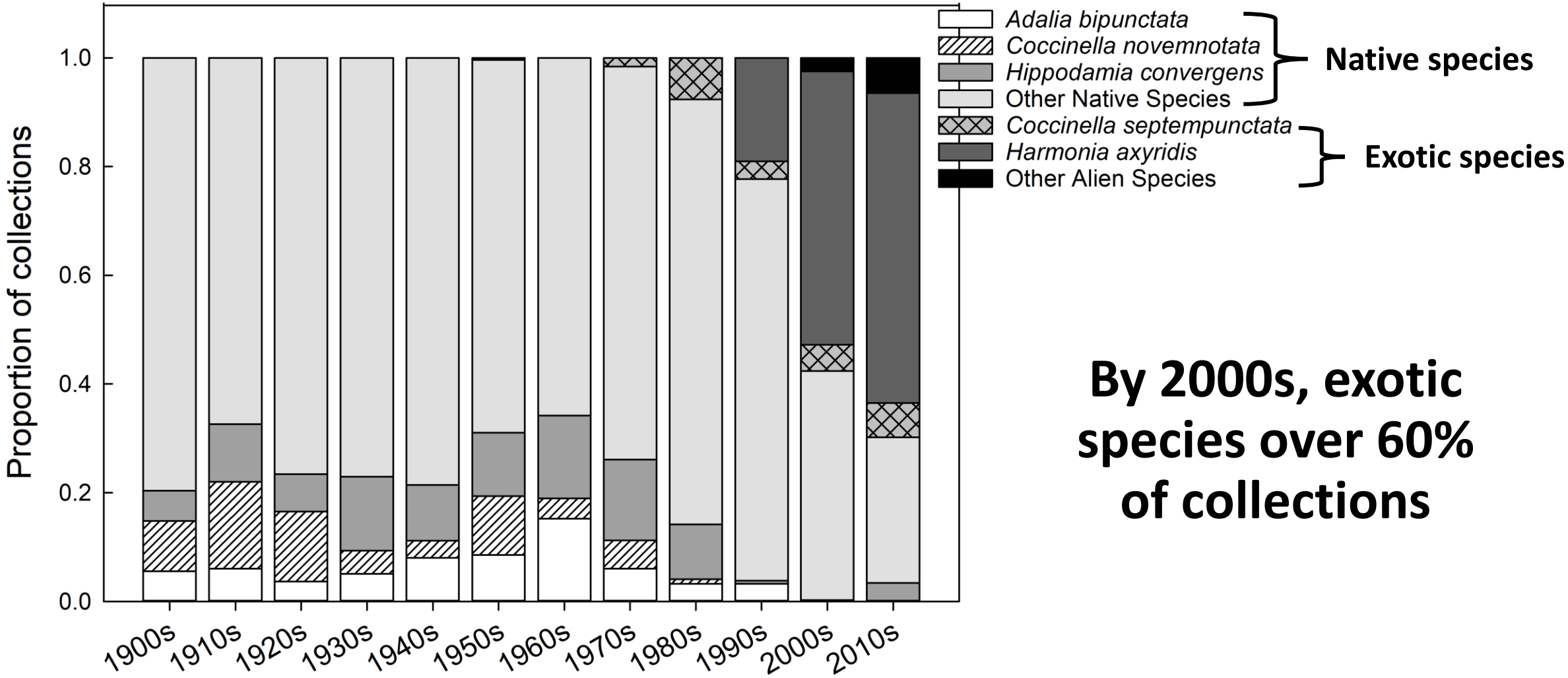
Coccinella undecimpunctata
1953

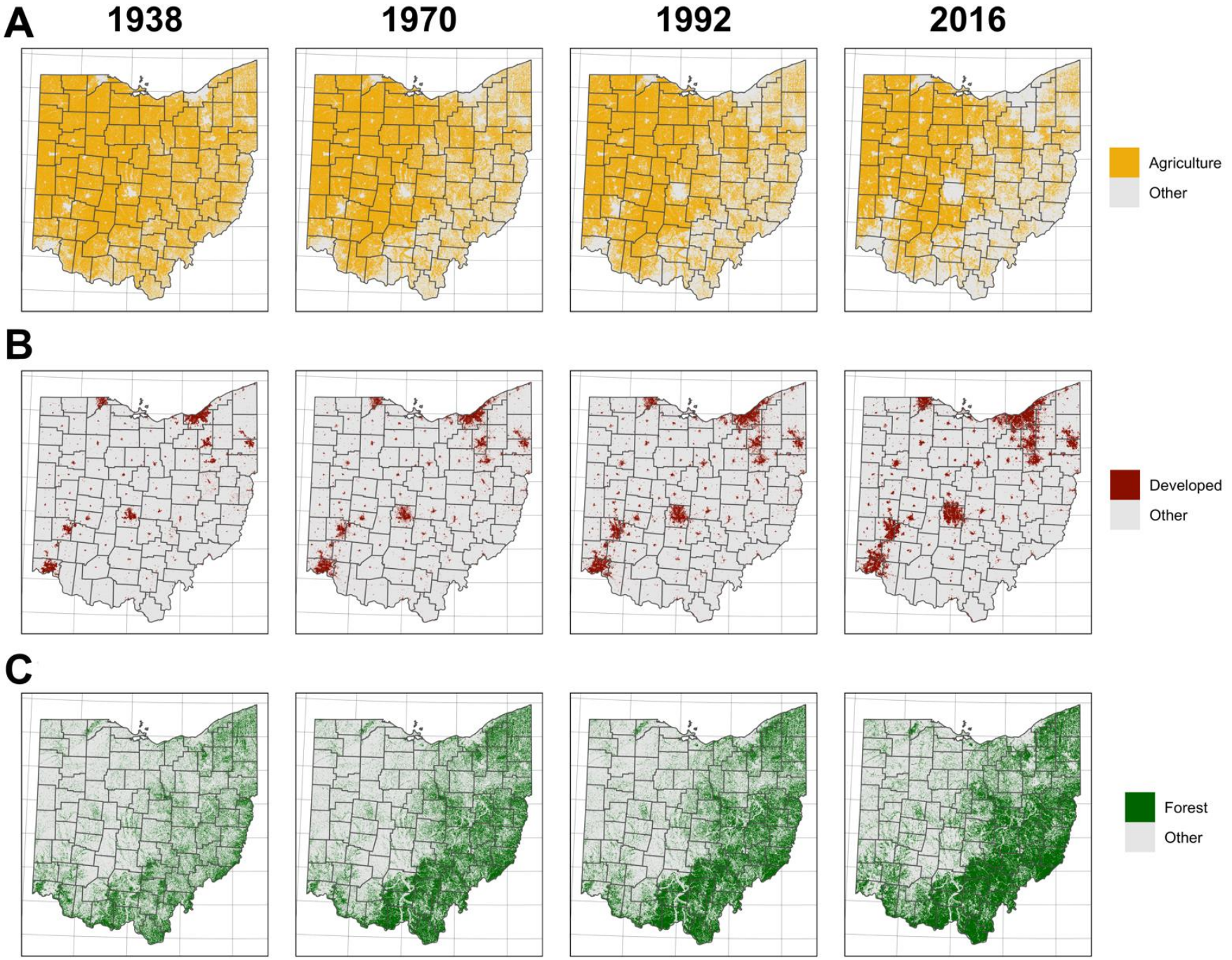
Captures of native species varied from year to year



Since 1980s – proportion of native lady beetles in collections decreased as exotic species increased



By 2000s, exotic species over 60% of collections

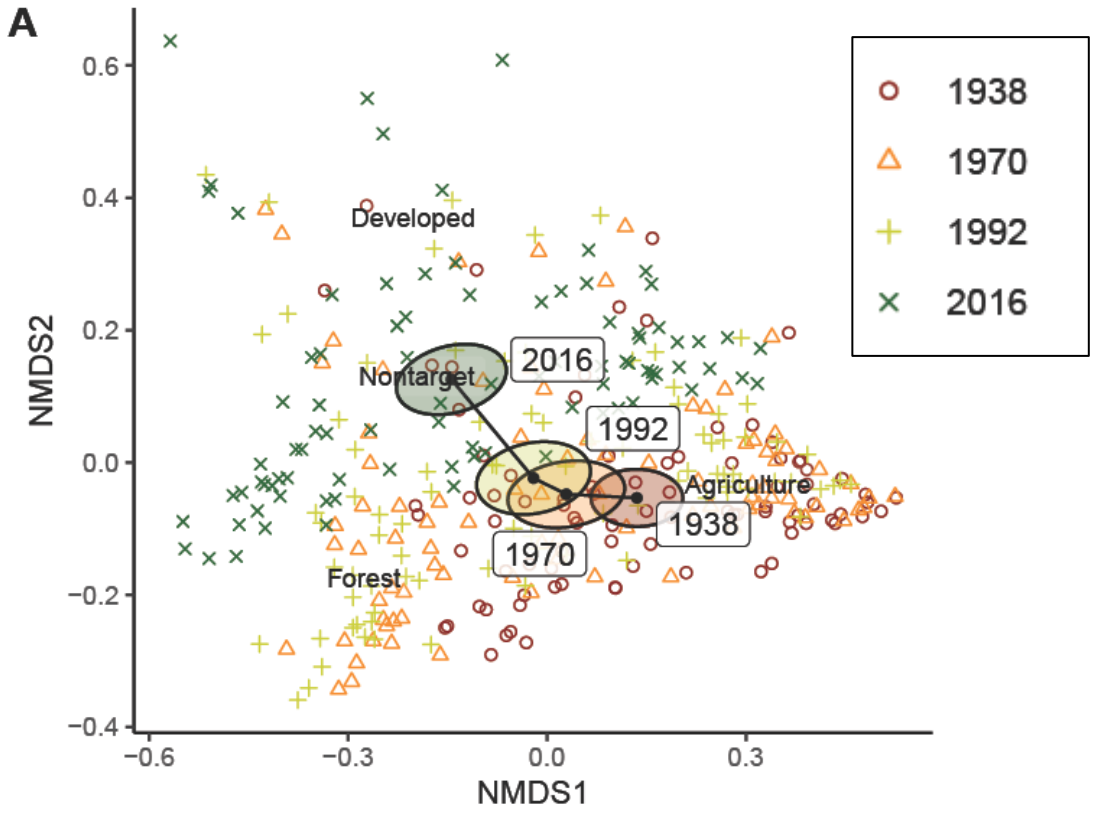


Decreased agricultural land cover

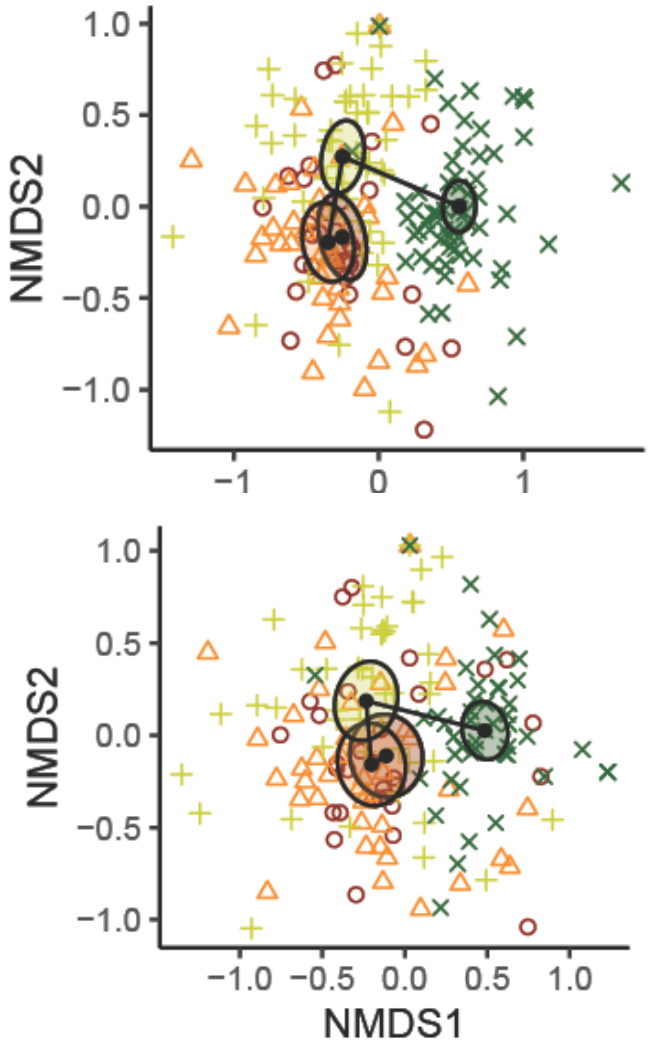
Increased urban and forest land cover

Parallel shifts in land cover and lady beetles from 1992-2016

Land Cover



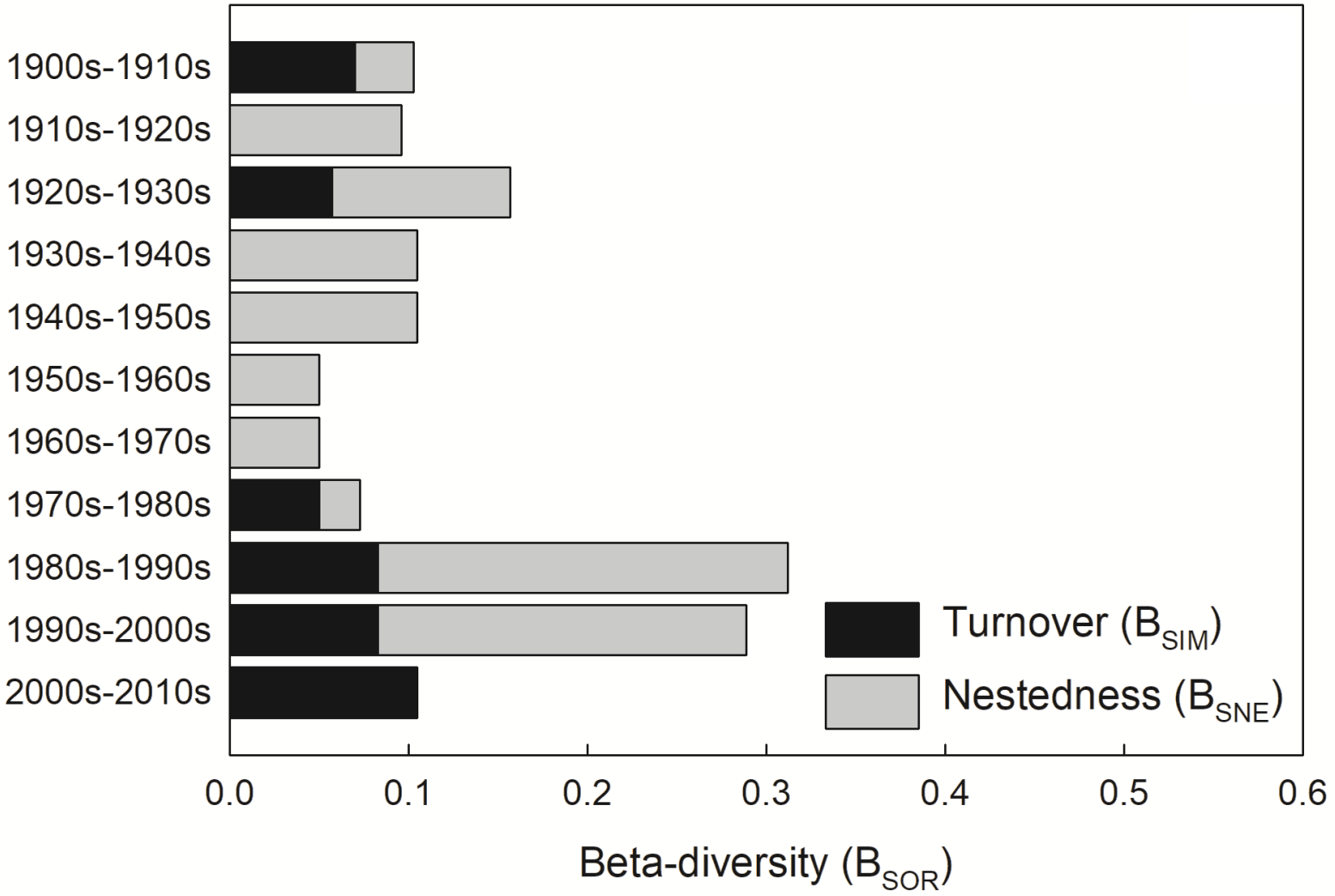
Lady beetle communities



All species

Native species only

Changes in lady beetle species composition shifted over time from nestedness to turnover

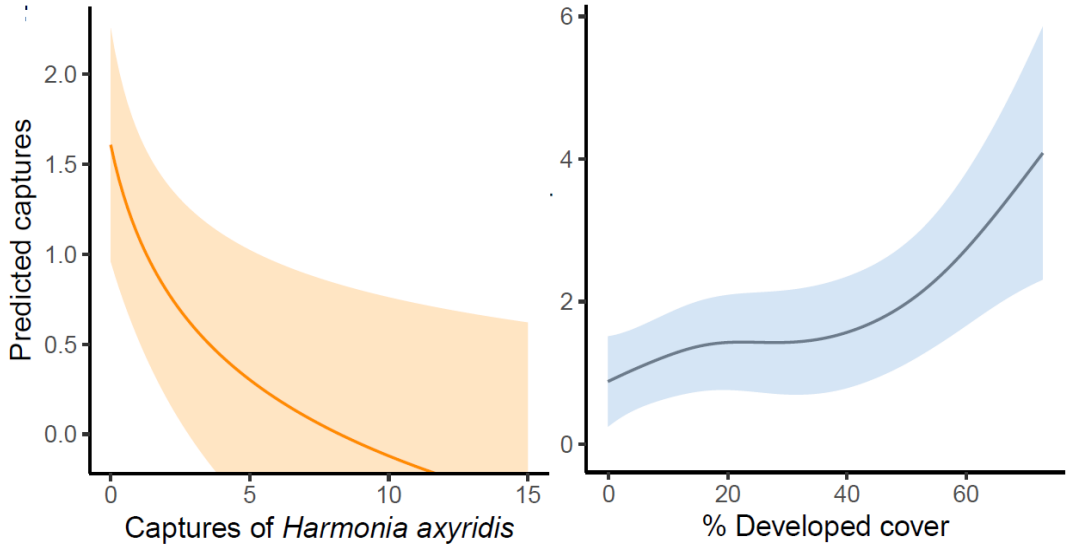


Gain/loss of native species in collections over time

Replacement of native captures by exotic captures

Species-specific patterns for exotic species and landscape change

Hippodamia convergens



Declines began in 1970s

Last record in 2015

Species-specific patterns for exotic species and landscape change

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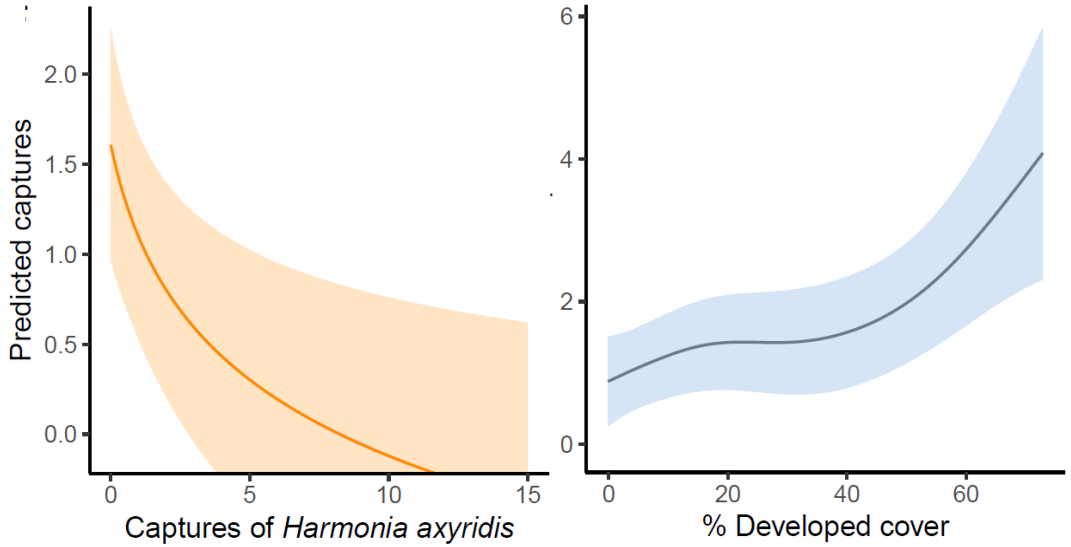

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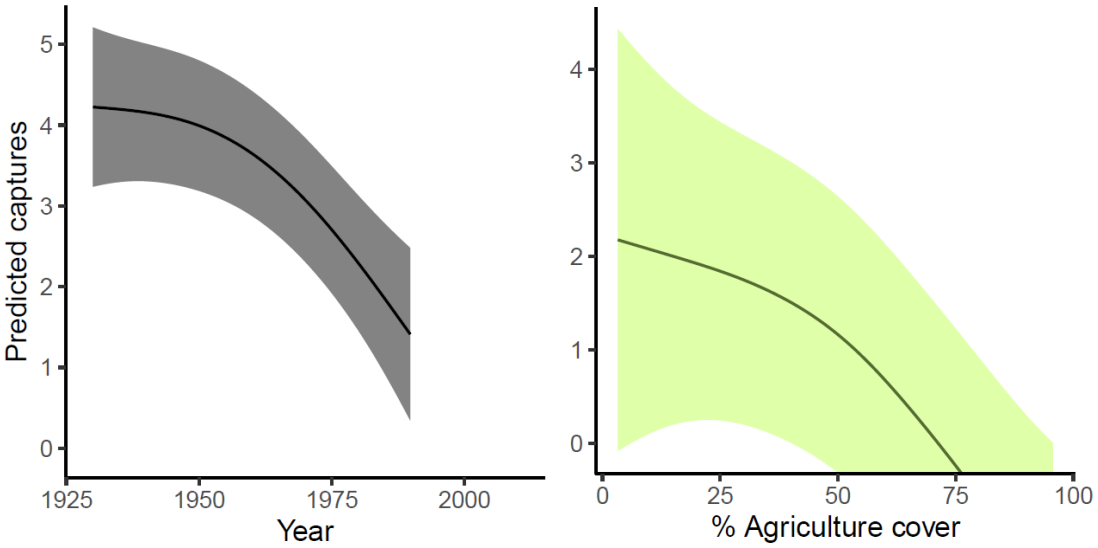
Coccinella novemnotata



Declines began in 1950s

Last record in 1985

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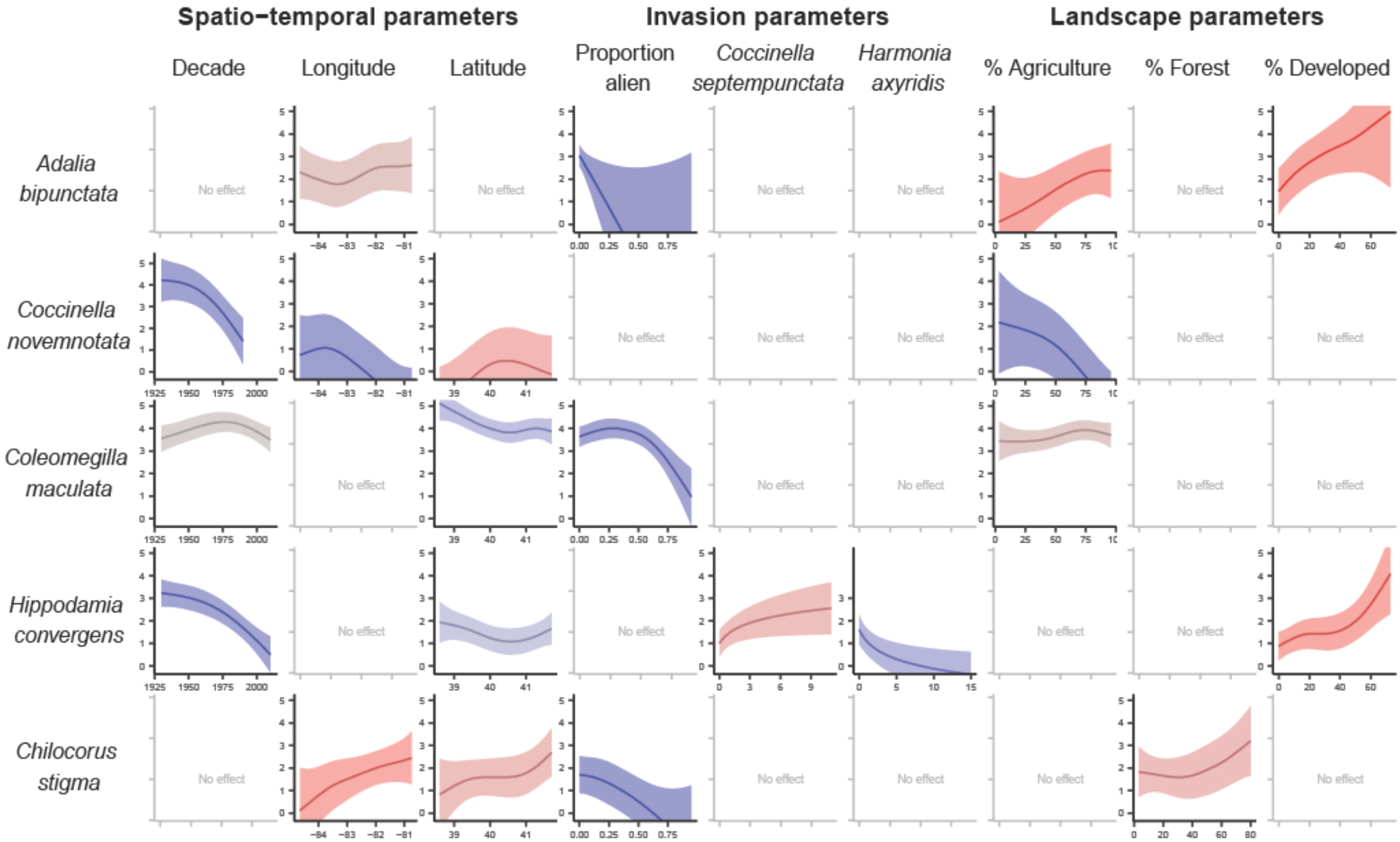
Spatio−temporal parameters
Invasion parameters
Landscape parameters
Decade
Longitude
Latitude
Proportion alien
Coccinella septempunctata
Harmonia axyridis
% Agriculture
% Forest
% Developed
Adalia bipunctata
Coccinella novemnotata
Coleomegilla maculata
Hippodamia convergens
Chilocorus stigma
No effect

Summary

<u>Using museum collections from 12 decades</u>:

(1) Beginning in 1980s, shifts in lady beetle communities as exotic species increased in dominance

(2) Parallel shifts in land cover and lady beetles from 1992-2016 driven by turnover in species

(3) Detected declines in captures of native aphidophagous lady beetle species

(4) Drivers of declines in captures species-specific

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Implications of native lady beetle decline

Mechanisms of decline in native species cannot be generalized even among closely related species

- Landscape change and exotic species

Exotic lady beetle species are not ecologically equivalent, have different impacts on natives

Landscape scale management to balance the opposing needs of native species

Exotic species may be required to maintain pest management in the future (Bahlai et al. 2021)

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All materials provided in GitHub repository:

https://github.com/kiperry/ESA_Statistics_Workshop_2025