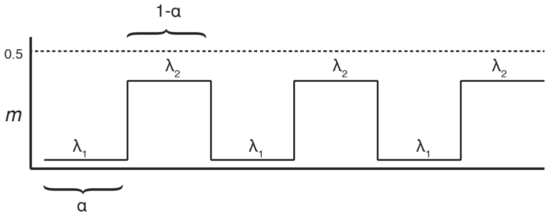
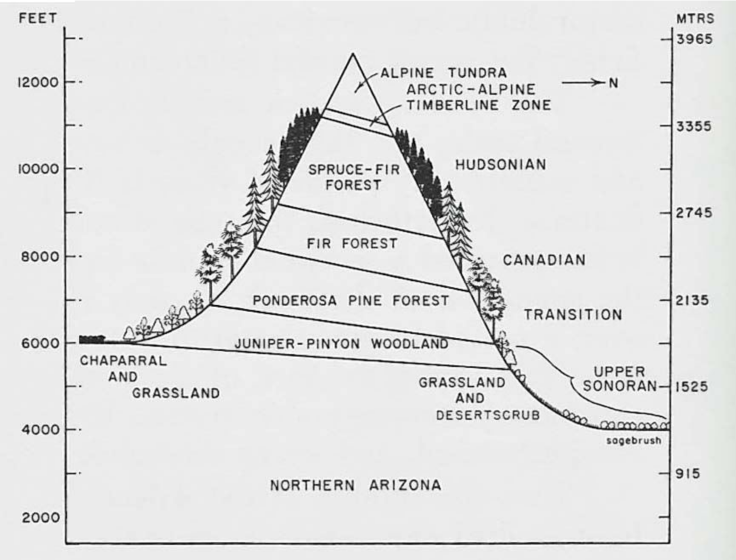


Climate fidelity, genetic variation, and evolutionary potential

Ethan B. Linck

University of Wyoming
Department of Zoology & Physiology
@ethanblinck

Climate structures biodiversity



(Merriam 1890)

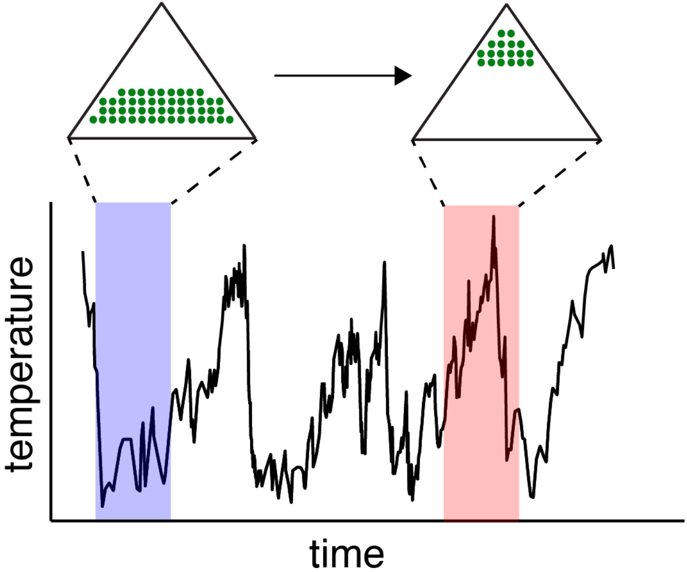
Climate structures biodiversity




(iNaturalist obs. 128348716, 30912579, 31832514, 33570367)

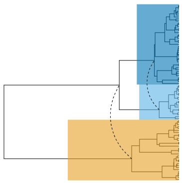
Climate fidelity: the tendency of a species or population to track its climatic niche through time (Wang et al. 2023 *PNAS*)

Climate fidelity

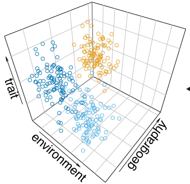


Integrative population genetics

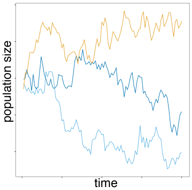
genetic differentiation



species range evolution



global change biology



Linck et al. 2020 *J. Evol. Biol.*

Linck et al. 2019 *Syst. Biol.*

Linck & Battey 2019 *Mol. Ecol. Res.*

Battey, Linck et al. 2018 *Am. Nat.*

Linck et al. 2023 *Am. Nat.*

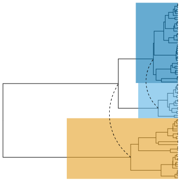
Linck et al. 2020 *Ecol. Evol.*

Linck et al. 2021 *Biol. Lett.*

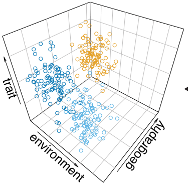
Mamantov et al. 2023 *Glob. Ecol. Biogeogr*

Integrative population genetics

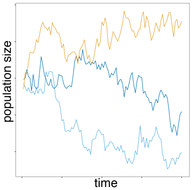
genetic differentiation



species range evolution



global change biology



Linck et al. 2020 *J. Evol. Biol.*

Linck et al. 2019 *Syst. Biol.*

Linck & Battey 2019 *Mol. Ecol. Res.*

Battey, Linck et al. 2018 *Am. Nat.*

Linck et al. 2023 *Am. Nat.*

Linck et al. 2020 *Ecol. Evol.*

Linck et al. 2021 *Biol. Lett.*

Mamantov et al. 2023 *Glob. Ecol. Biogeogr*

How does climate fidelity structure genetic variation, and why do we care?

Outline

- Q_1: How has climate fidelity shaped genetic variation in Western *Empidonax* flycatchers?
- Q_2: What can we learn from adding climatic complexity to population genetic models?
- Q_3: What can climate fidelity tell us about evolutionary potential?
- Q_4: What is the role of evolutionary thinking in conservation biology?

Outline

- Q_1: **How has climate fidelity shaped genetic variation in Western *Empidonax* flycatchers?**
- Q_2: What can we learn from adding climatic complexity to population genetic models do?
- Q_3: What can climate fidelity tell us about evolutionary potential?
- Q_4: What is the role of evolutionary thinking in conservation biology?

Acknowledgements:

- **Collaborators**: Kevin Epperly, Paul van Els, Garth Spellman, Rob Bryson, John McCormack, **Ricardo Canales-del-Castillo**, John Klicka, **Alex Hopping**
- **Funding**: Department of Defense NDSEG Fellowship

Climatic cycles shape biodiversity

GLACIATION, A FACTOR IN SPECIATION

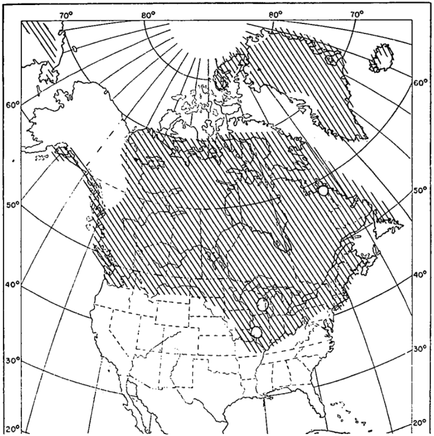
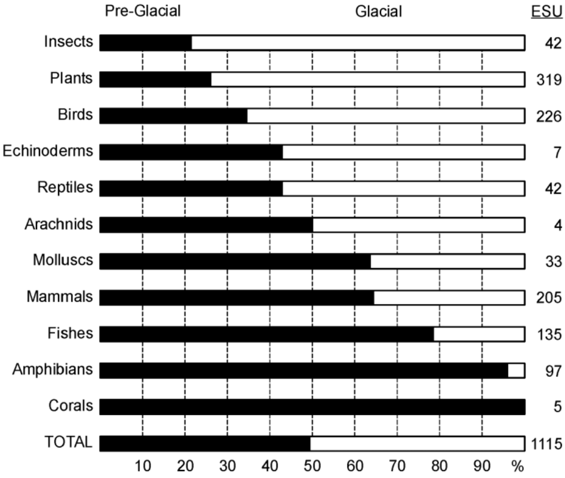


FIG. 1. Maximum extent of solid ice sheets according to Hulten, 1937; additional local glaciation also occurred. Flint (see fig. 2) believes that glaciation was more extensive than this.

(Rand 1948 *Evolution*)

Climatic cycles shape biodiversity



(Rull 2008 *Molecular Ecology*)

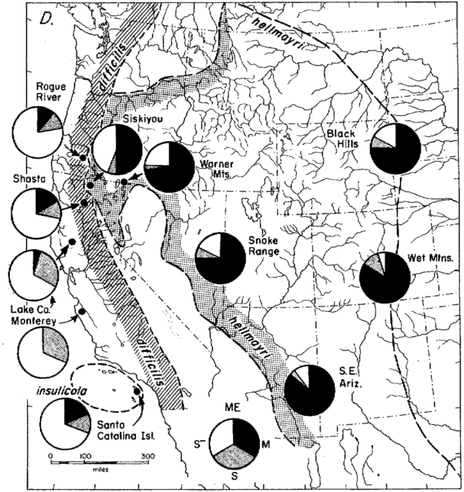
“Western” *Empidonax* Flycatchers

Cordilleran Flycatcher (COFL)
Empidonax occidentalis

Pacific-slope Flycatcher (PSFL)
Empidonax difficilis

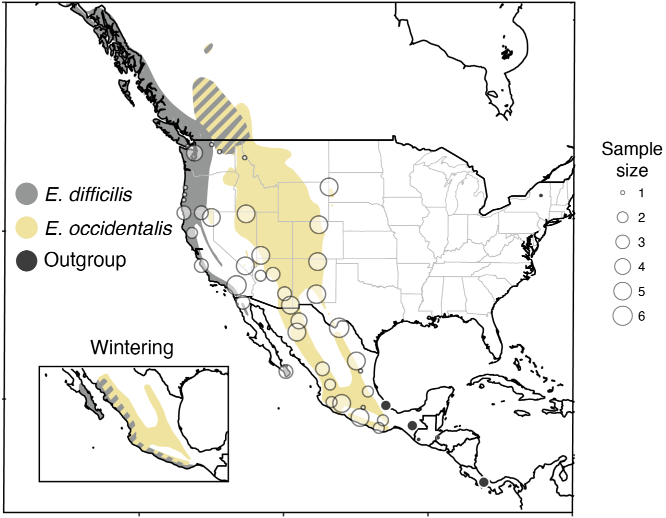
(Macaulay Library 109315481 & 236799211)

One species or two?



(Johnson & Marten 1988 *Auk*)

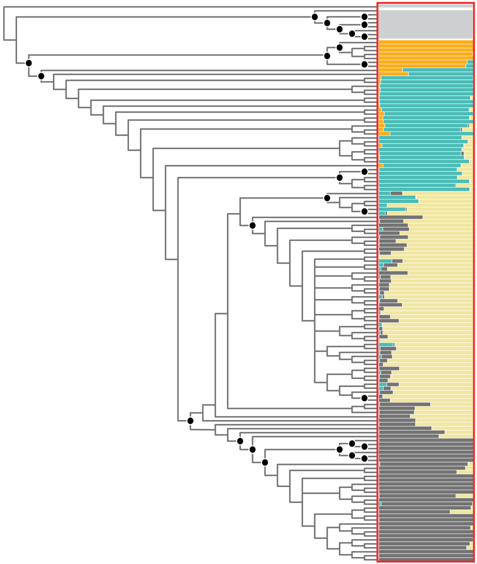
New information, more genes, more geography



(Linck et al. 2019 *Syst. Biol.*)

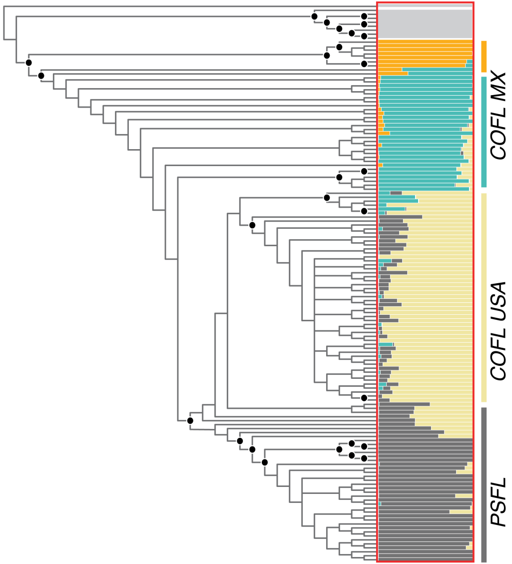
H_1: Mountain ranges structure genetic variation in Western *Empidonax*

Geographically structured populations



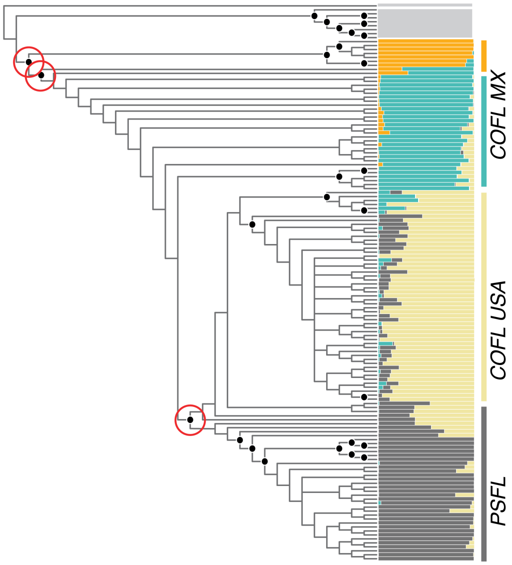
(Linck et al. 2019 *Syst. Biol.*)

Geographically structured populations



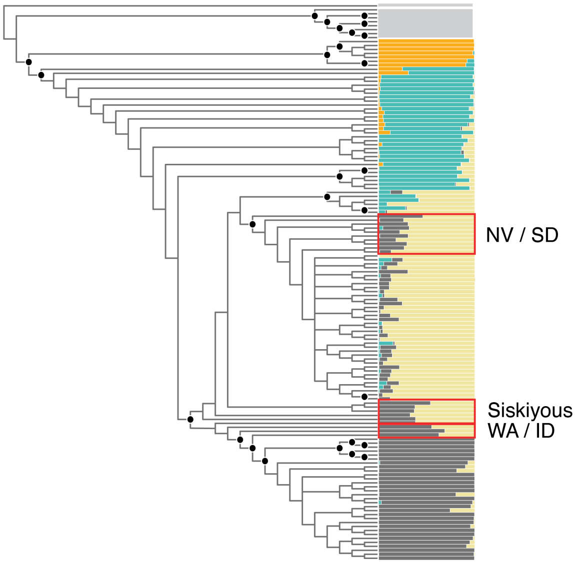
(Linck et al. 2019 *Syst. Biol.*)

COFL is paraphyletic!



(Linck et al. 2019 *Syst. Biol.*)

Hybridization at forest corridors



(Linck et al. 2019 *Syst. Biol.*)

Takeaways

- 1 species of WEFL (for now)
- Hybridization is key
- There's no getting around comprehensive sampling for delimitation of management units
- Climate fidelity and montane geography explain genetic structure in *Empidonax* flycatchers

Outline

- Q_1: How has climate fidelity shaped genetic variation in Western *Empidonax* flycatchers?
- Q_2**: What can we learn from adding climatic complexity to population genetic models?**
- Q_3: What can climate fidelity tell us about evolutionary potential?
- Q_4: What is the role of evolutionary thinking in conservation biology?

Acknowledgements:

- **Collaborators**: CJ Battey, Ana Bedoya
- **Funding**: NSF DDIG #1701224

Climatic cycles shape biodiversity

GLACIATION, A FACTOR IN SPECIATION

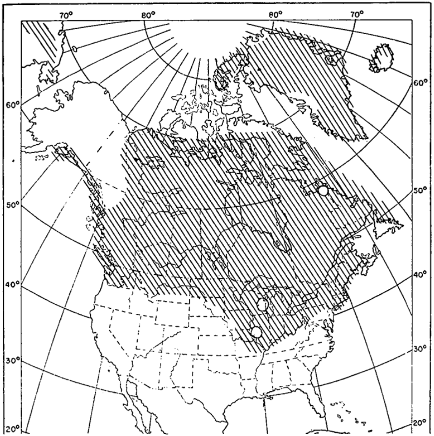
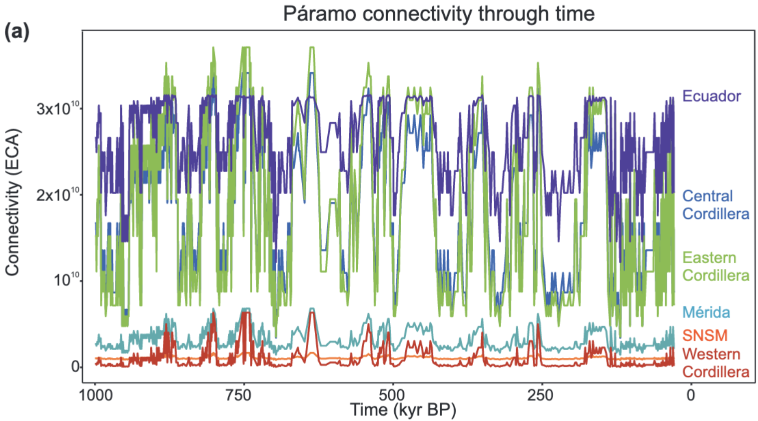


FIG. 1. Maximum extent of solid ice sheets according to Hulten, 1937; additional local glaciation also occurred. Flint (see fig. 2) believes that glaciation was more extensive than this.

(Rand 1948 *Evolution*)

Climate fidelity and cyclical contact



(Flantua et al. 2019 *J. Biogeog.*)

Simple models of divergence

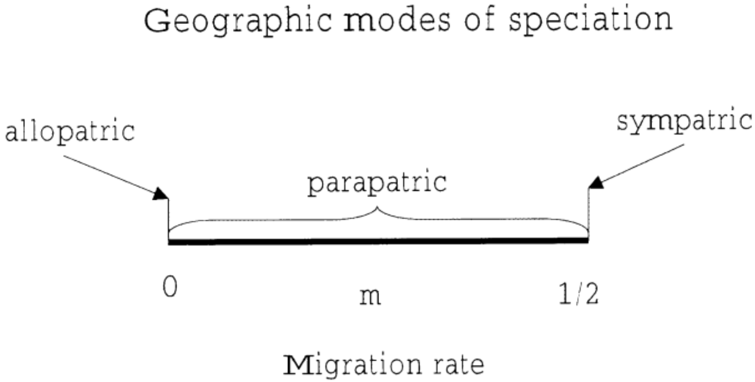


FIG. 1. Geographic modes of speciation.

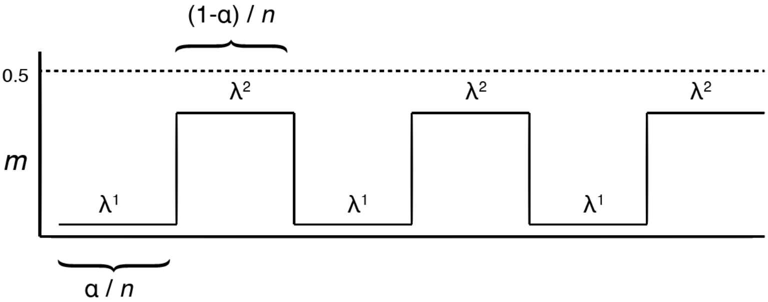
(Gavrilets 2003 *Evolution*)

For example: allopatric speciation

$$\overbrace{T^a}^{\text{time to speciation}} = \underbrace{2}_{\text{no. alleles}} * \overbrace{\frac{1}{\mu}}^{\text{substitution rate}} = \frac{2}{\mu}$$

H_1: Cyclical contact slows divergence,
but not *that* much

Our own toy model

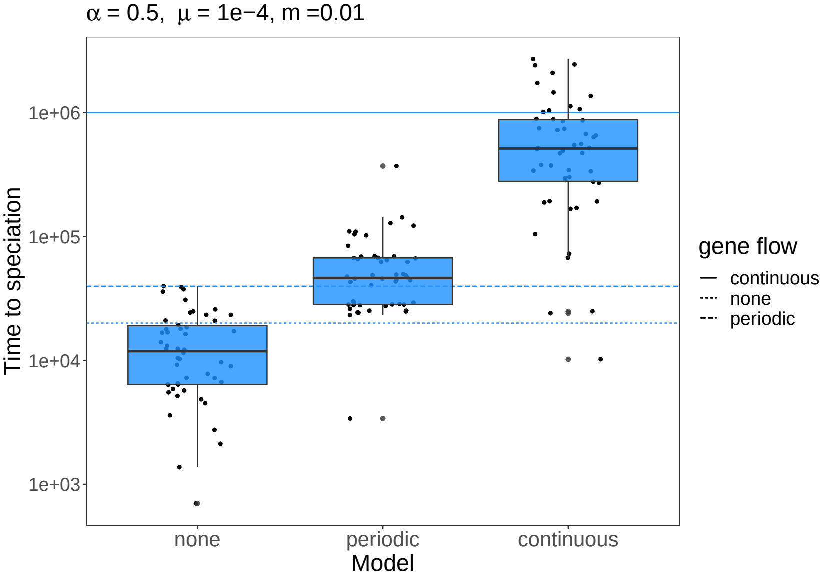


(Linck & Battey In revision *Am. Nat.*)

Our own toy model

$$\overbrace{T^t}^{\text{time to speciation}} = \frac{\overbrace{n}^{\text{number of climate cycles}}}{\sum_{i=1}^{n} \underbrace{\alpha}_{\text{time in allo.}} \underbrace{\left(\frac{\mu}{2}\right)}_{\text{allo. model}} + \underbrace{(1-\alpha)}_{\text{time in para.}} \underbrace{\left(\frac{\mu^2}{m}\right)}_{\text{para. model}}}$$

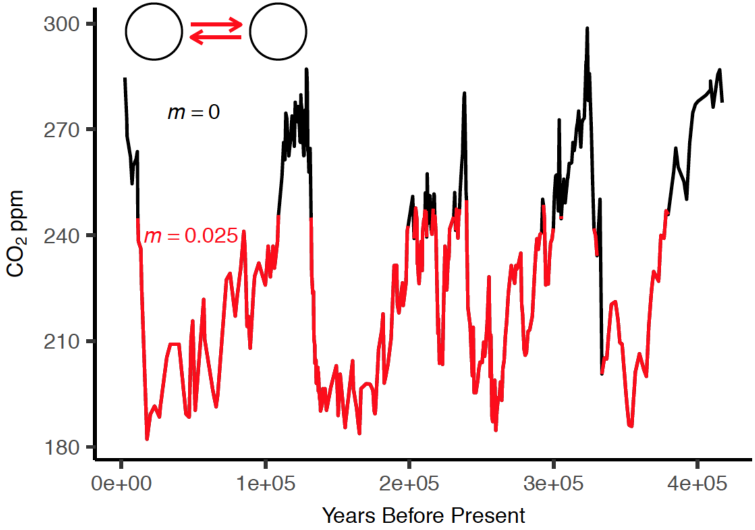
Our own toy model



(Linck & Battey In revision *Am. Nat.*)

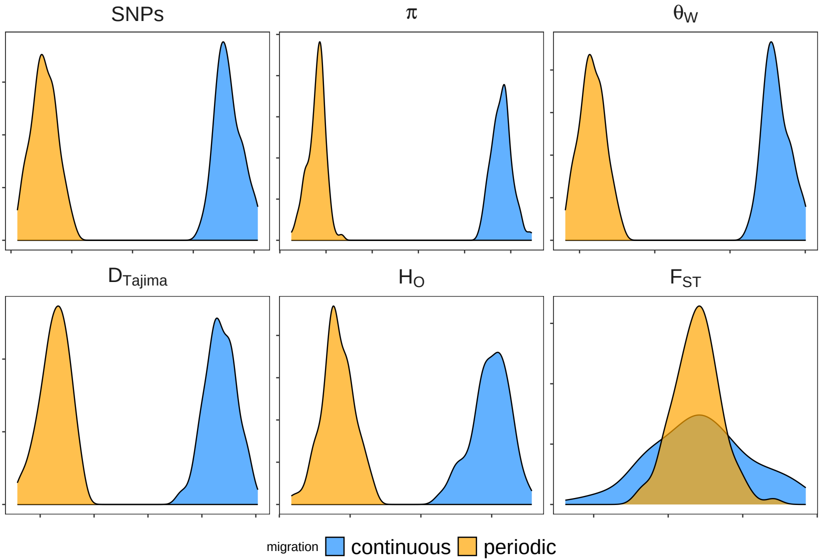
H_2: Cyclical contact has a distinct genomic signature

Parameterizing simulations



(Linck & Battey In revision *Am. Nat.*)

Different summary statistics



(Linck & Battey In revision *Am. Nat.*)

Takeaways

- Climate fidelity involved in an efficient mode of divergence
- The timing of gene flow matters
- Potentially detectable with sequence data
- Climatic complexity adds value to population genetic models

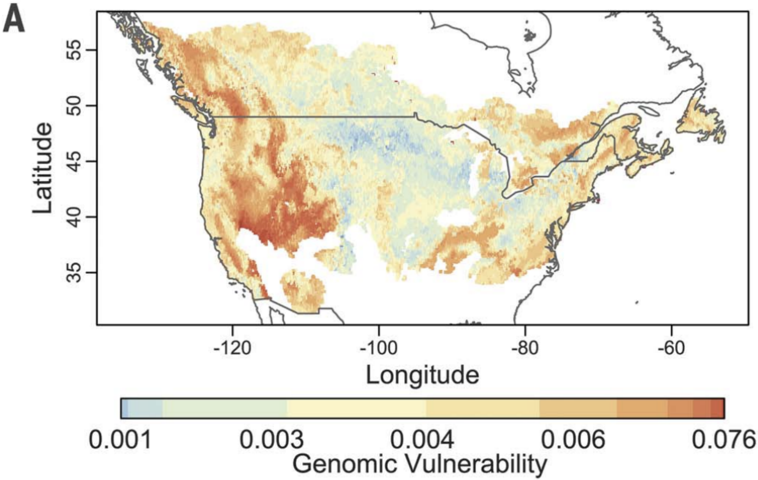
Outline

- Q_1: How has climate fidelity shaped genetic variation in Western *Empidonax* flycatchers?
- Q_2: What can we learn from adding climatic complexity to population genetic models?
- **Q_3: What can climate fidelity tell us about evolutionary potential?**
- Q_4: What is the role of evolutionary thinking in conservation biology?

Acknowledgements:

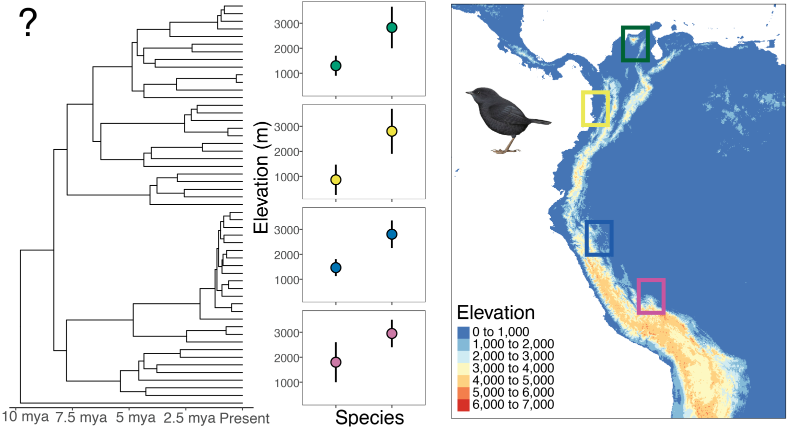
- **Collaborators**: Daniel Cadena, Cameron Ghalambor, Ben Freeman, Laura Céspedes
- **Funding**: NSF PRFB

Move, **adapt** / acclimate, or die



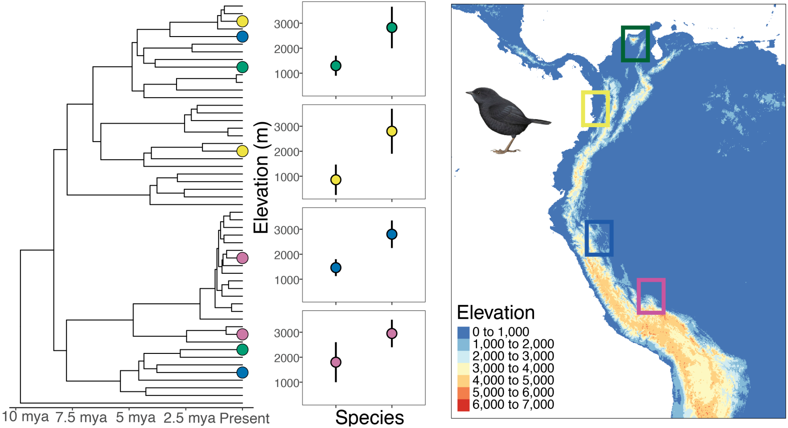
(Bay et al. 2018 *Science*)

How quickly do species adapt to new climates?



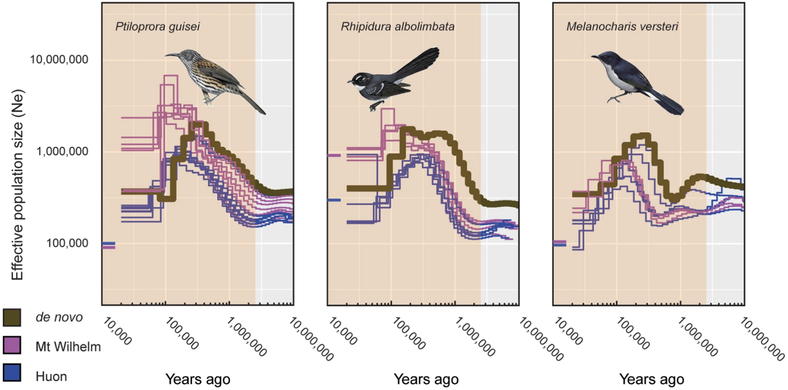
(Linck et al. 2021 *Biol. Lett.*)

Climate fidelity across phylogeny in tapaculos



(Linck et al. 2021 *Biol. Lett.*)

Climate fidelity shapes population trajectories



(Pujolar et al. 2022 *Nat. Comm.*)

H_1: Climate fidelity is negatively correlated with evolutionary potential

Proxies for evolutionary potential

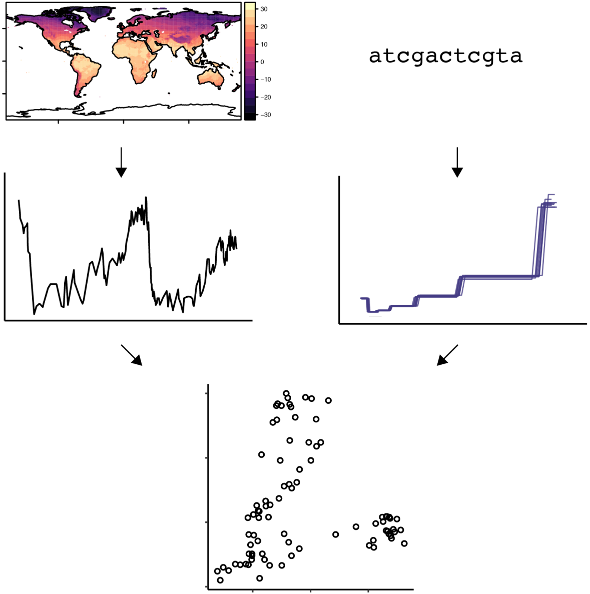
Table 1. Examples of proxies for estimating evolutionary potential (EP), including their data requirements, strengths, and weaknesses

Proxy	Data requirements	Strengths for quantifying EP	Weaknesses for quantifying EP
Narrow-sense heritability or evolvability of a trait	Fitness-relevant trait data; pedigrees or genomic data	Directly assesses short-term EP of a trait in a population by quantifying additive genetic variance	Estimates are trait-, population-, and environment-specific; trait might not reflect those most important for future adaptation; data can be difficult or impossible to collect for at-risk species
Genetic markers identified through genotype–environment associations	Genomic data; environmental data	Identifies genetic markers associated with environmental variation; can identify local adaptation, reflecting spatially variable EP across landscapes; generality (ie not trait-specific) might better capture species-wide EP	Relevant traits and heritability are unknown; results are correlative without further validation
Genome-wide genetic diversity	Genomic data	Quantifies overall genetic diversity across populations that might be correlated with EP; generality (ie not trait- or environment-specific) might better capture species-wide EP	Does not always reflect EP (eg EP in some traits can be retained even with low genome-wide diversity); difficult to incorporate into quantitative extinction-risk assessments
Ecotypes	Phenotypes; environmental data; sometimes genetic/ genomic data	Links phenotypic and environmental variation reflecting potential functional variation that might correlate with species-wide EP; sometimes includes genetic distinctiveness	Phenotypes might not be heritable (ie phenotypic variation can be due to plasticity); trait(s) might not reflect those needed for future adaptations; relationships are correlative
Full breadth of ecological variation	Environmental data	Reflects variable environmental selection that might correlate with species-wide EP; can be estimated for any species with location data; generality (ie not trait-specific) might better capture species-wide EP	Populations inhabiting different environments might not be locally adapted; relevant traits and heritability are unknown; difficult to incorporate into quantitative extinction-risk assessments

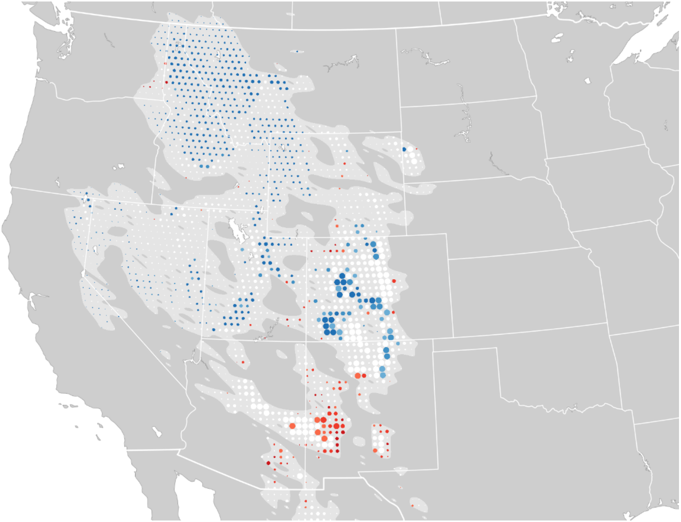
Notes: a full list of proxies and references is provided in WebTable 3.

(Forester et al. 2022 *Front. Ecol. Environ.*)

Testing for correlations



Can Western Flycatchers adapt to a hotter west?

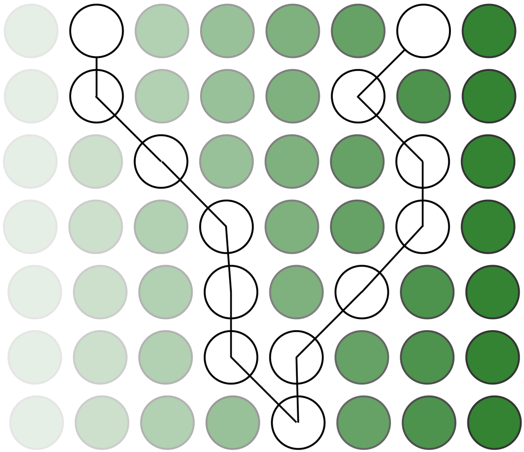


(eBird)

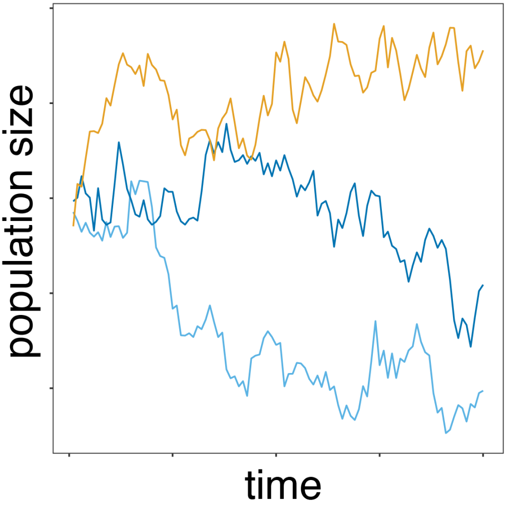
Outline

- Q_1: How has climate fidelity shaped genetic variation in Western *Empidonax* flycatchers?
- Q_2: What can we learn from adding climatic complexity to population genetic models?
- Q_3: What can climate fidelity tell us about evolutionary potential?
- Q_4**: What is the role of evolutionary thinking in conservation biology?**

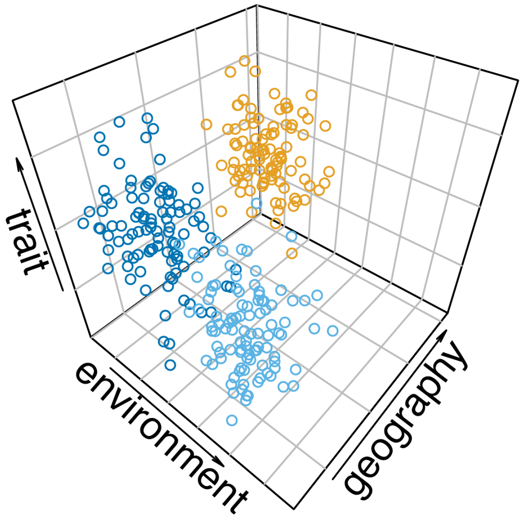
Linck Lab @ Montana State University, Fall 2023



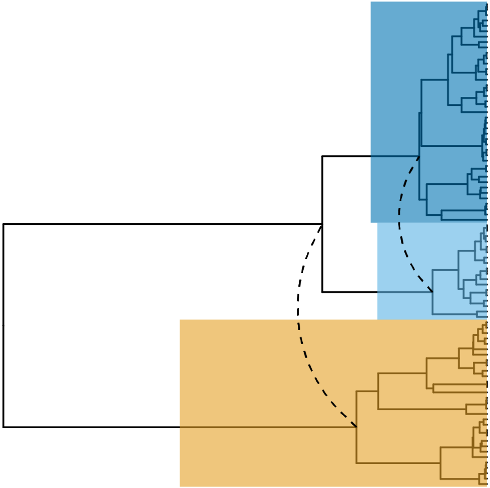
Evolutionary biology can tell us about **evolution**



Evolutionary biology can tell us about **traits**



Evolutionary biology can tell us about **values**



Resources

- slides and code: https://github.com/elinck/misc_talks/
- website: https://elinck.org/
- twitter: @ethanblinck

References

- Merriam 1890. *North. Am. Faun.*, 10.5962/bhl.title.86972
- Wang et al. 2023. *PNAS*, 120(7), e2201946119.
- Rand 1948. *Evolution*, 2(4), 314-321.
- Rull 2008. *Molecular Ecology*, 17(11), 2722-2729.
- Johnson & Marten 1988. *The Auk*, 105(1), 177-191.
- Linck et al. 2019. *Systematic Biology*, 68(6), 956-966.
- Flantua et al. 2019. *J. Biogeography*, 46(8), 1808-1825
- Gavrilets 2003. *Evolution*, 57(10), 2197-2215.
- Bay et al. 2018. *Science*, 359(6371), 83-86.
- Linck et al. 2021. *Biology Letters*, 17(10), 20210363.
- Pujolar et al. 2022. *Nature Communications*, 13(1), 268.
- Forester et al. 2022. *Front. Ecol. Environ.* 20(9), 507-515.

Thanks!

- Q_1: Climate fidelity and montane geography explain genetic structure in *Empidonax* flycatchers
- Q_2: Climatic complexity adds value to population genetic models
- Q_3: Climate fidelity may be inversely correlated with evolutionary potential
- Q_4: Evolutionary thinking in conservation biology is about more than adaptative responses