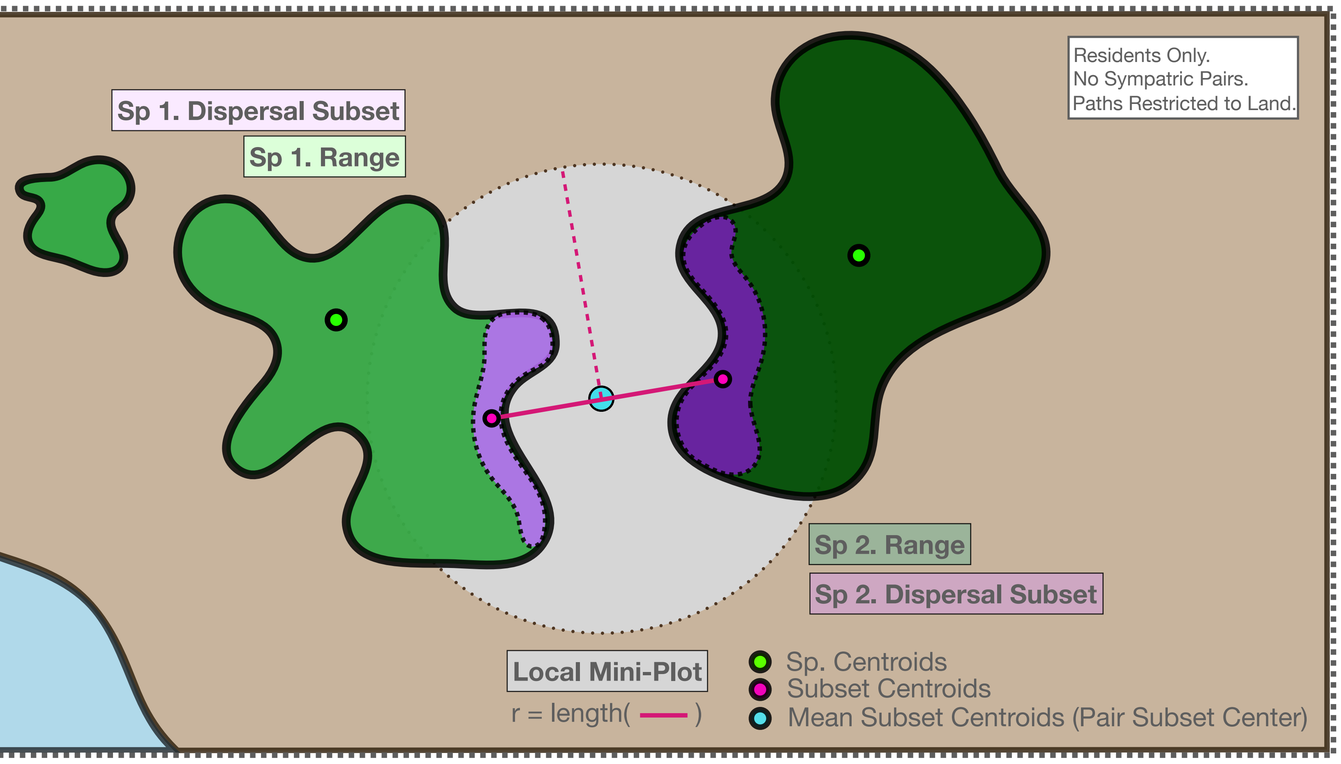
Are Elevational Barriers More Effective at Limiting the Movement of Organisms (Dispersal / Gene-Flow) in Thermally Aseasonal Locations?

	Temperature Var. with Elevation	Thermal Tolerance & Acclimation Cap.	
Thermally Seasonal	**LARGE**	**WIDE**	→ **Large Barriers *Needed* for Speciation**
Thermally Aseasonal	**SMALL**	**NARROW**	→ **Small Barriers *Sufficient* for Speciation**



MODEL SPECIFICATION

ln(**Elevational Barrier Size**) ~

Variance Temperature +
Variance Precipitation +
Mountain Mass +
Water Buffering +
Dispersal Ability +
Mean Annual Temperature +
Pair Age +
Distance +
Length of Range Boundary

Secondary dependent variables
- ln(MAT Barrier Size)
- ln(VarT Barrier Size)

MAIN EFFECTS

Temperature Variance

ACROSS ENTIRE SPECIES RANGES

mean(var(tas_m1:tas_m12) , var(tas_m1:tas_m12))

var(Tas) ~ Lat

Why Include? MAIN EFFECT

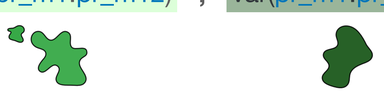
Prediction: Ele. Barrier Size ~ Tas Variance

Interpretation: LARGER BARRIERS ARE REQUIRED FOR SPECIATION WHEN SPECIES HAVE WIDE PHYSIOLOGICAL TOLERANCES.

Precipitation Variance

ACROSS ENTIRE SPECIES RANGES

mean(var(pr_m1:pr_m12) , var(pr_m1:pr_m12))



MAY SEE NO EFFECT OF Pr., SHOULD BE WEAK RELATIVE TO Tas.

Why Include? SECONDARY EFFECT

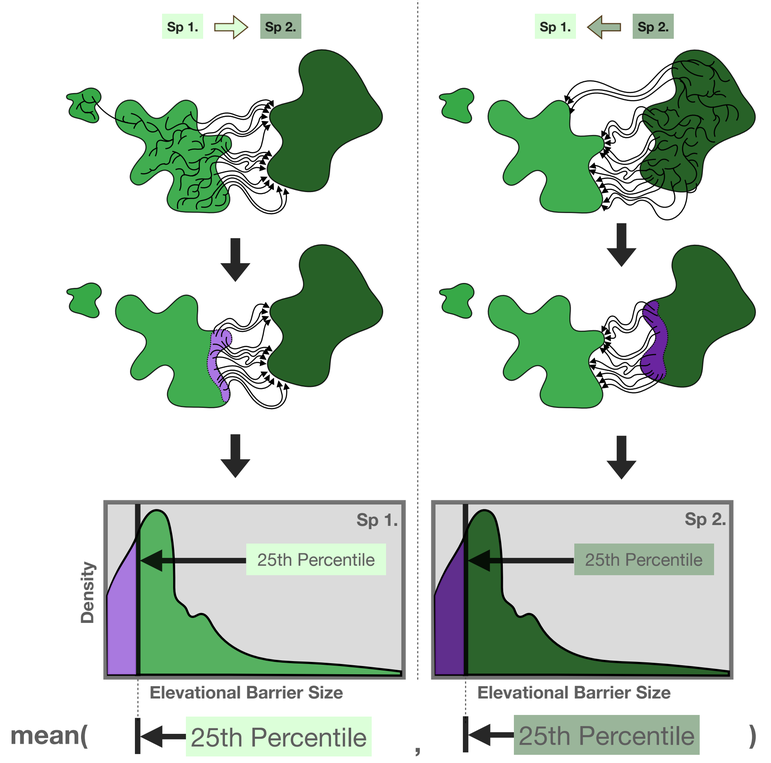
Prediction: Ele. Barrier Size ~ Pr Variance

Interpretation: LARGER BARRIERS ARE REQUIRED FOR SPECIATION WHEN SPECIES HAVE WIDE PHYSIOLOGICAL TOLERANCES.

DEPENDENT VARIABLE

Elevational Barrier Size *

SINGLE VALUE PER SPECIES PAIR



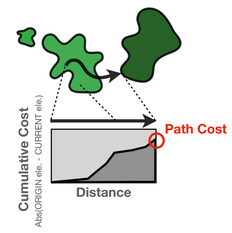
*Identical method used to calculate MAT and VarT barrier size.

Why Include?
THIS IS THE DEPENDENT VARIABLE!

What is an "Elevational Barrier"?
BARRIER TO DISPERSAL CAUSED BY THE PHYSIOLOGICAL CHALLENGES OF TRAVERSING ENVIRONMENTS AT DIFFERENT ELEVATIONS FROM THE STARTING LOCATION.

How are "Elevational Barriers" quantified?
ELEVATIONAL BARRIERS ARE THE SUM OF ELEVATIONAL COSTS ENCOUNTERED WHILE TRAVERSING THE LEAST-COST-PATH IN ELEVATIONAL SPACE FROM A LOCATION IN THE RANGE OF sp 1. TO A LOCATION IN THE RANGE OF sp 2.

Example.
A PATH FROM AN ORIGIN IN:
TO *THE BEST* DESTINATION IN:



What about Latitude?
LATITUDE IS A CONVENIENT PROXY…

Prediction: Ele. Barrier Size ~ Latitude

Note: JANZEN USED ELEVATION AND LATITUDE (B/C THAT IS WHAT WAS AVAILABLE), BUT MADE PREDICTIONS FOR ELEVATIONAL BARRIERS *CAUSED BY* CLINES IN AVERAGE TEMPERATURE AND TEMPERATURE VARIATION!

COVARIATES

Mountain Mass *

IN MINI-PLOT AREA

(N mountain cells in ◯) / (N total cells in ◯)

*A single radius is currently being used across all species. This radius is at the peak density in the density plot for all pairwise length(—)

Why Include? IMPACTS LOCAL THERMAL VARIABILITY

Prediction: Ele. Barrier Size ~ Mountain Mass

Interpretation: MOUNTAIN MASS REDUCES THERMAL VARIABILITY, THEREFORE SMALLER BARRIERS SUFFICIENT TO DRIVE SPECIATION.

Pair Age *

FROM COONEY MCC DATASET

Age of divergence for sister species pair (MYA).

*Conduct sensitivity analysis (> 5 MYA, <= 5 MYA)

Why Include?
CAN IMPACT ANAGENESIS, RANGE FILLING, RANGE SHIFTS, CLIMATE CHANGES, & SIGNAL LOSS

Prediction: Ele. Barrier Size ~ Pair Age

Interpretation: OLDER PAIRS HAVE HAD MORE TIME FOR RANGE SHIFTS, RANGE FILLING, AND ANAGENESIS IN THEIR PHYSIOLOGICAL NICHES, WHICH CAN REDUCE MEASURED BARRIER SIZE.

Prediction: Ele. Barrier Size ~ Pair Age

Interpretation: SIGNAL LOSS IN OLDER PAIRS COULD INTRODUCE NOISE IN MEASURED VARIABLES. NOISE MAY BE DIRECTIONAL BY CHANCE OR DUE TO UNMEASURED VARS.

Water Buffering

FROM CENTROID OF CHEAPEST SUBSETS

T.B.D.

Consider modifying method in Kalmar & Currie 2006

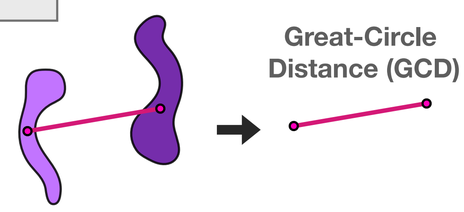
Why Include? IMPACTS LOCAL THERMAL VARIABILITY

Prediction: Ele. Barrier Size ~ Water Buffering

Interpretation: WATER BUFFERING REDUCES THERMAL VARIABILITY, THEREFORE SMALLER BARRIERS SUFFICIENT TO DRIVE SPECIATION.

Distance

SP 1. SUBSET <—> SP 2. SUBSET



Why Include? METHODOLOGICAL CONSTRAINT

Prediction: Ele. Barrier Size ~ Distance

Interpretation: BARRIER COST ACCUMULATES WITH PATH LENGTH, NULL EXPECTATION IS THAT LONGER PATHS ARE MORE COSTLY SIMPLY BECAUSE THEY ARE LONGER.

Dispersal Ability

BASED ON HAND-WING-INDEX (HWI)

mean(Sp 1. Hand-Wing-Index , Sp 2. Hand-Wing-Index)

Data Paper: https://doi.org/10.1038/s41467-020-16313-6

Why Include? IMPACTS REALIZED BARRIER EFFECTIVENESS

Prediction: Ele. Barrier Size ~ Dispersal Ability

Interpretation: LARGER BARRIERS REQUIRED FOR REDUCED GENE-FLOW WHEN DISPERSAL ABILITY IS HIGH; CAN "IGNORE" BARRIERS.

Length of Boundary *

ACROSS CHEAPEST SUBSET RANGES ONLY

mean(mean(pairwise GCD among cells ◯) , mean(pairwise GCD among cells ◯))

*Previously: mean(N cells Sp 1. Range , N cells Sp 2. Range)

Why Include? METHODOLOGICAL CONSTRAINT

Prediction: Ele. Barrier Size ~ Boundary Length

Interpretation: PAIRS WITH LONGER BOUNDARIES IN THEIR SUBSET RANGES FIND CHEAPER PATHS SIMPLY BECAUSE THEY HAVE MORE ORIGIN AND DESTINATION OPTIONS.

Mean Annual Temperature *

ACROSS ENTIRE SPECIES RANGES

mean(mean(tas_m1:tas_m12) , mean(tas_m1:tas_m12))

var(Tas) ~ Lat

*MAT is NOT just latitude: ele. barrier = +L*VarT -M*MAT +N*Latitude

Why Include? ASSOCIATED WITH LOCAL THERMAL VARIABILITY & IMPACTS EVOLUTIONARY OUTCOMES

Prediction: Ele. Barrier Size ~ MAT

Interpretation: LARGER BARRIERS REQUIRED FOR REDUCED GENE-FLOW IN COLDER PLACES; ADAPT TO COLD THROUGH NICHE EXPANSION OR SPECIAL CHARACTERS.

HYPOTHESIS ORIGIN:

Why Mountain Passes are Higher in the Tropics. Daniel H. Janzen. The American Naturalist. 1967. *https://www.jstor.org/stable/2458977*

NOTEWORTHY REVIEWS:

Are Mountain Passes Higher in the Tropics? Ghalambor et al. Integrative & Comparative Biology. 2006. https://doi.org/10.1093/icb/icj003

Fifty Years of Mountain Passes: A Perspective on Dan Janzen's Classic Article. Sheldon et al. The American Naturalist. 2018. https://doi.org/10.1086/697046

Janzen's Mountain Passes Hypothesis is Comprehensively Tested in its Fifth Decade. Smith. Proc. Natl. Acad. Sci. USA. 2018. https://doi.org/10.1073/pnas.1817774115

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