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Coping with Climate Uncertainty in Projected Ranges of Pests Using Hypervolumes

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Introduction

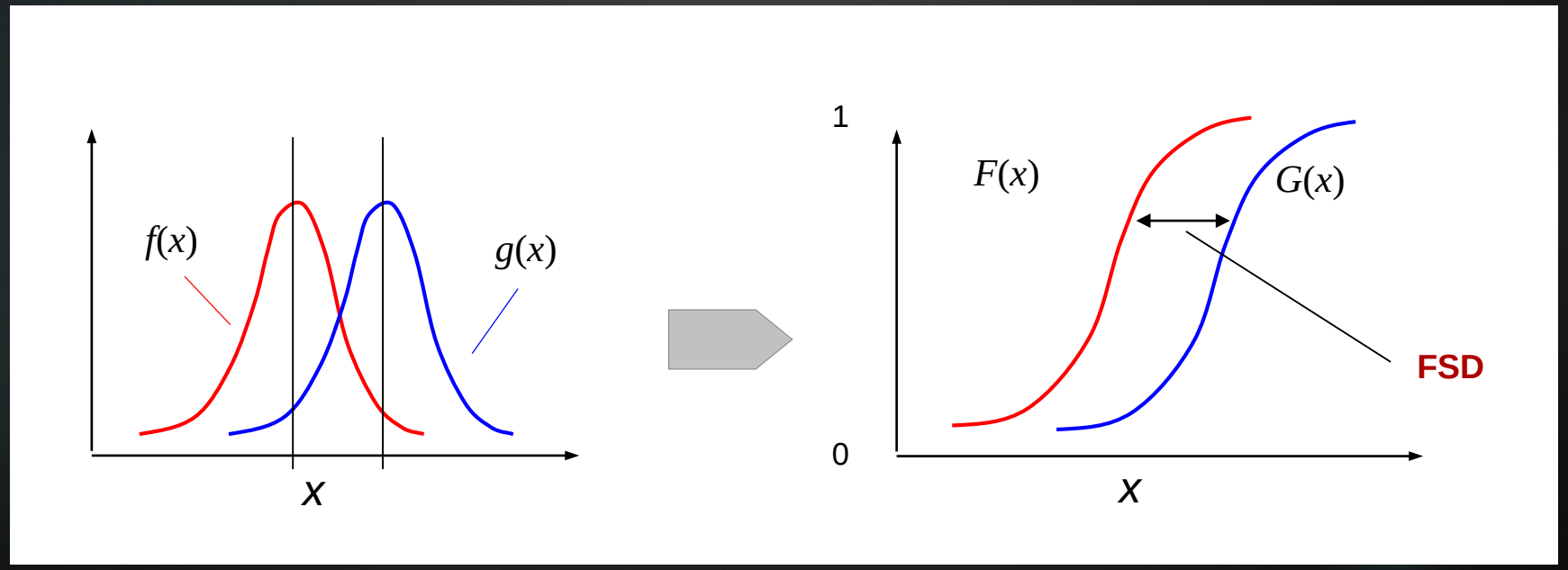
- Modeling suitable ranges of invasive species under climate change
  - Many GCMs and emission scenarios, plus time = many plausible outcomes
  - Thus highly uncertain predictions
  - Limited uptake by decision makers

Managing uncertainty in projected suitable ranges

- How to handle uncertain projections?
- Averaging ignores uncertainty
- Other approaches incorporate uncertainty directly
- For example, methods using stochastic efficiency

First-degree stochastic dominance (FSD)

- Comparing two stochastic variables, *f*(x) and *g*(x)
- Using their cumulative distribution functions, *F*(x) and *G*(x)
- In this example, *G*(x) dominates *F*(x)



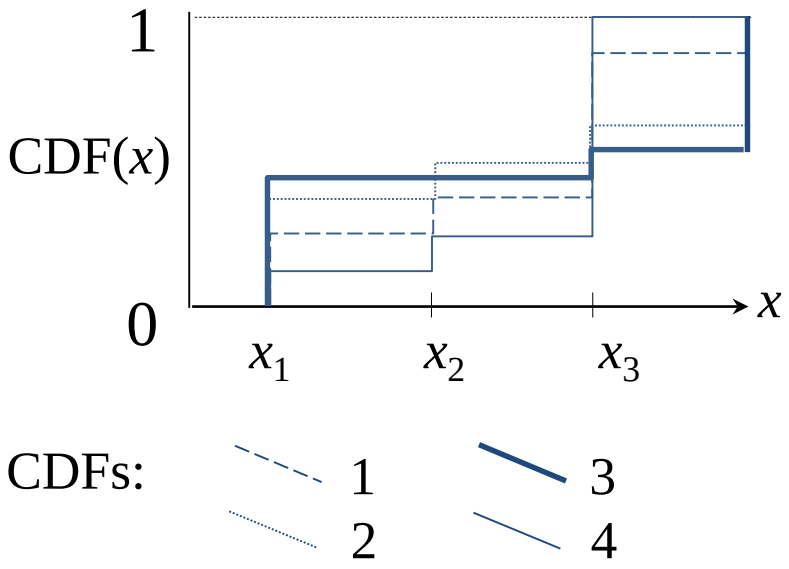
Non-dominant subsets

- Can use FSD to find non-dominant subsets of a set
  - e.g., pixels/locations in a map
  - Each has a CDF of plausible values
  - Compare via FSD to place them in subsets
- These non-dominant subsets can be ordered
- Thus, FSD = ordinal measure that incorporates uncertainty
- Hypervolume approach takes this further, arranging the non-dominant subsets in continuous space

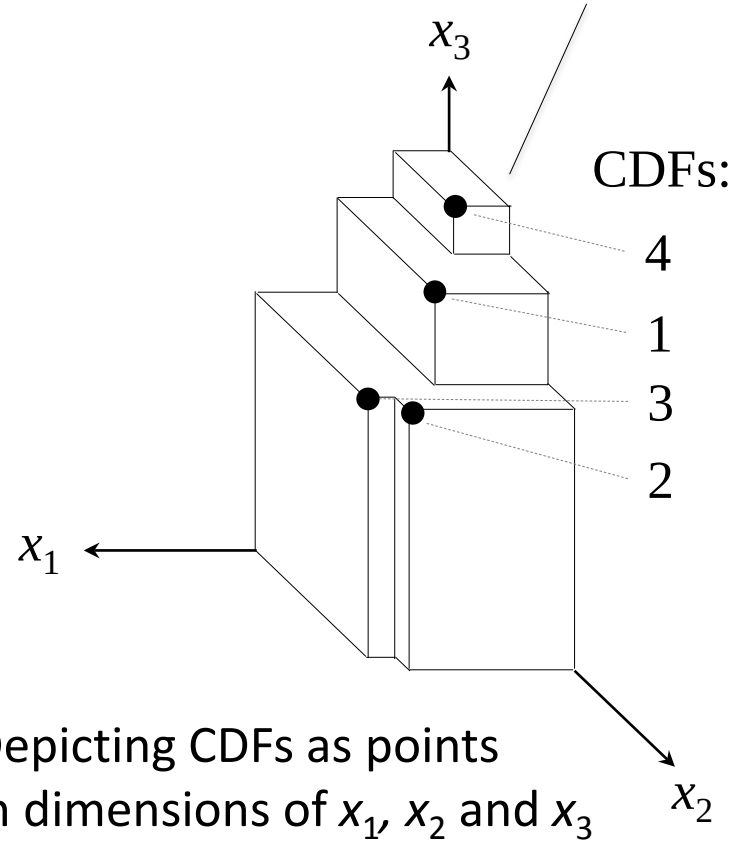
Hypervolumes: a geometric illustration

Consider a set *A* of four CDFs sampled at discrete points x_1, x_2, x_3:

CDF 1: (0.25, 0.375, 0.875)
CDF 2: (0.375, 0.5, 0.625)
CDF 3: (0.45, 0.45, 0.55)
CDF 4: (0.125, 0.25, 1)



A hypervolume under a set of points 1-4 and a reference point *r* = (0,0,0)



Depicting CDFs as points in dimensions of x_1, x_2 and x_3

Basic idea: calculate volumes of hyperspaces for points in non-dominant subsets…

…with these volumes, can arrange subsets in continuous space

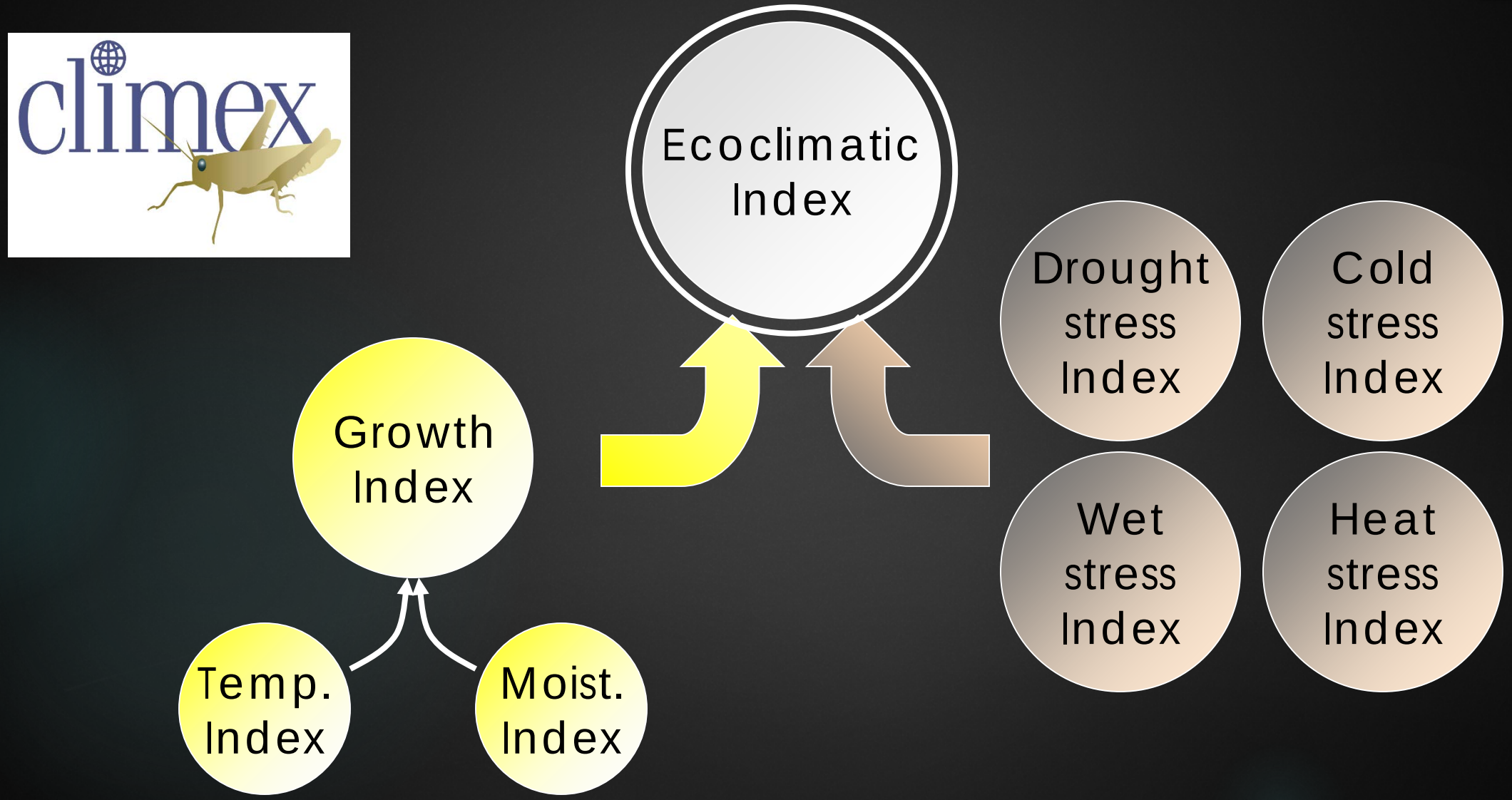
Comparing approaches via example

- Hypothetical invasive insect in North America
- Used CLIMEX to model its suitable range under current climate ... as well as ...

8	×	3	×	3	=	72
General Circulation Models		Emissions scenarios (a1, a2, b1)		Time horizons (2020, 2050, 2080)		Projected outcomes

[Data provided by worldclim.org, downscaled to 30 arcsecond resolution]

CLIMEX indices

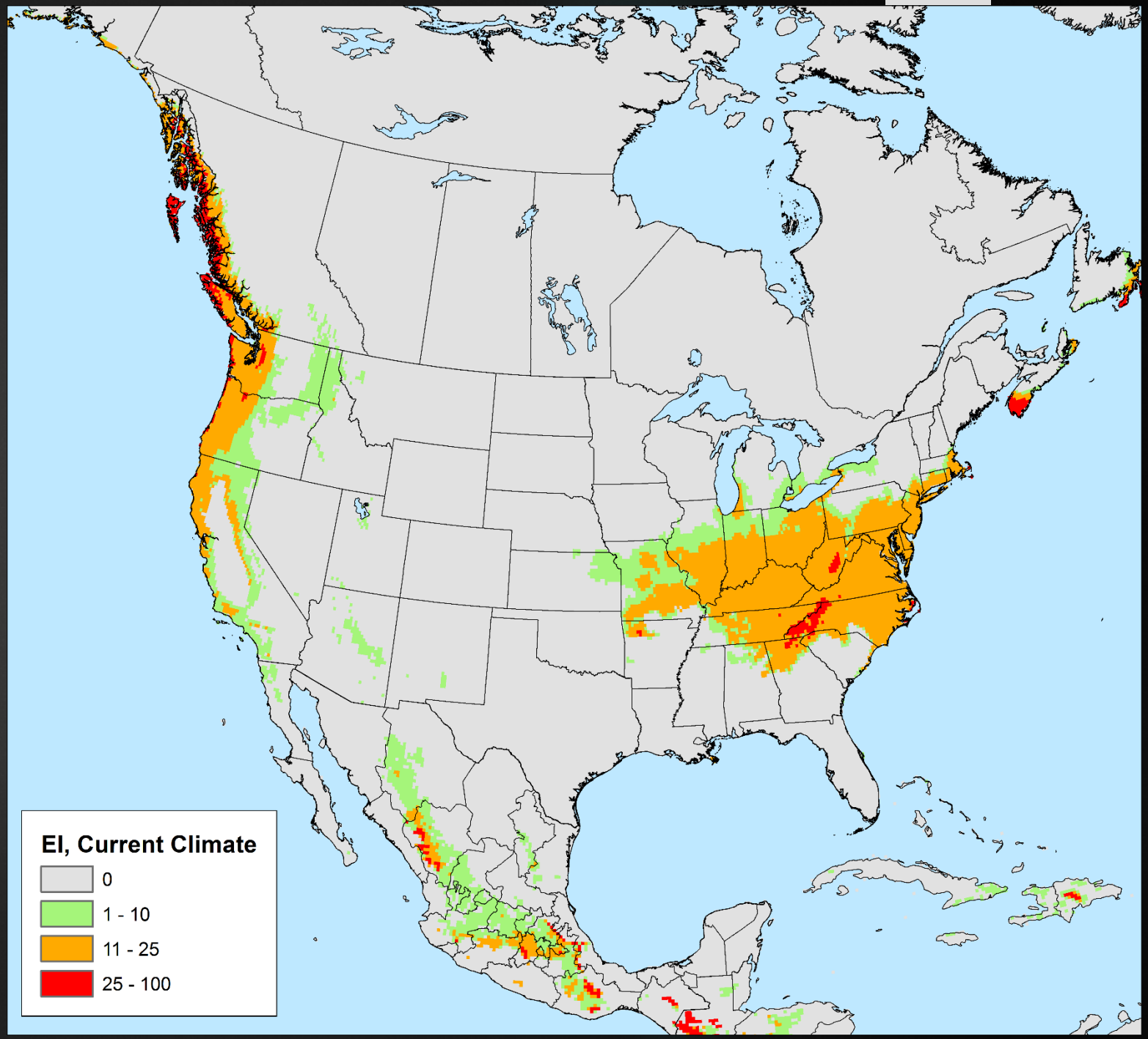


Baseline EI under current climate

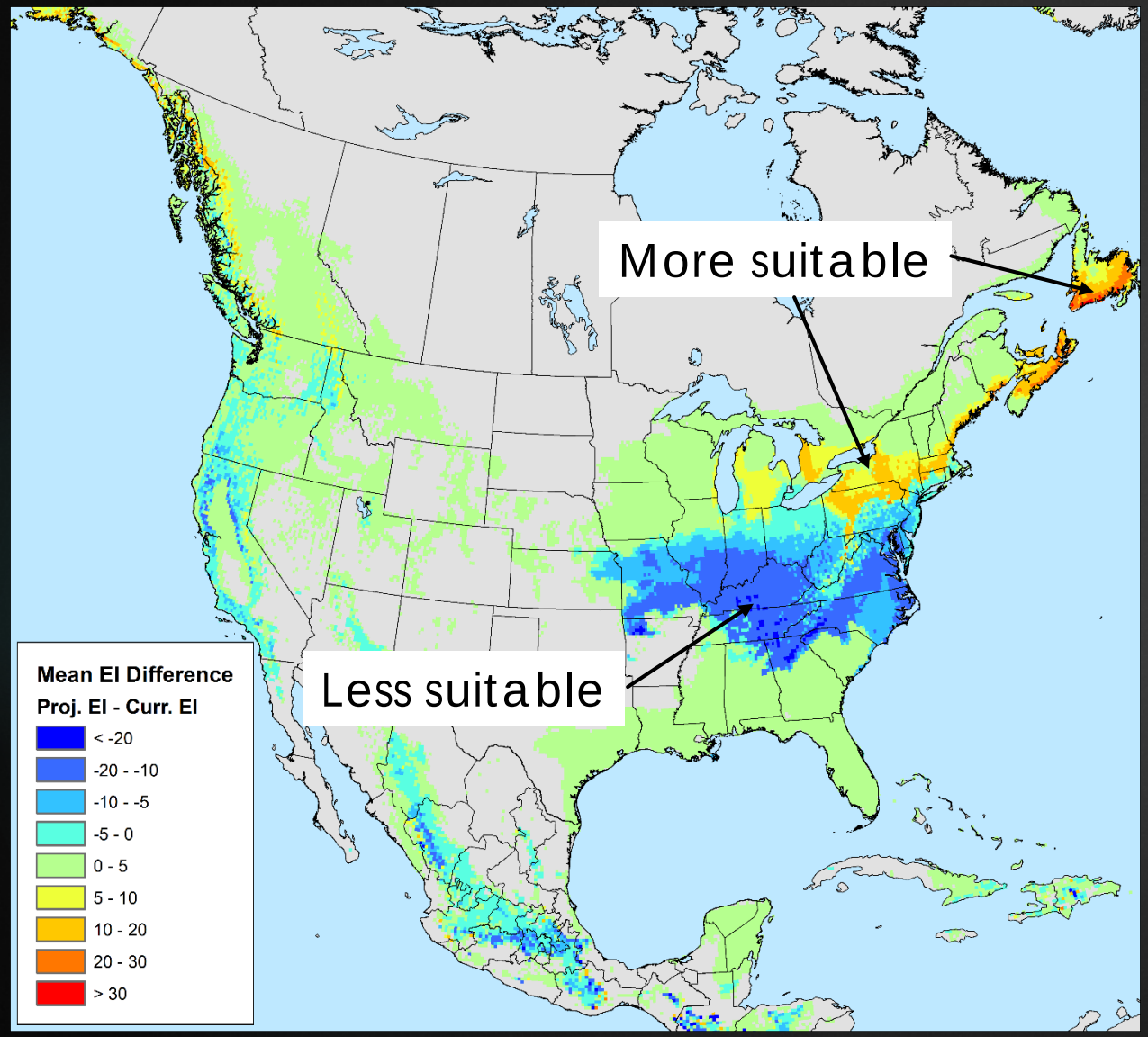
EI

100

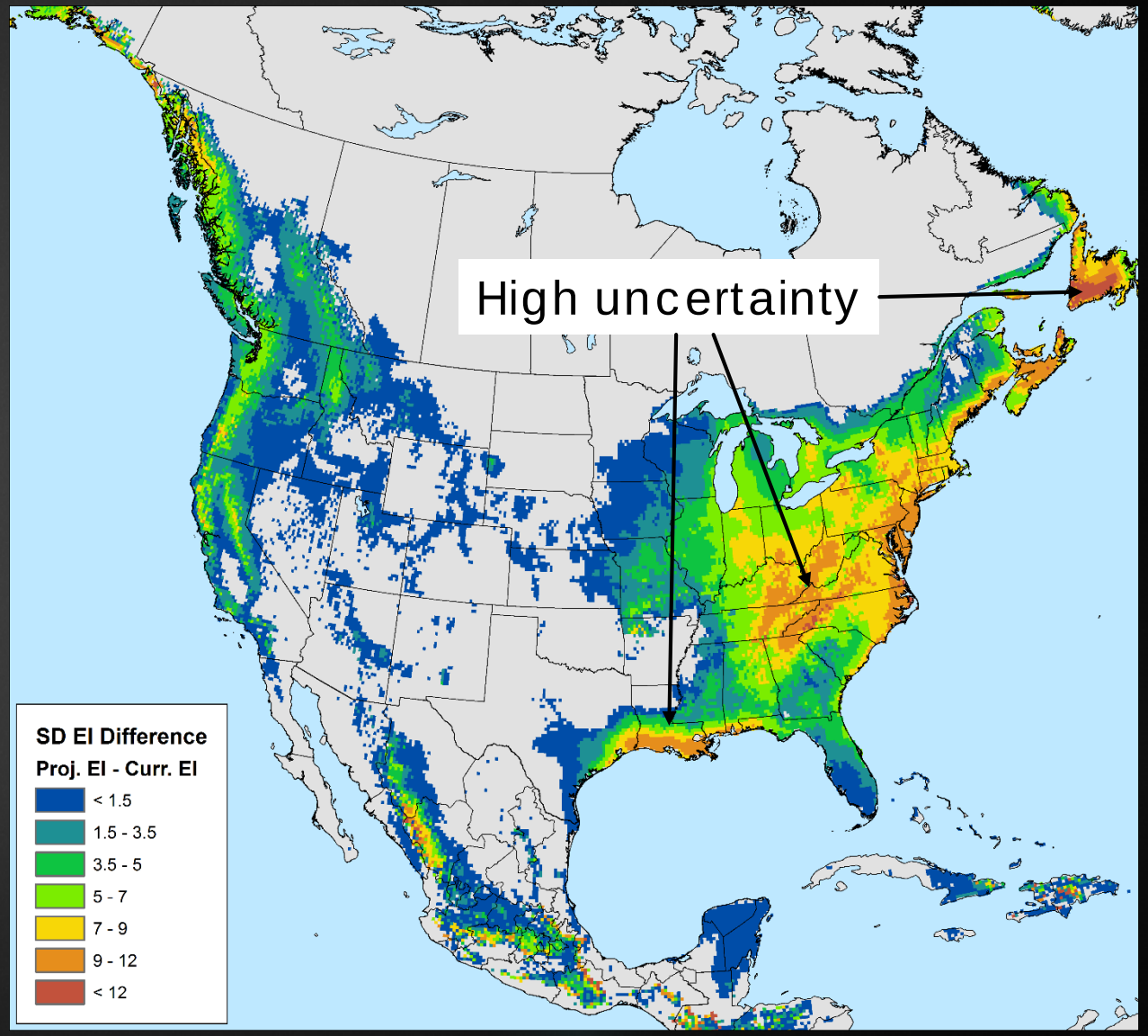
0 (unsuitable)



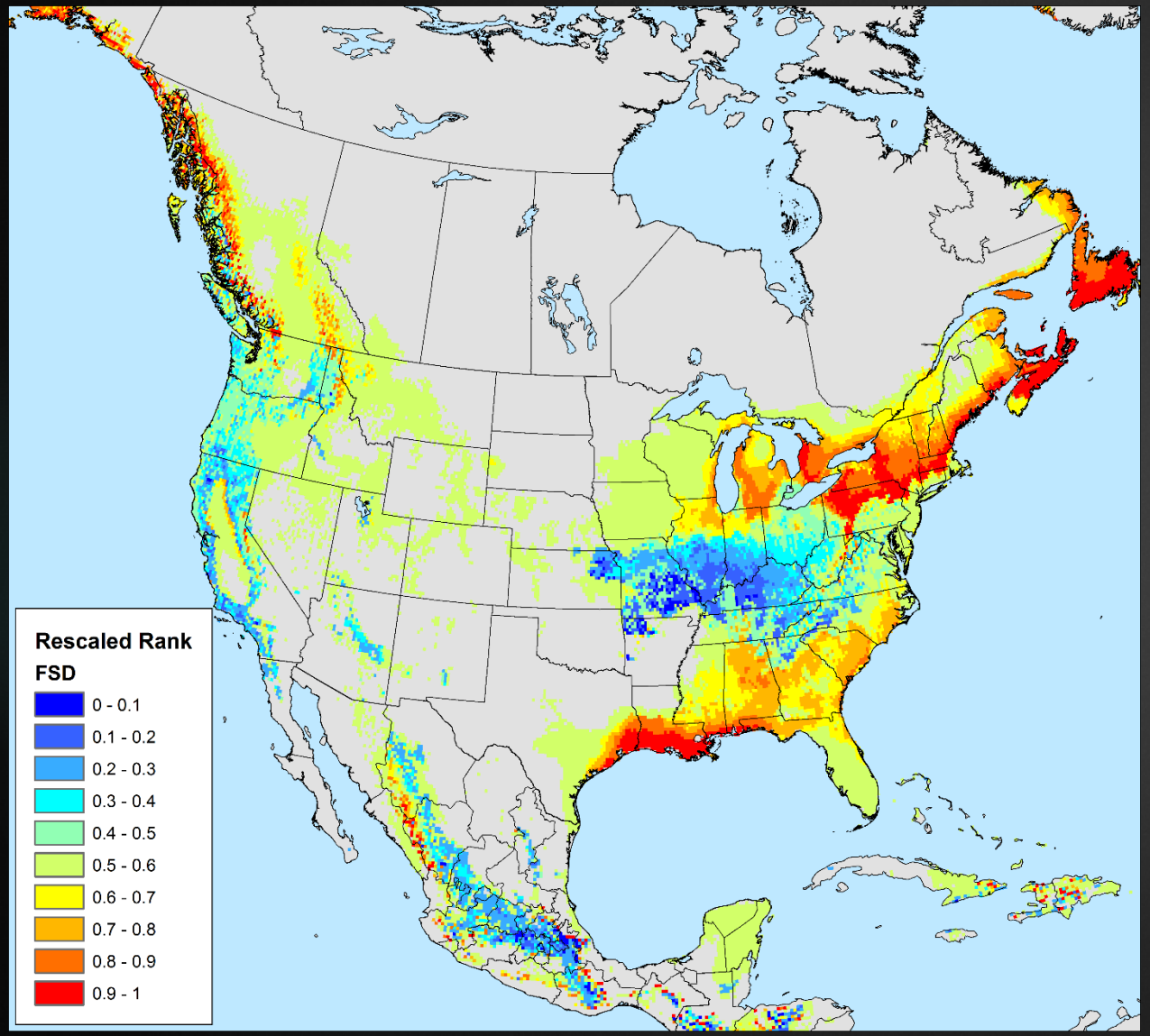
Mean EI difference, projected – current climate



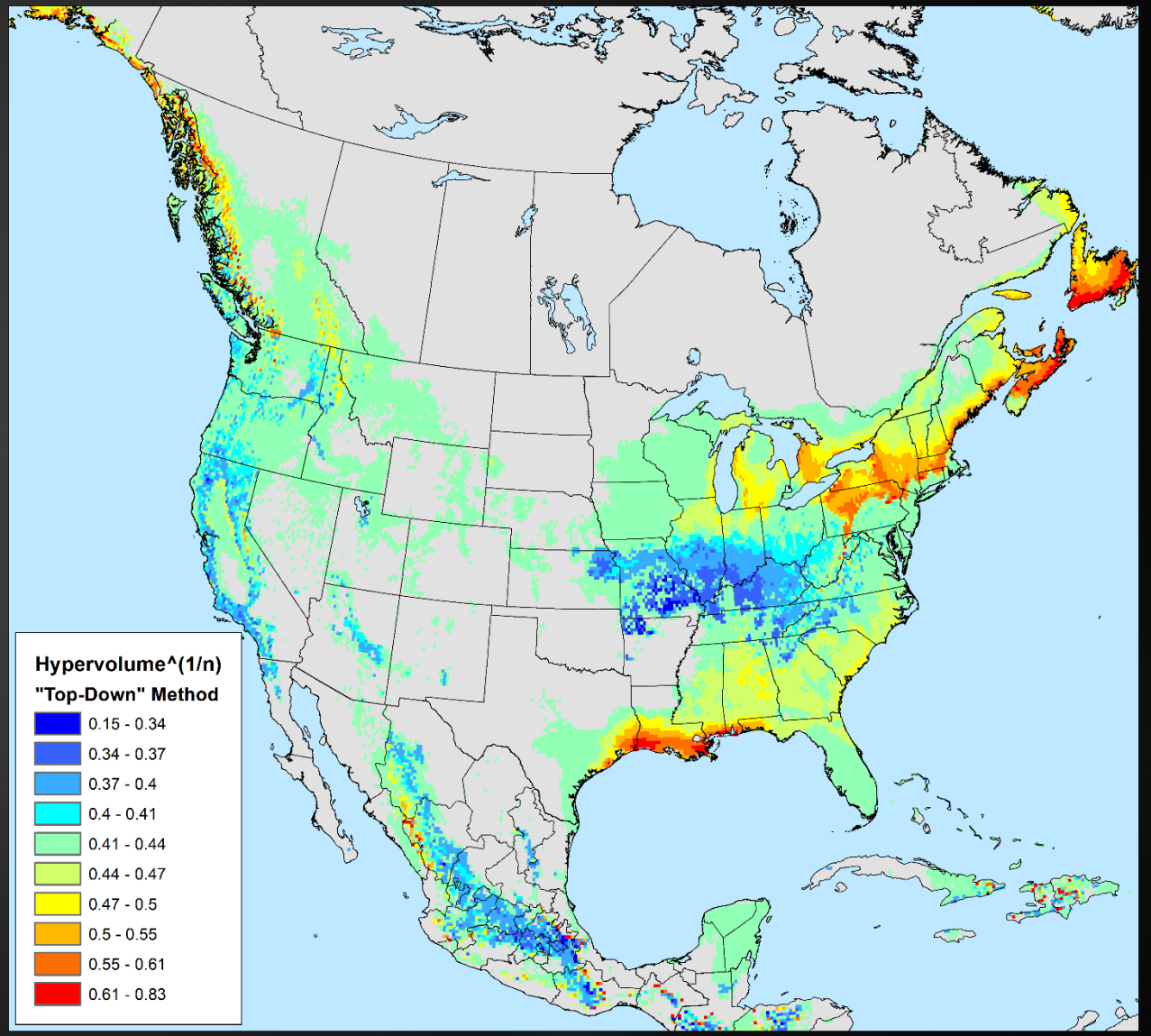
Standard deviation of EI difference



Rescaled rank (0-1) from FSD

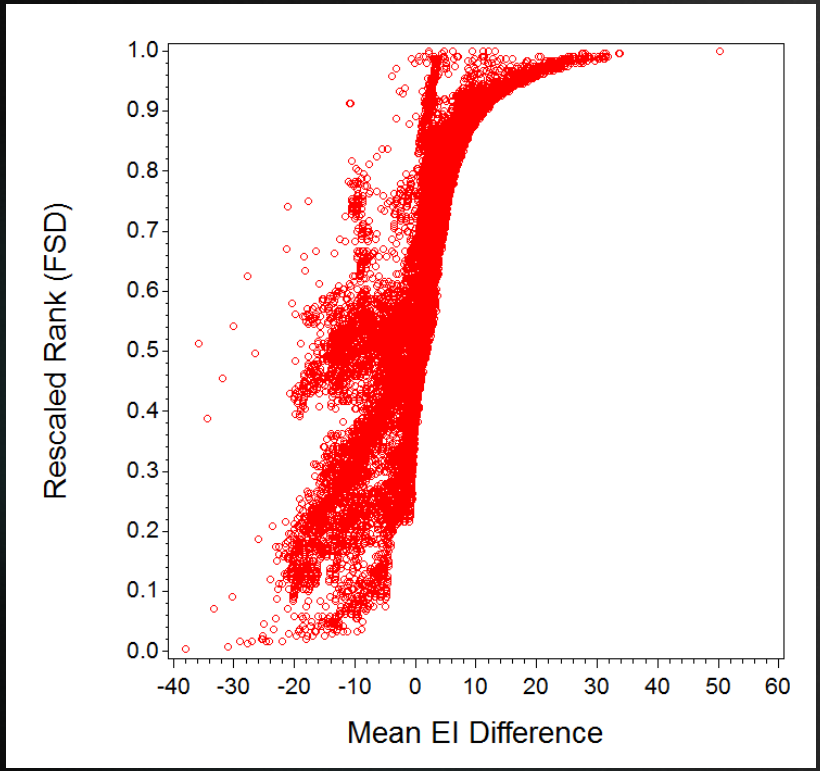


Hypervolume^(1/n)

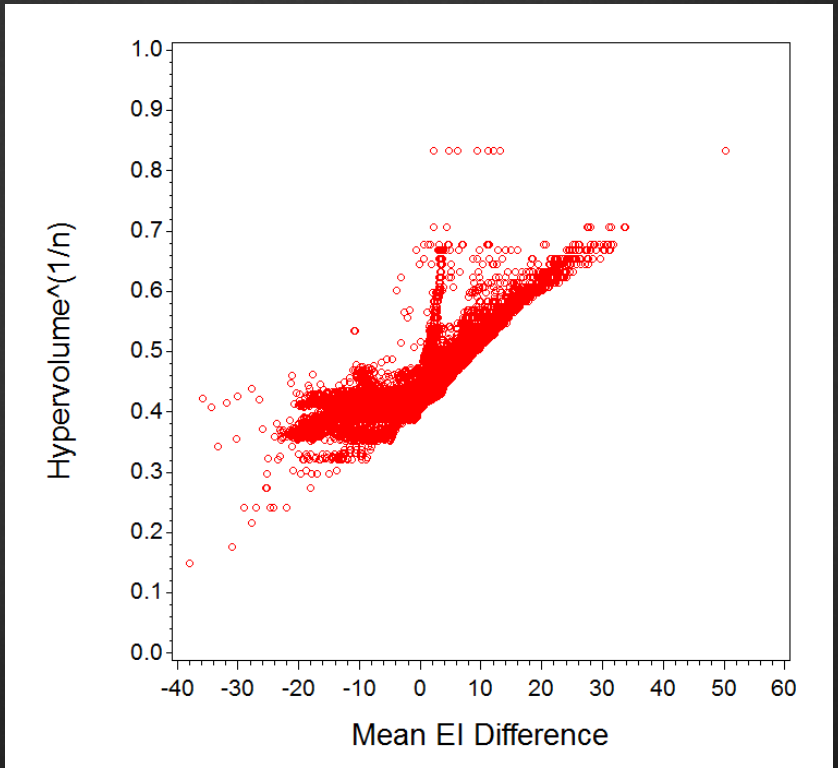


Plotting measures against one another

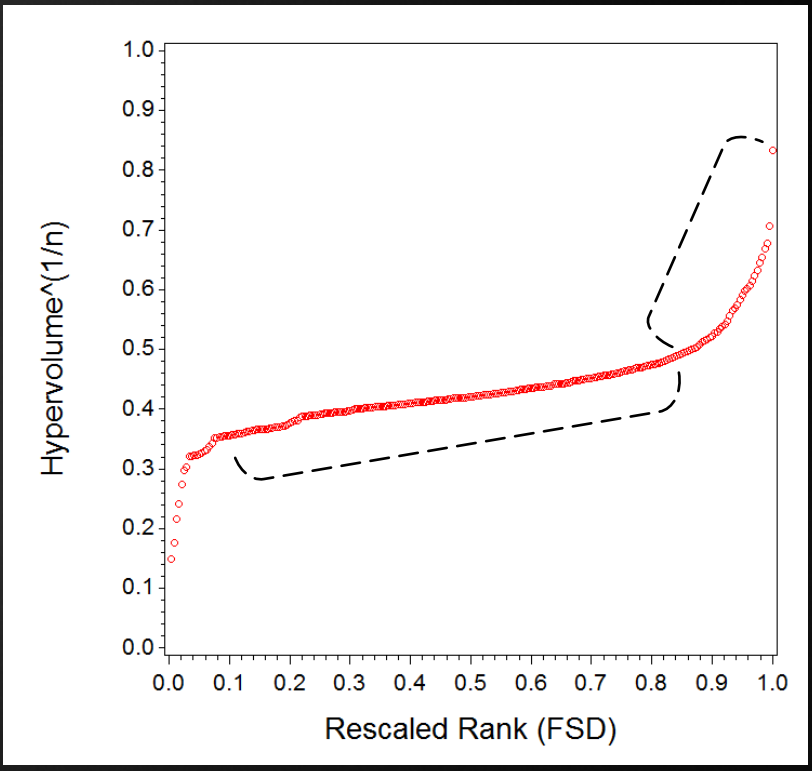
Rescaled rank (FSD) vs. mean EI difference



Hypervolume^(1/n) vs. mean EI difference



Hypervolume^(1/n) vs. rescaled rank (FSD)



Summary points

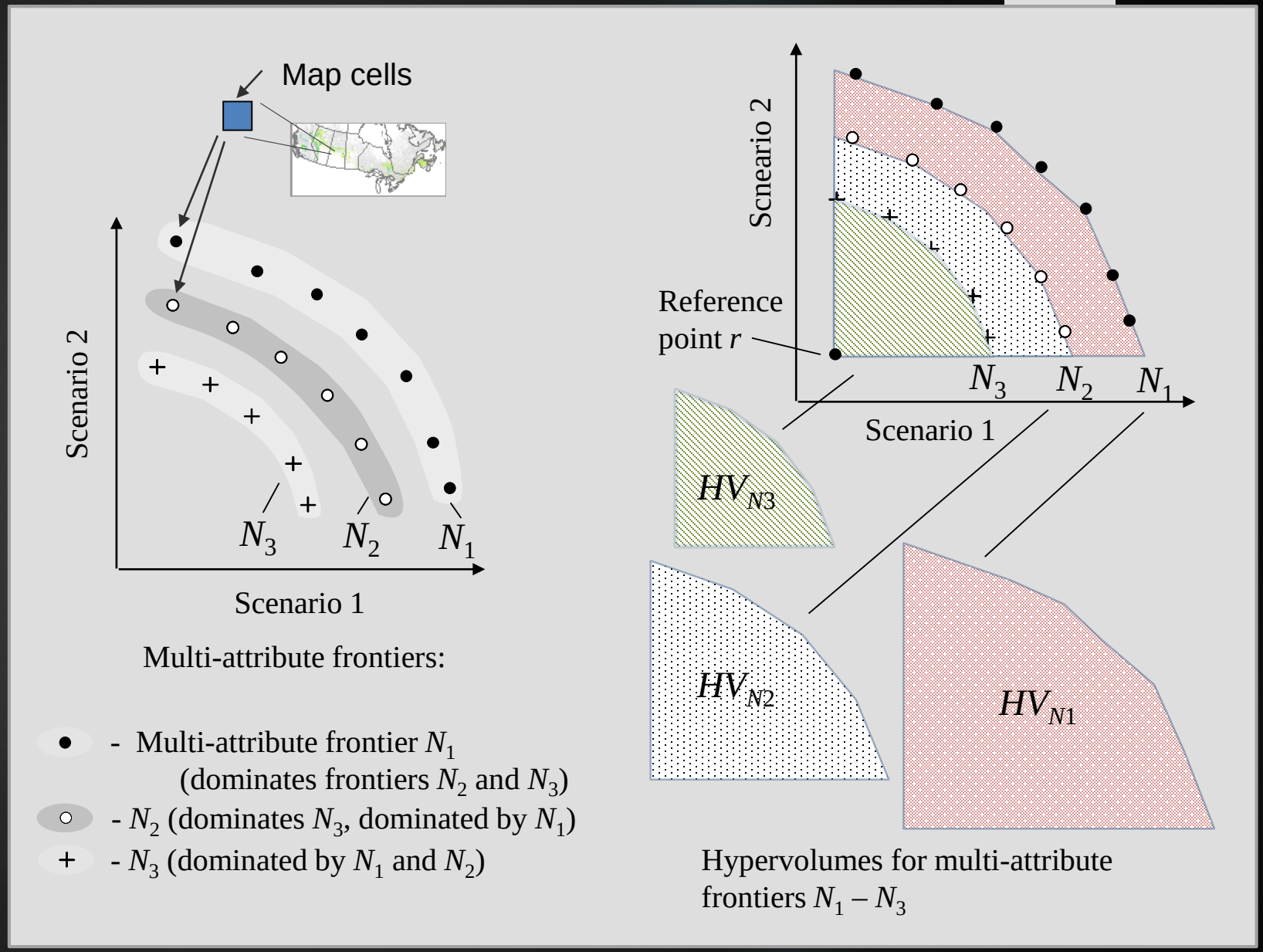
- Both FSD and the hypervolume measure incorporate uncertainty
  - Only dealing with “known unknowns”
- Theoretically, hypervolume measure better than FSD alone
  - More information at top (and bottom) of scale
  - Is this important in practical terms?
- Can use hypervolume measure to compare species
  - Assuming consistent underlying metric, sampling intervals

Additional thoughts

- Outlined approach works well when only considering climate
  - Underlying criteria highly correlated
- But what about other, uncorrelated factors?
  - For example, economic and geopolitical factors
  - May have disparate (and highly uncertain) outcomes
- In this case, scenario analysis may be appropriate
  - Can still use hypervolumes
  - Instead of FSD, use multi-attribute frontier aggregation (MAFs)

Scenario analysis: 2D example

- Scenario 1 = Northwest Passage
  - Stronger connection between northern Europe and western North America
- Scenario 2 = Panama Canal
  - Stronger connection between eastern Asia and eastern North America
- Practical limit is about 10-15 scenarios



Questions?

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