WS01 – Hypervolume modeling: a multivariate tool for seagrass ecosystem assessments

W. Ryan James, Rolando O. Santos, Benjamin Jones, Jennifer S. Rehage, Gina Badlowski, Jonathan Rodemann, Marianna Coppola

06/21/2024

SANTOS SEASCAPE ECOLOGY LAB

FIU Institute of Environment
FLORIDA INTERNATIONAL UNIVERSITY

PROJECT SEAGRASS

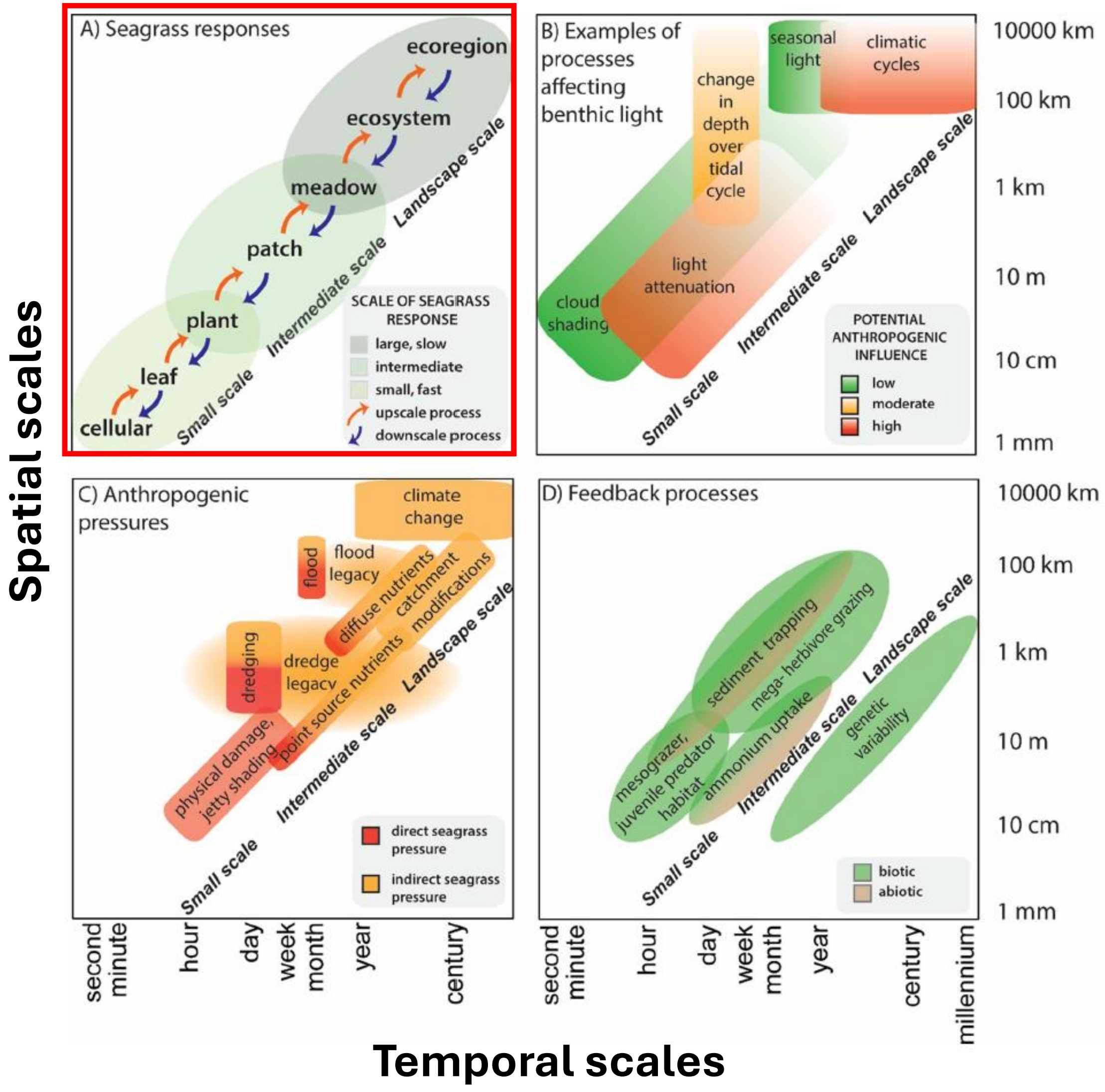
COASTAL FISHERIES RESEARCH LAB
FLORIDA INTERNATIONAL UNIVERSITY

Agenda and materials

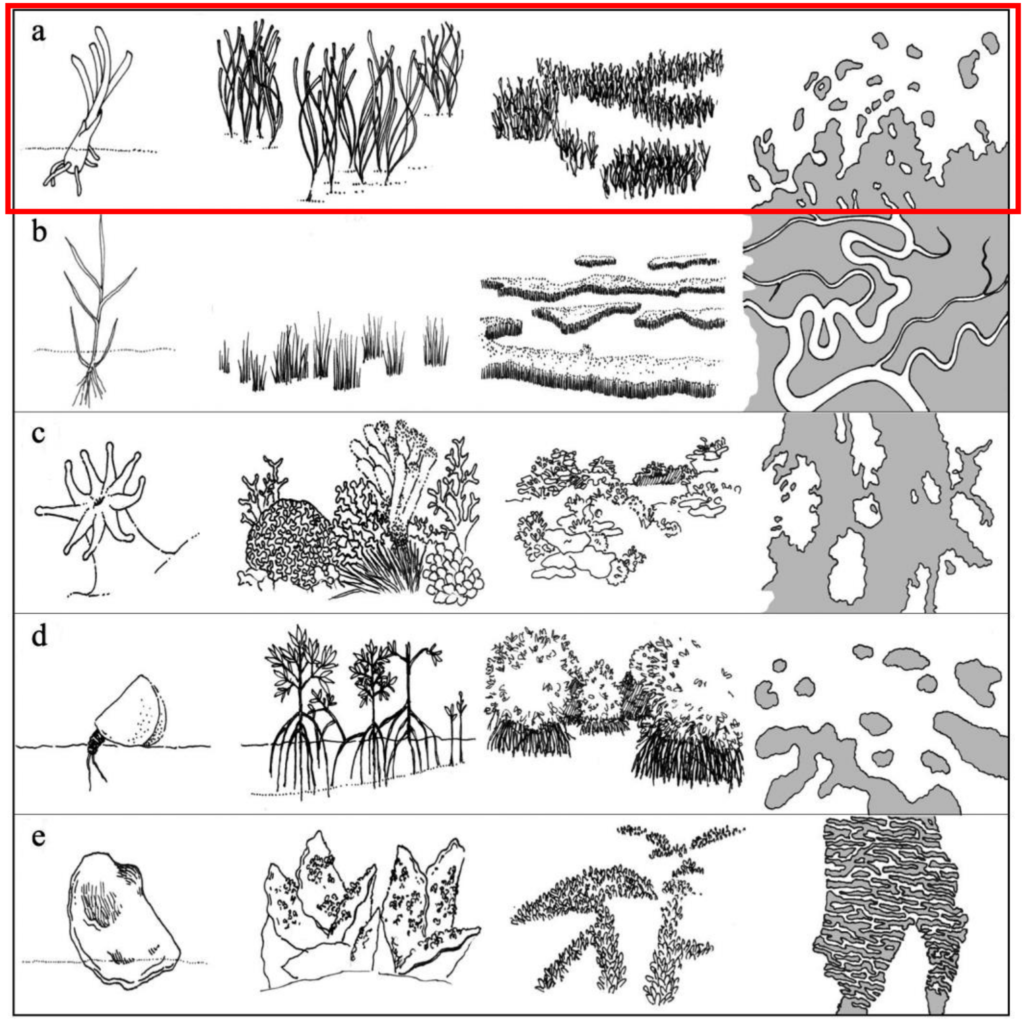
- 2:30 – Overview of hypervolumes and metrics
- 2:50 – Case studies
- 3:05 – Q & A
- 3:20 – Code run through

- Workshop website: https://coastalfishscience.github.io/ISBW_HVworkshop/
- Padlet for questions: https://padlet.com/badlowski2/hypervolume-modelling-pteo4vn56sk8z2bk

Many ecological questions are multivariate in nature – e.g. multiscale processes and responses

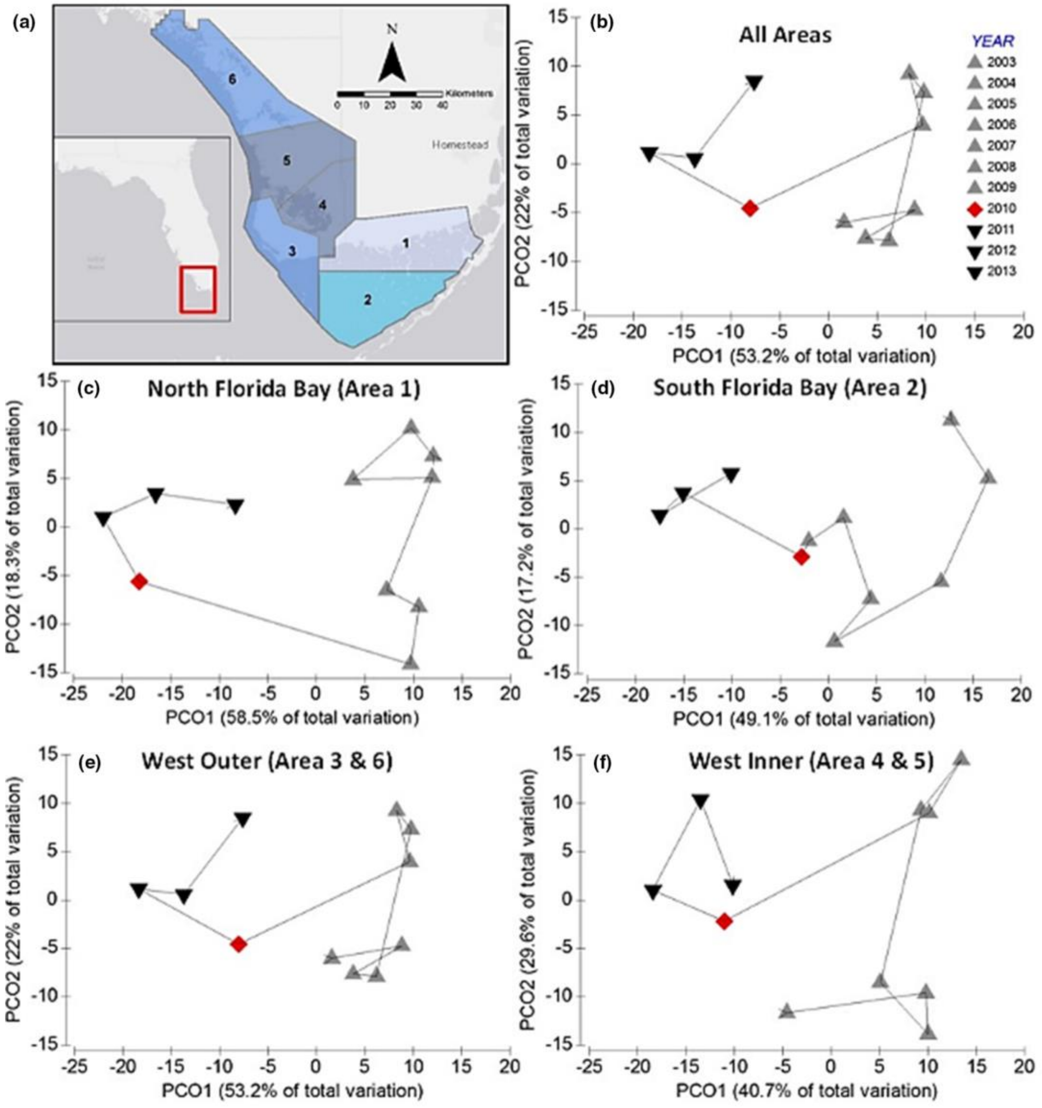


O'Brien et al. 2017. Mar Pul Bul

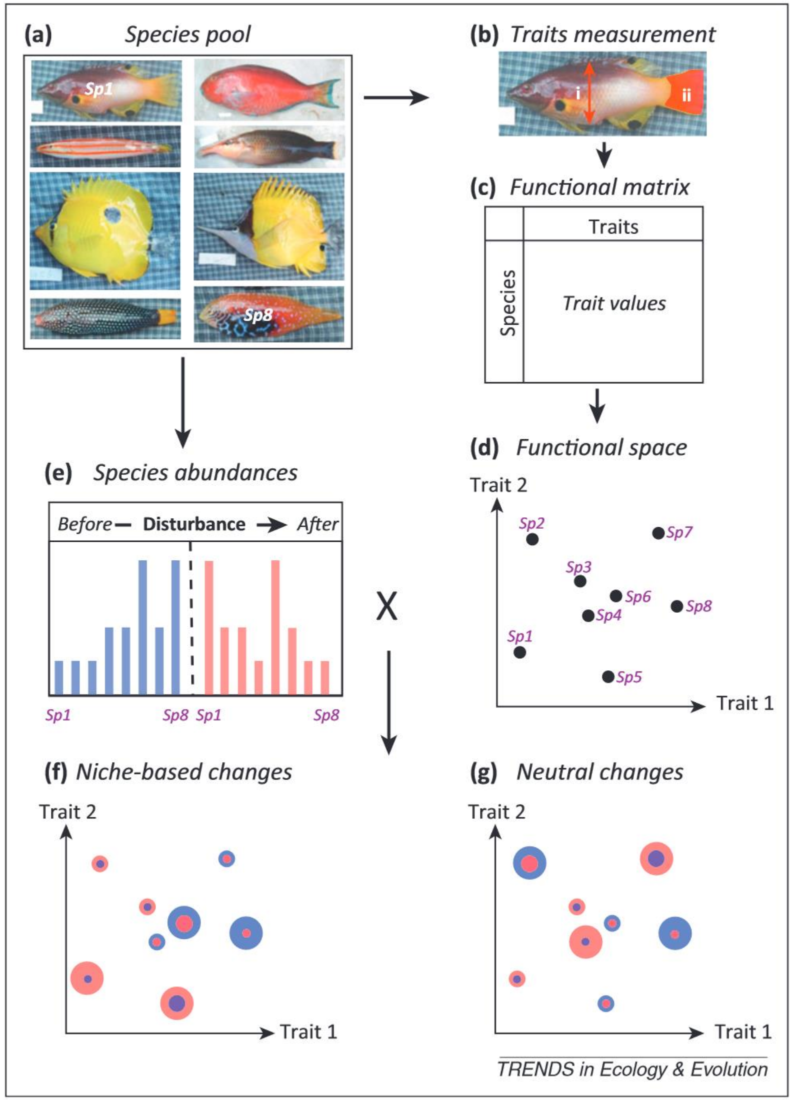


Boström et al. 2011. MEPS

Many ecological questions are multivariate in nature – e.g. taxonomic or trait structure

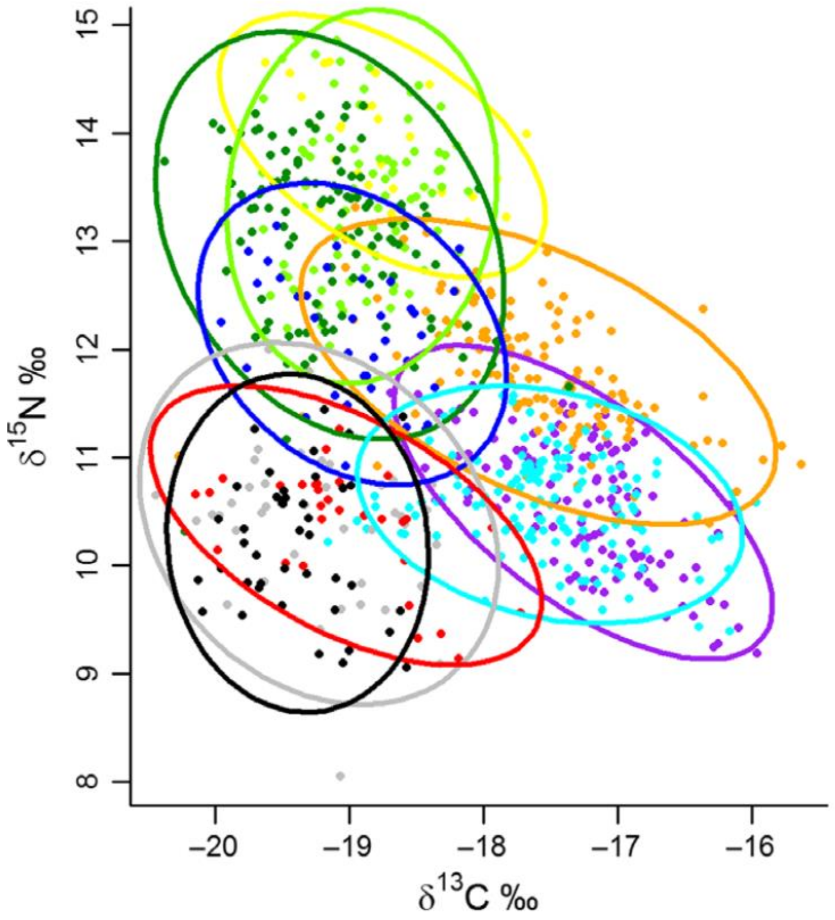


Santos et al. 2016. Ecosphere

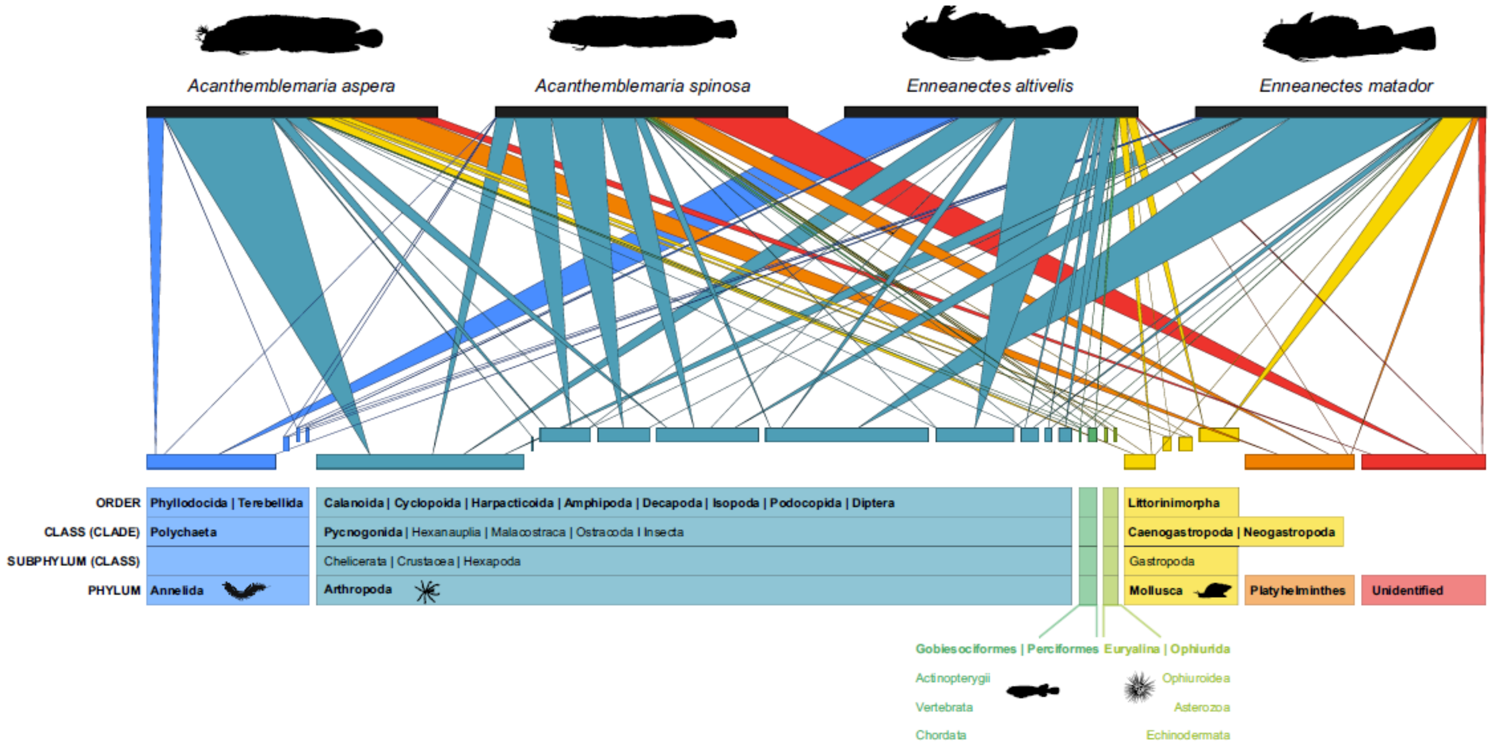


Mouillot et al. 2013. TREE

Many ecological questions are multivariate in nature – e.g. species interactions and trophic dynamics

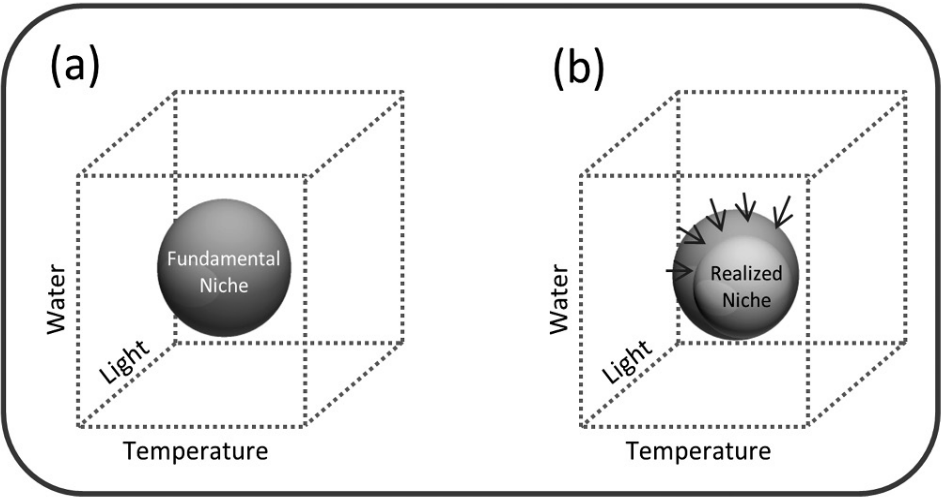


Sheppard et al. 2018. Ecol Lett



Brandl et al. 2020. Coral Reefs

Adaptation of the Hutchinson's n-dimensional hypervolume to address complex questions



Cambridge University Press

Computational Power =

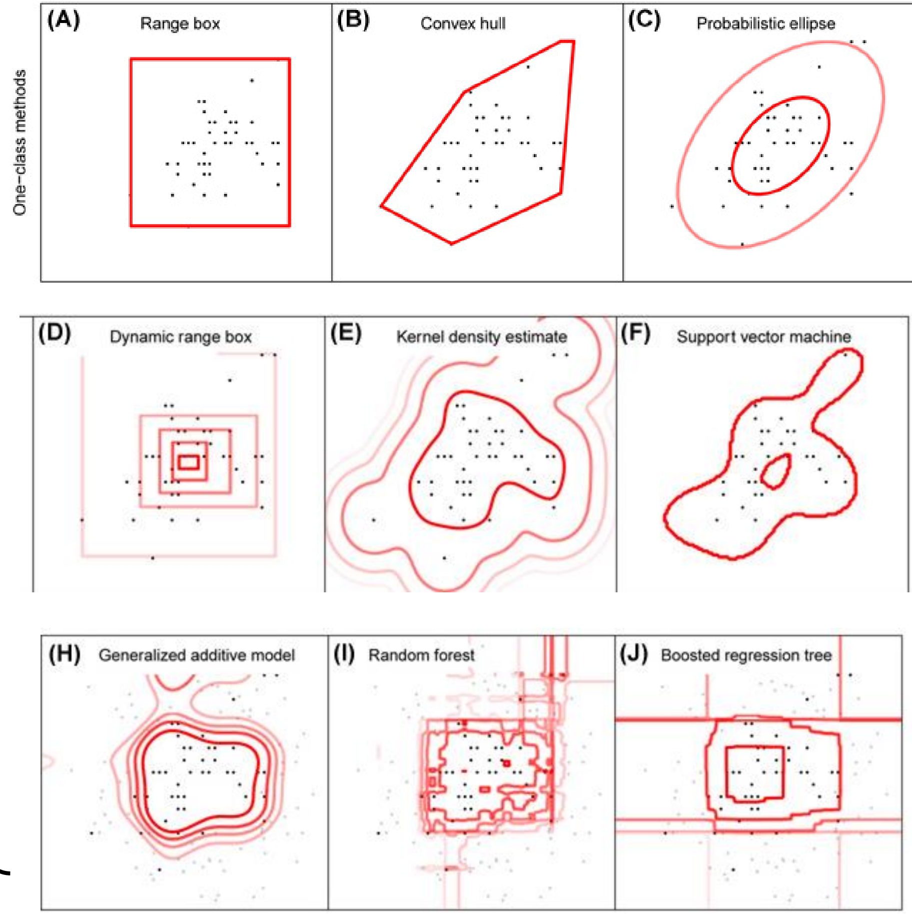
Trait Ecology

Trophic Ecology

Ecography

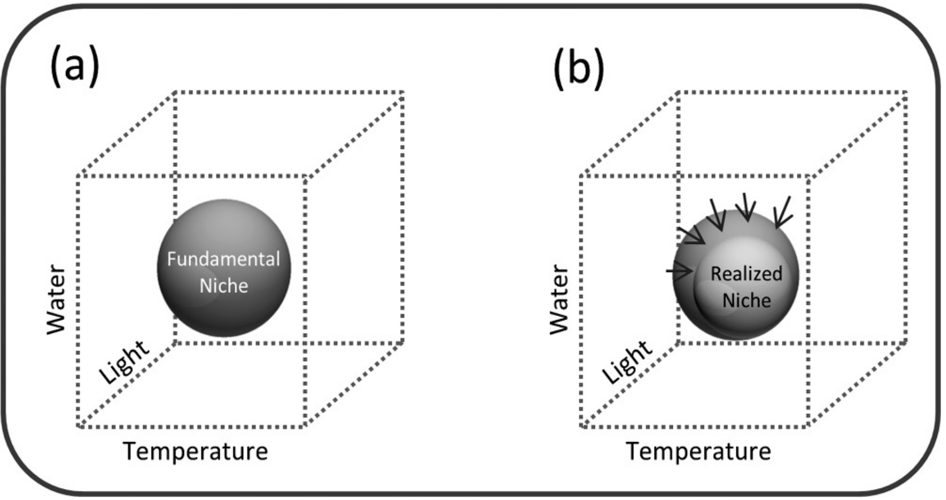
Ecosystem

Examples of analytical approaches



Blonder et al. 2017. Ecography

Adaptation of the Hutchinson's n-dimensional hypervolume to address complex questions



Cambridge University Press

Computational Power =

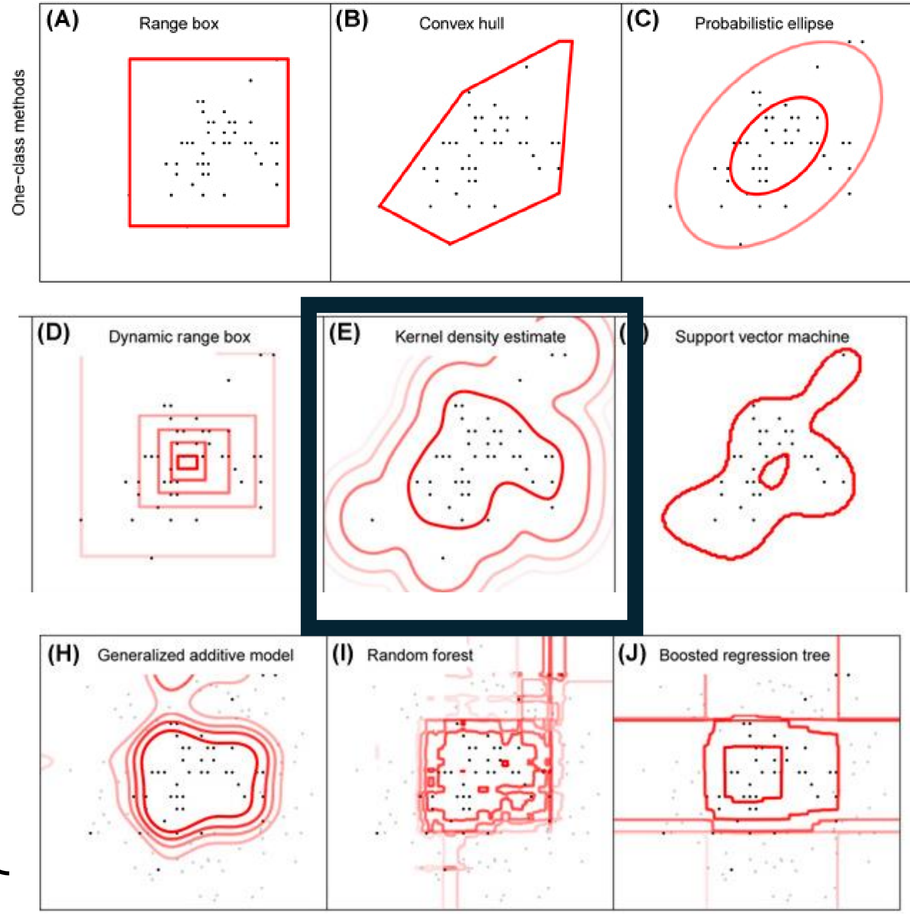
Trait Ecology

Trophic Ecology

Ecography

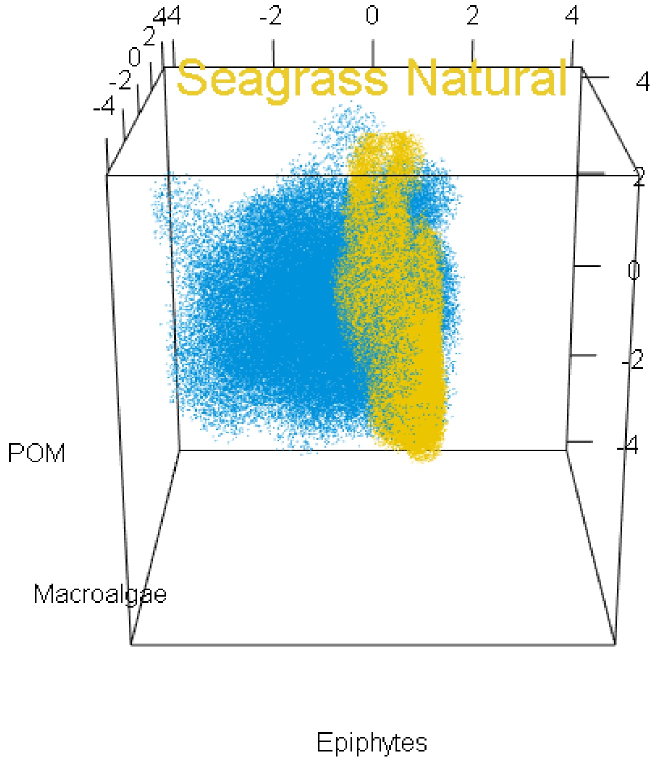
Ecosystem

Examples of analytical approaches



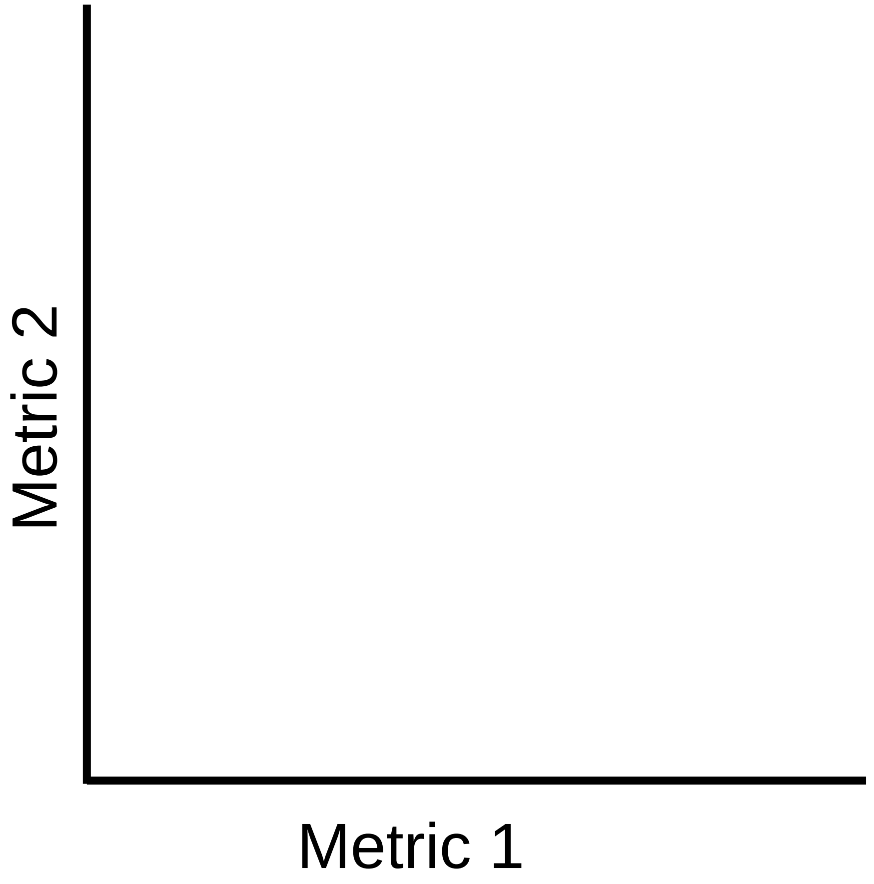
Blonder et al. 2017. Ecography

Hypervolumes

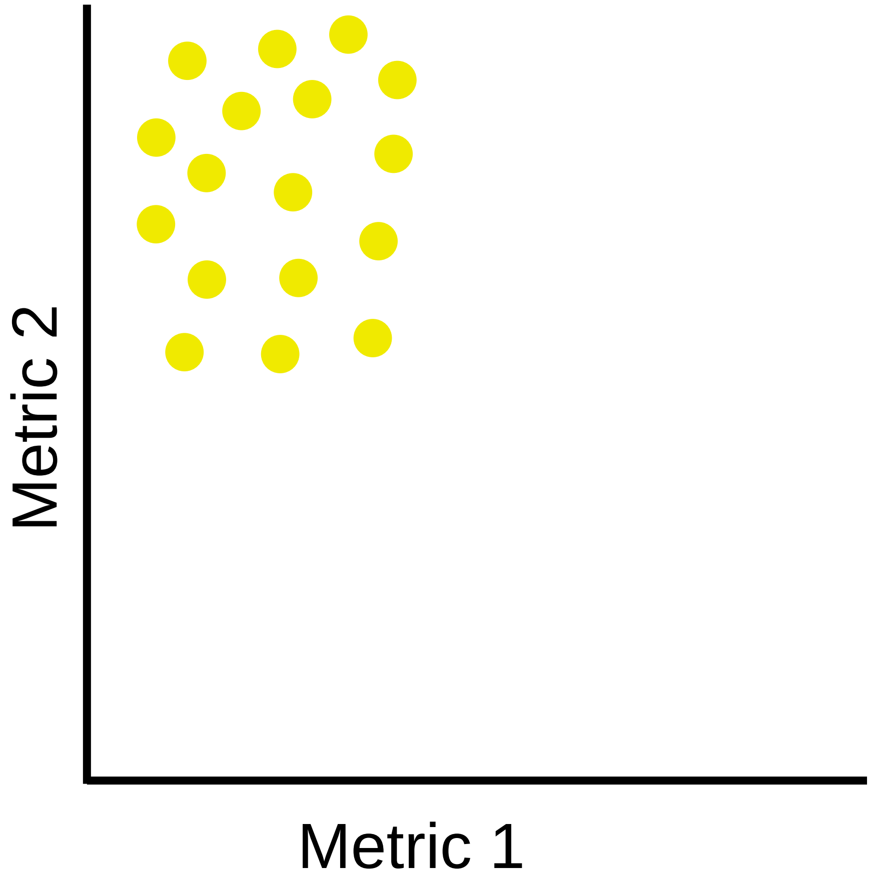


- Hypervolumes (Blonder et al. 2014, 2018)
- Kernal density estimation (but others in package)
- Multivariate tool (*n* – dimensional)
- Hypervolume metrics useful in ecological analysis

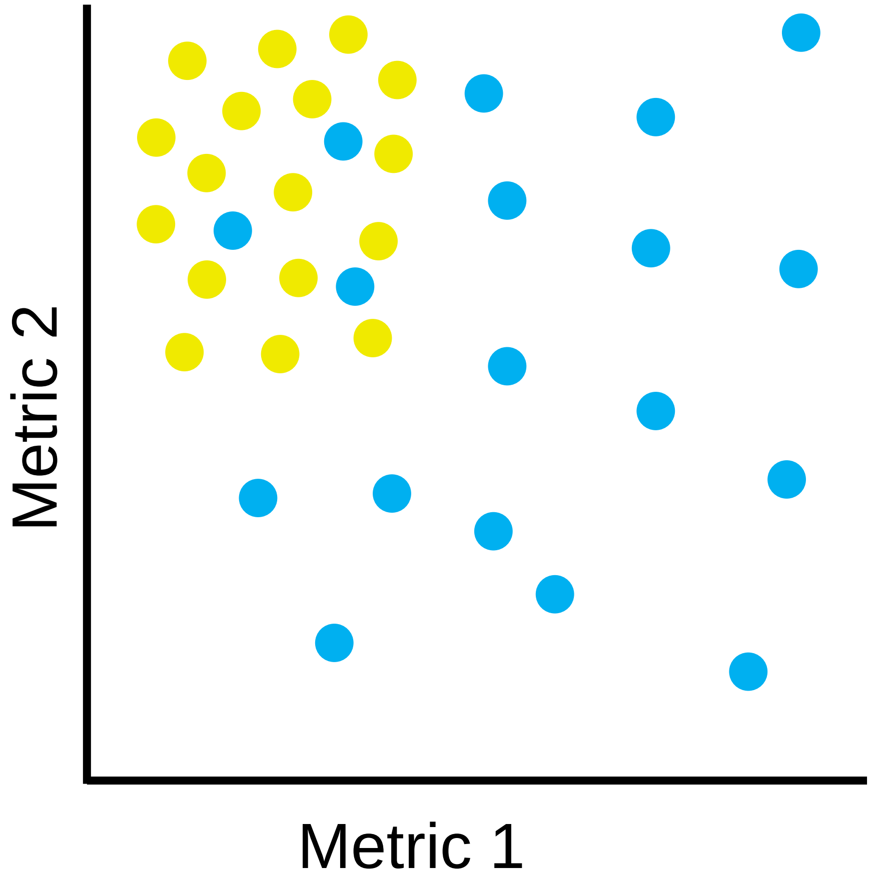
Building Hypervolumes



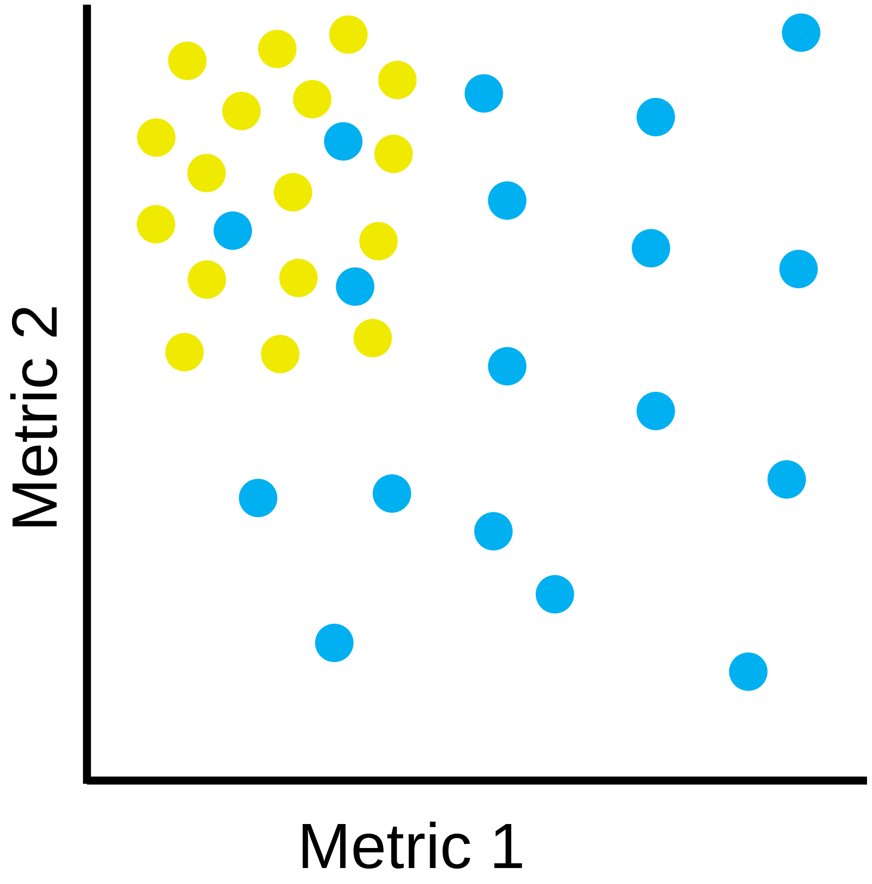
Building Hypervolumes



Building Hypervolumes

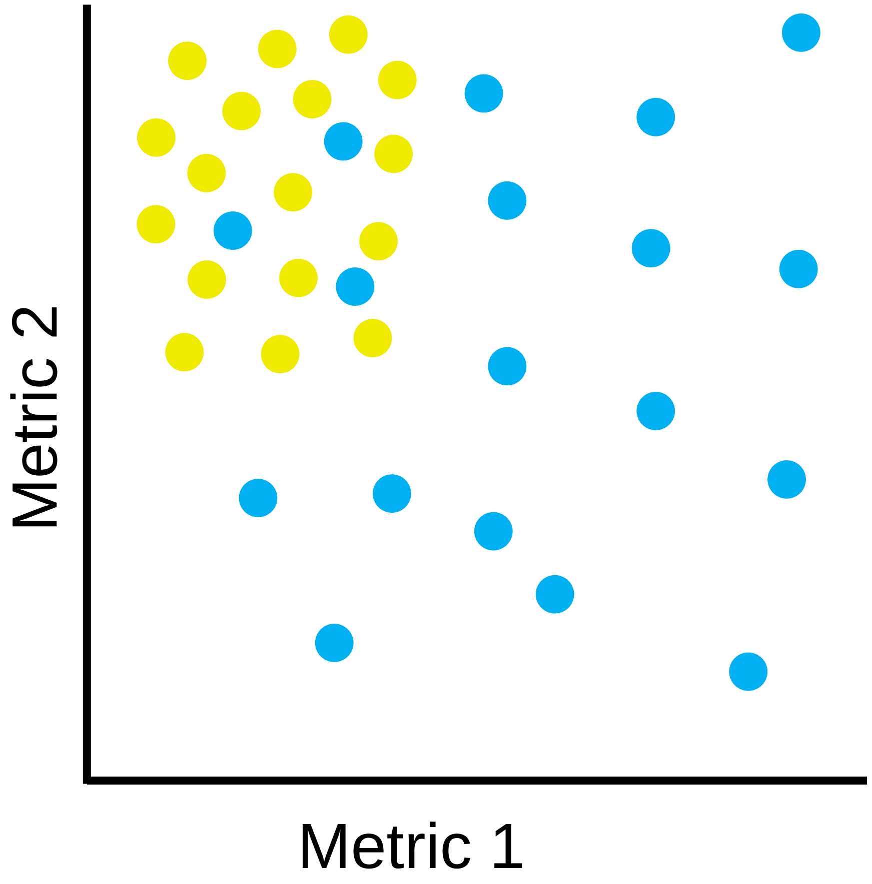


Building Hypervolumes

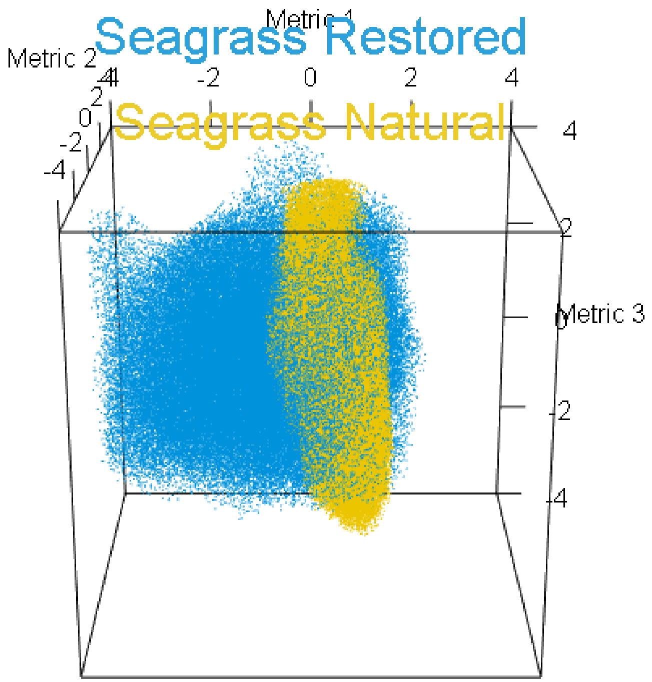


n dimensions

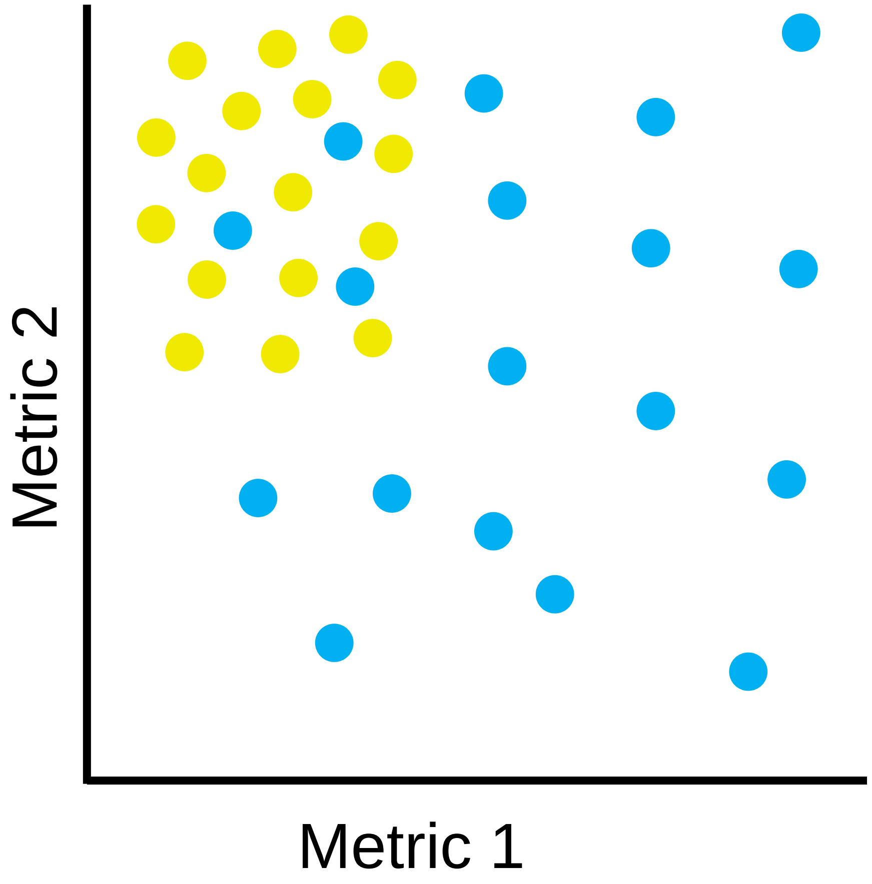
Building Hypervolumes



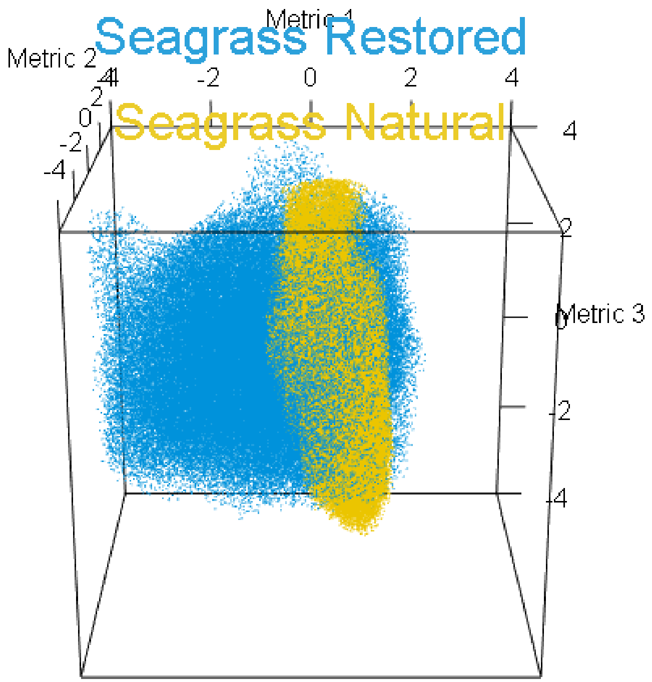
n dimensions



Building Hypervolumes

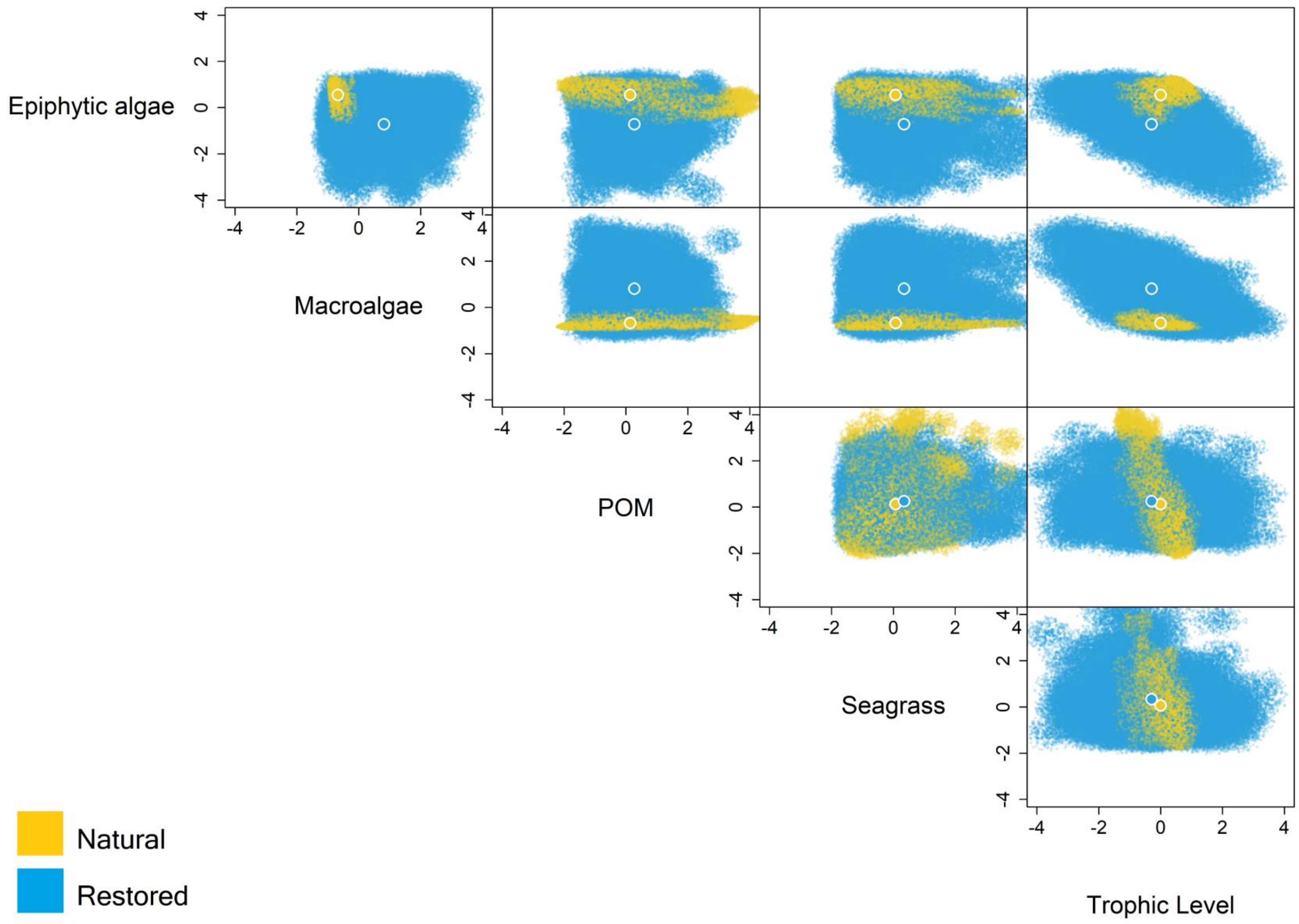


n dimensions

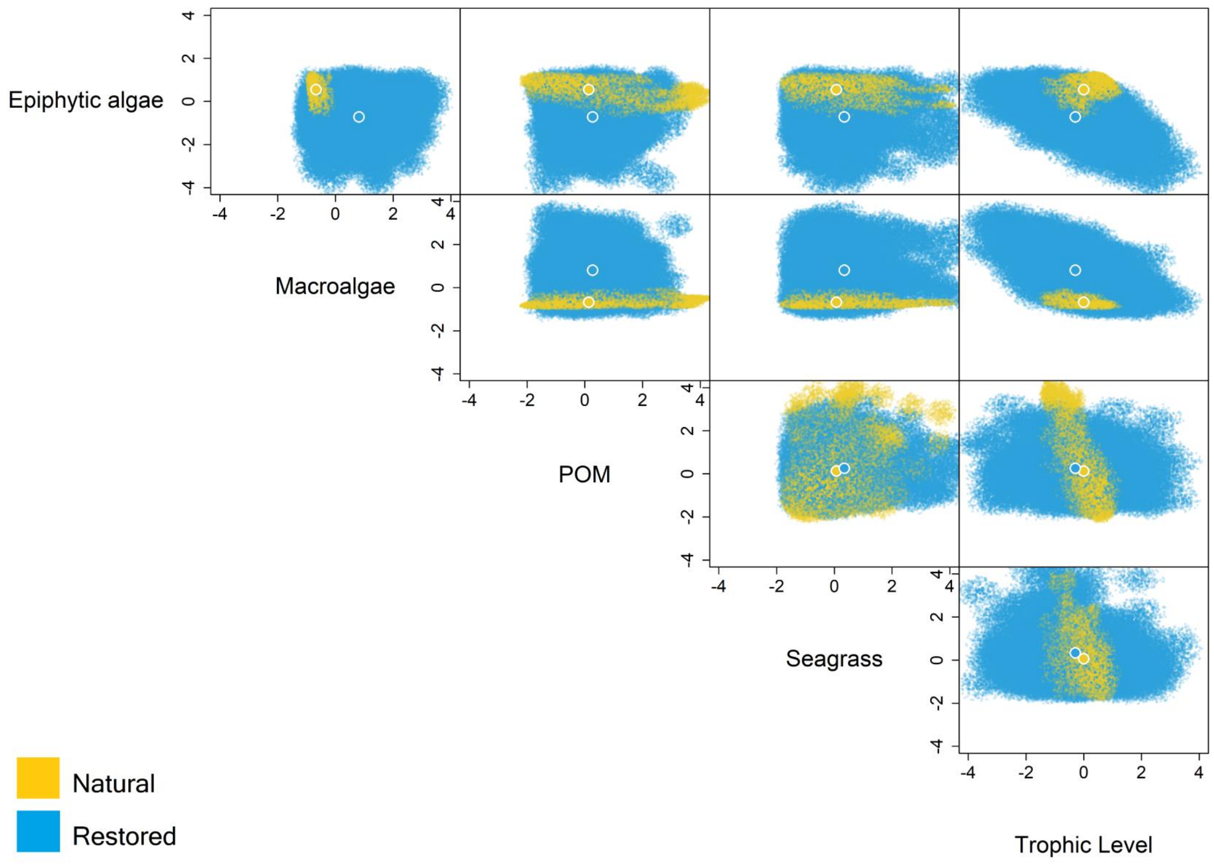


Size based on variability

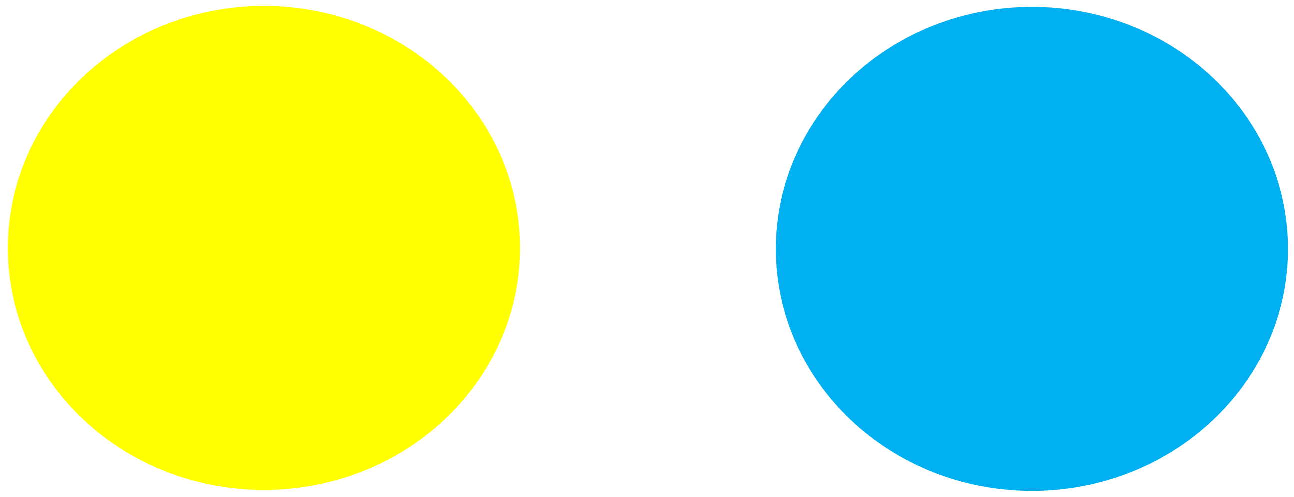
Hypervolume biplot



Hypervolume biplot



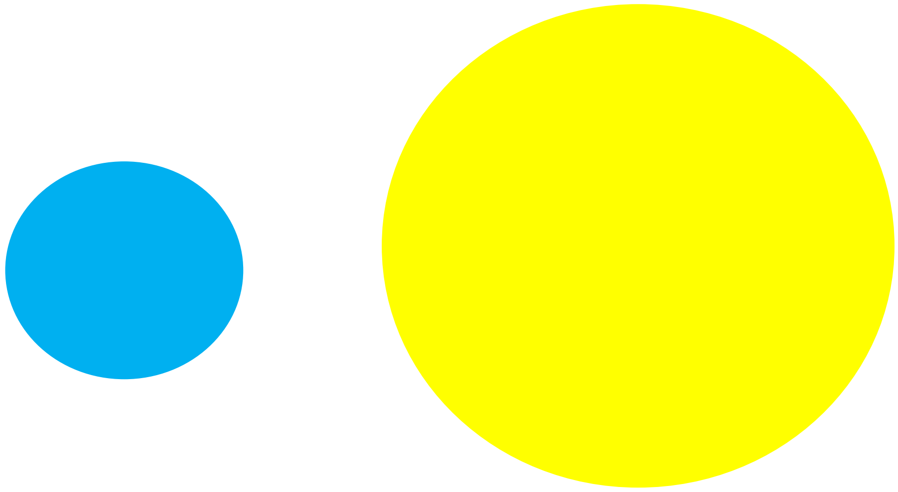
Hypervolume metrics



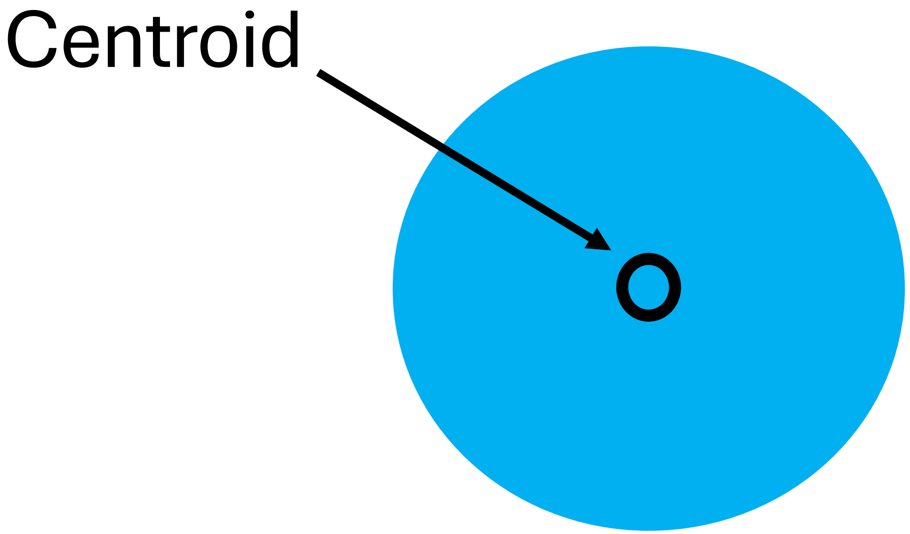
HV1 HV2

Hypervolume metrics – single

- Hypervolume size (volume) – total space occupied by a hypervolume
  - Variation of input data
  - Trophic niche size
  - Trait diversity
  - Spatial variability

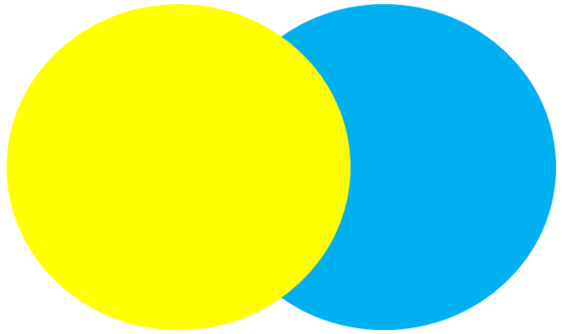


- Centroid – center point of hypervolume
  - Mean conditions / location in hypervolume space
  - Community weighted mean

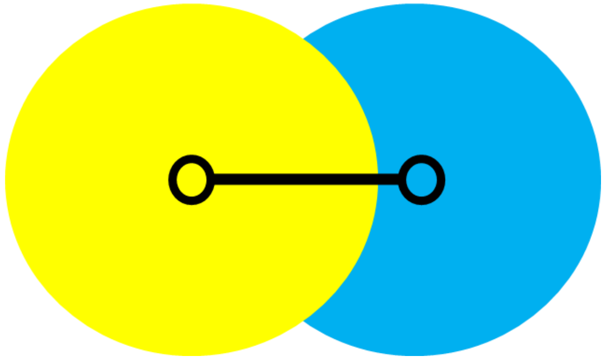


Hypervolume metrics – comparison

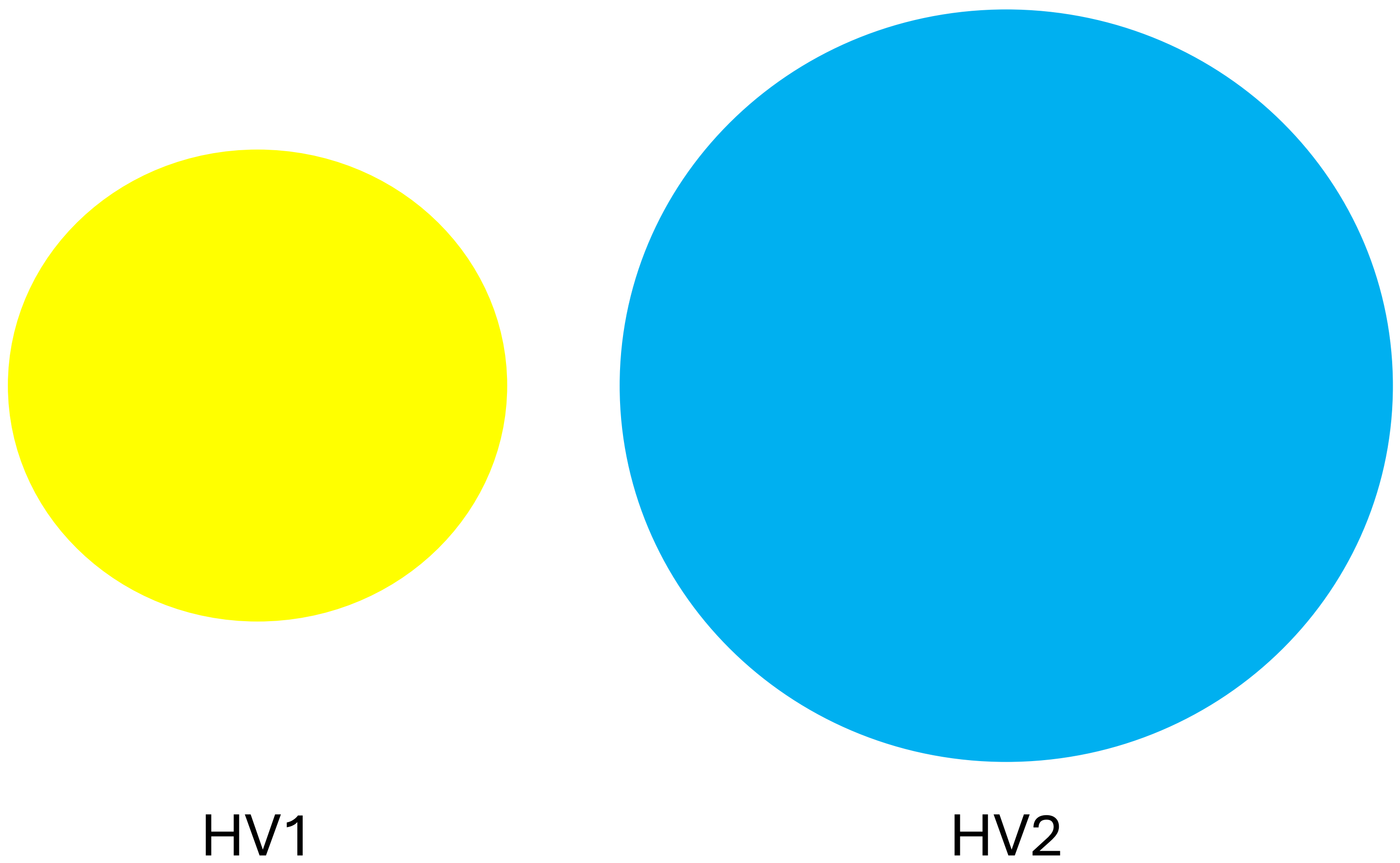
- Hypervolume overlap – amount of space two hypervolumes share relative to overall space of two hypervolumes
    - Similarity
    - Niche overlap/packing/resource partioning
    - Trait similarity/packing



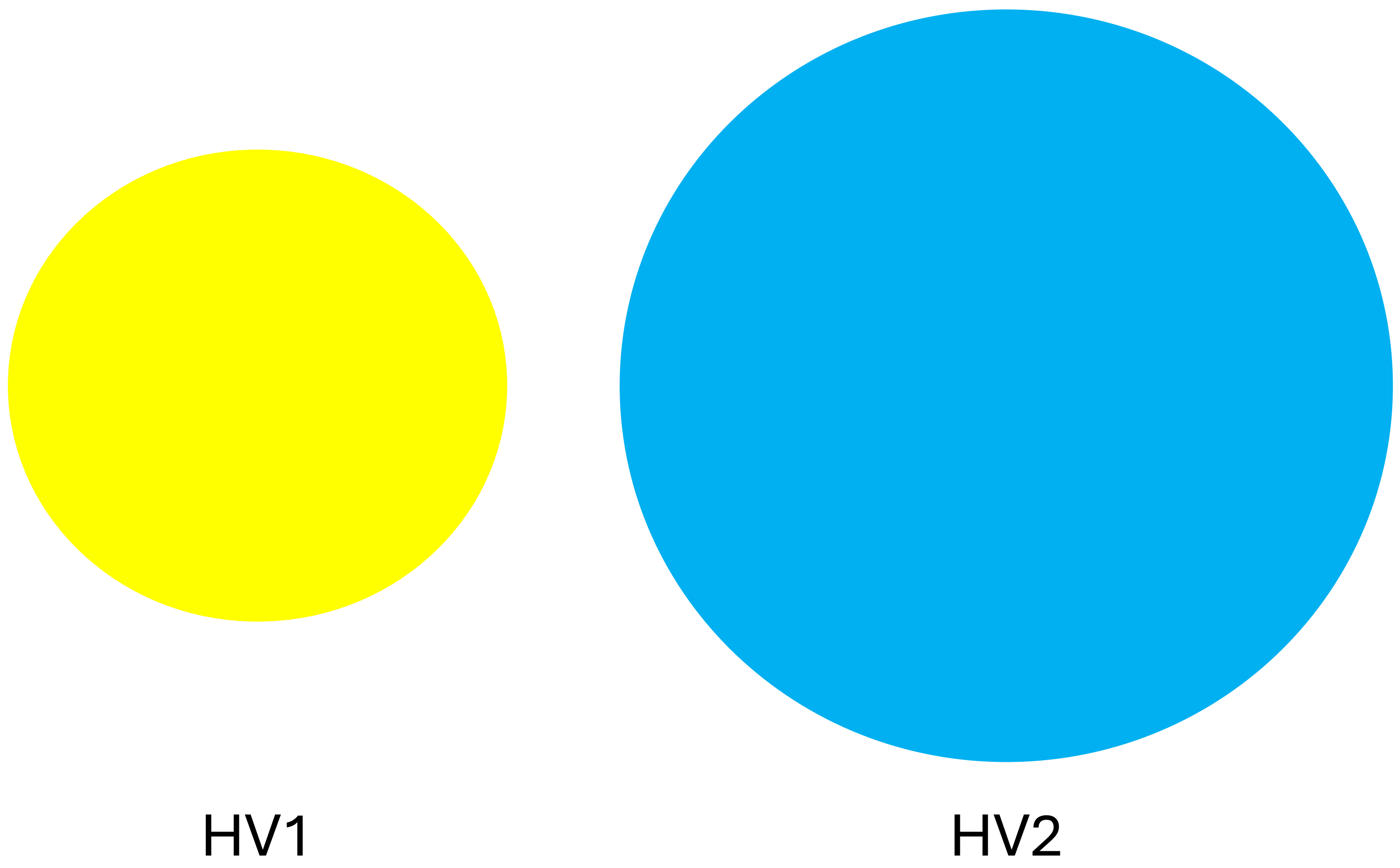
- Centroid distance – Euclidean distance between two hypervolume centroids
    - mean conditions / location in hypervolume space
    - Stability
    - Niche/trait shift



Hypervolume size

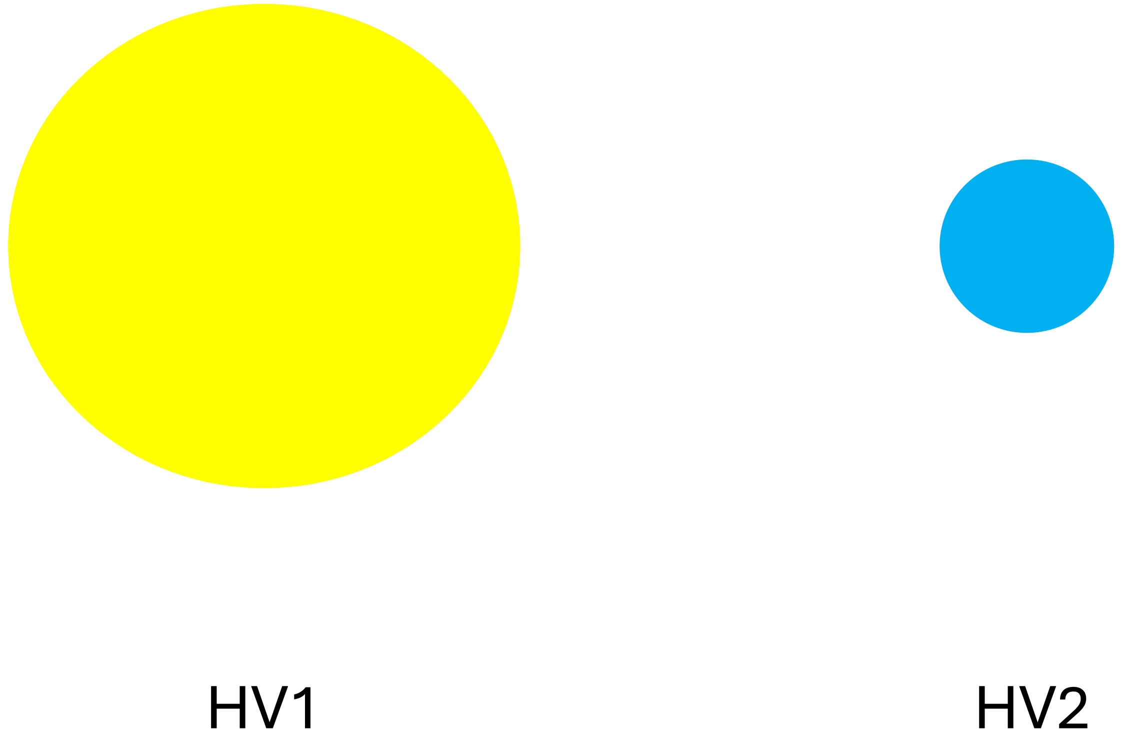


Hypervolume size

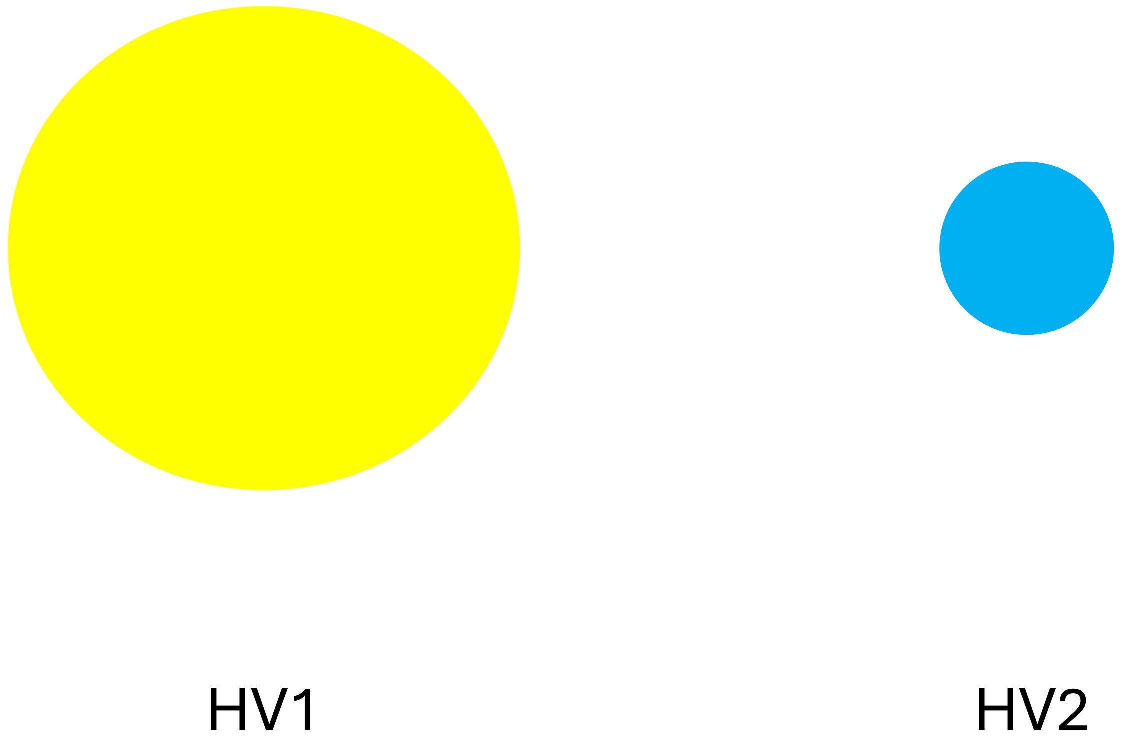


HV1 variation < HV2 variation

Hypervolume size



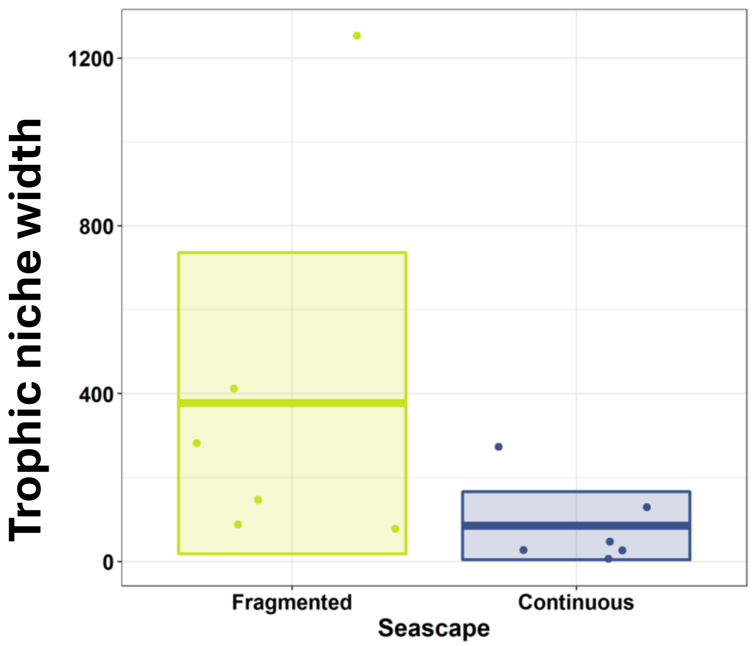
Hypervolume size

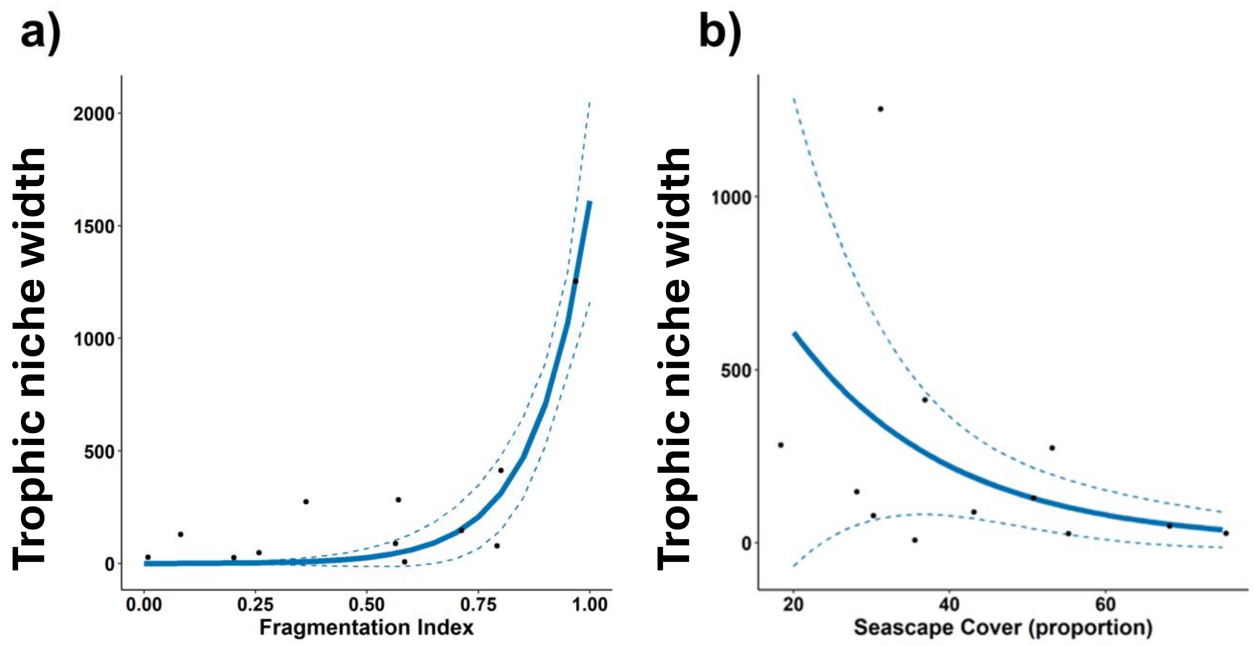


HV1 variation < HV2 variation

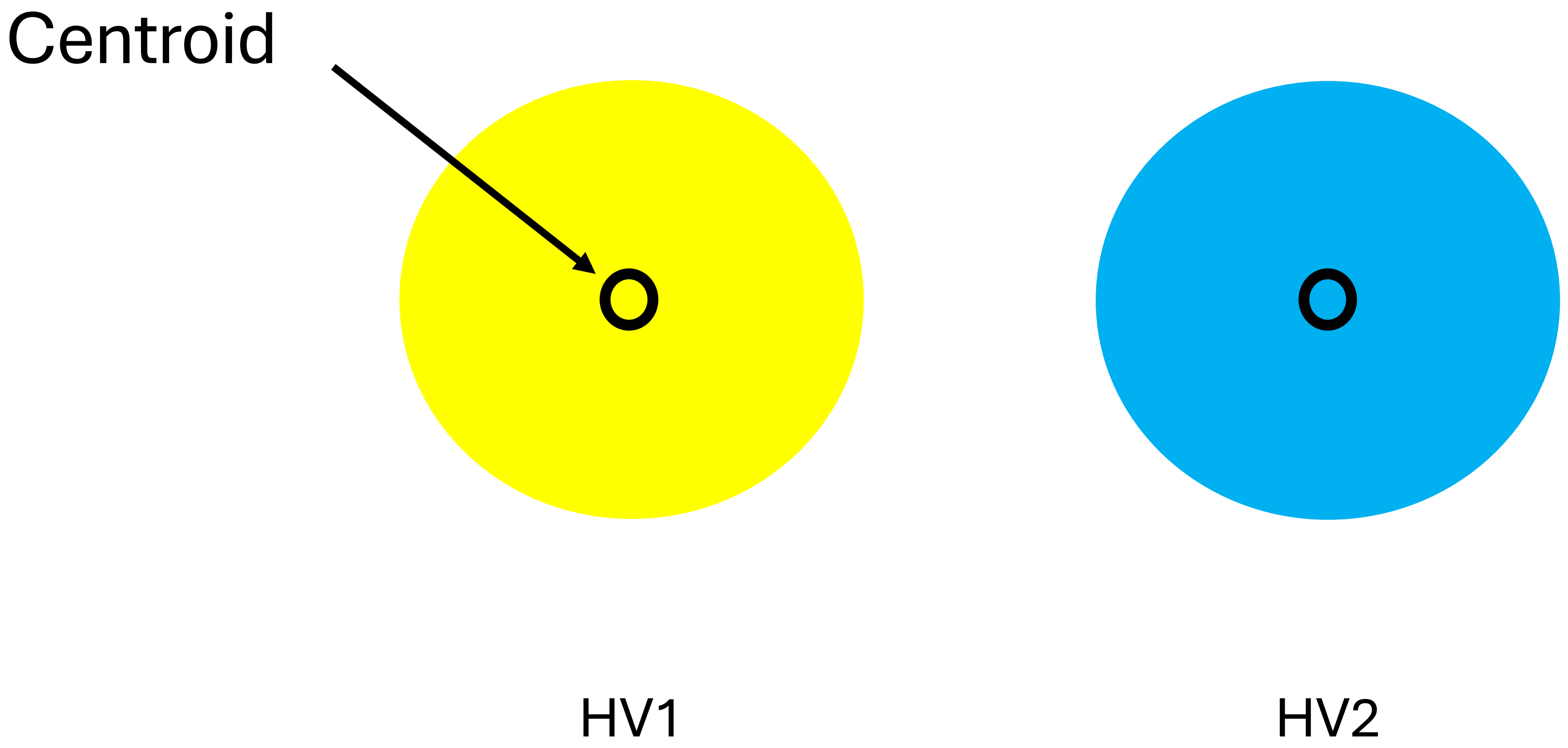
Hypervolume size to understand trophic niche width (Santos et al. 2022)

- Change in trophic niche based on seascape context
- Hypervolumes based on resource use and trophic level of pinfish

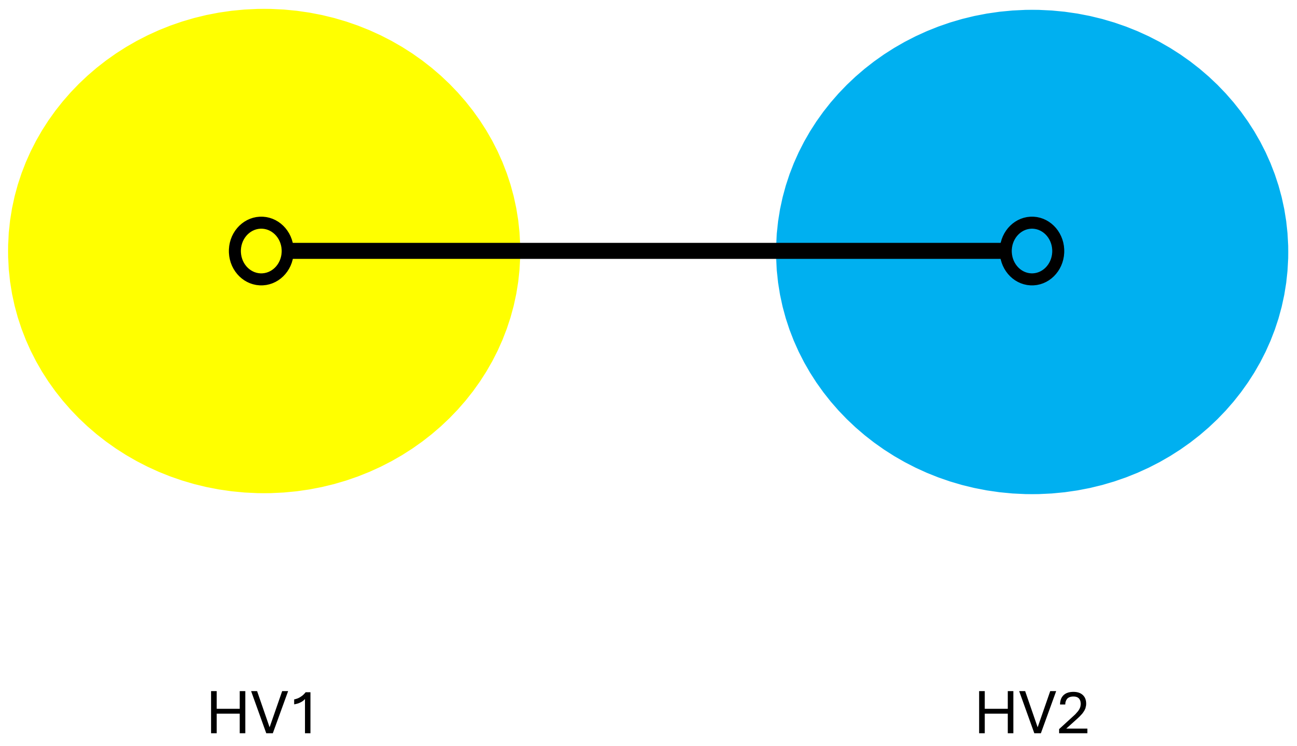




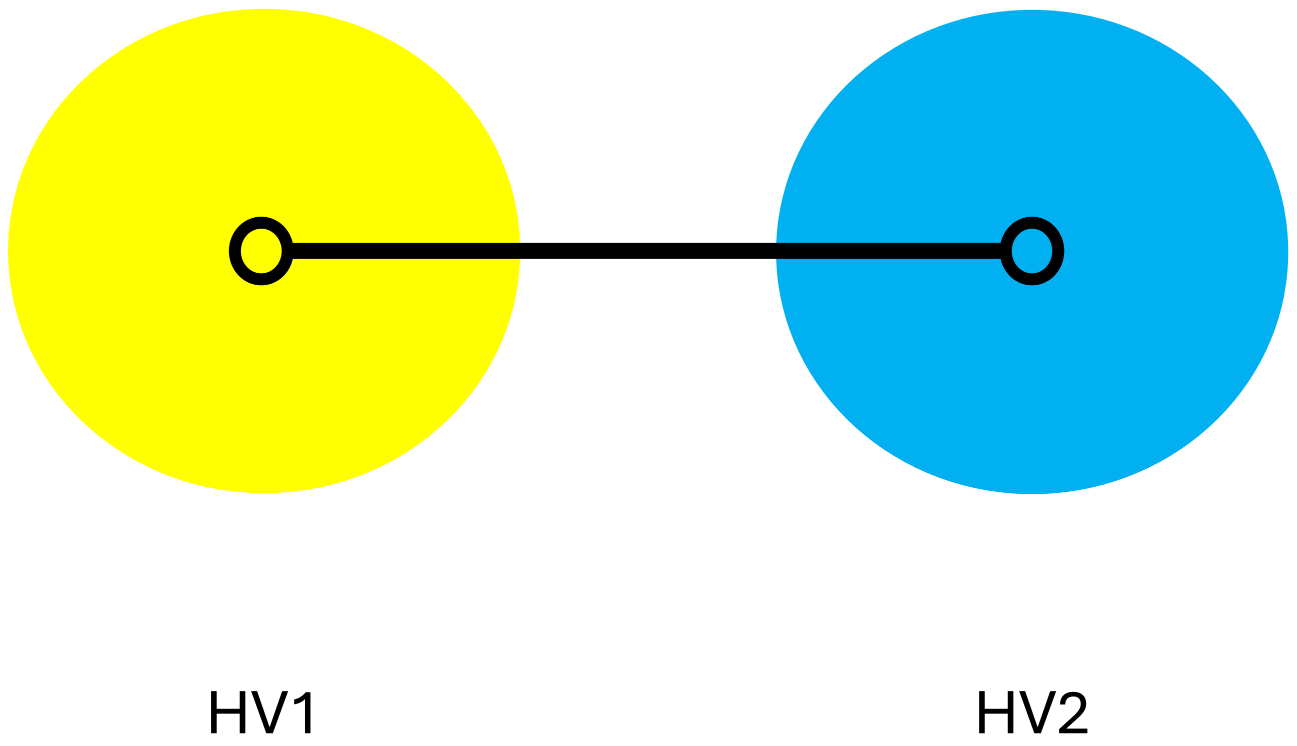
Centroid distance



Centroid distance

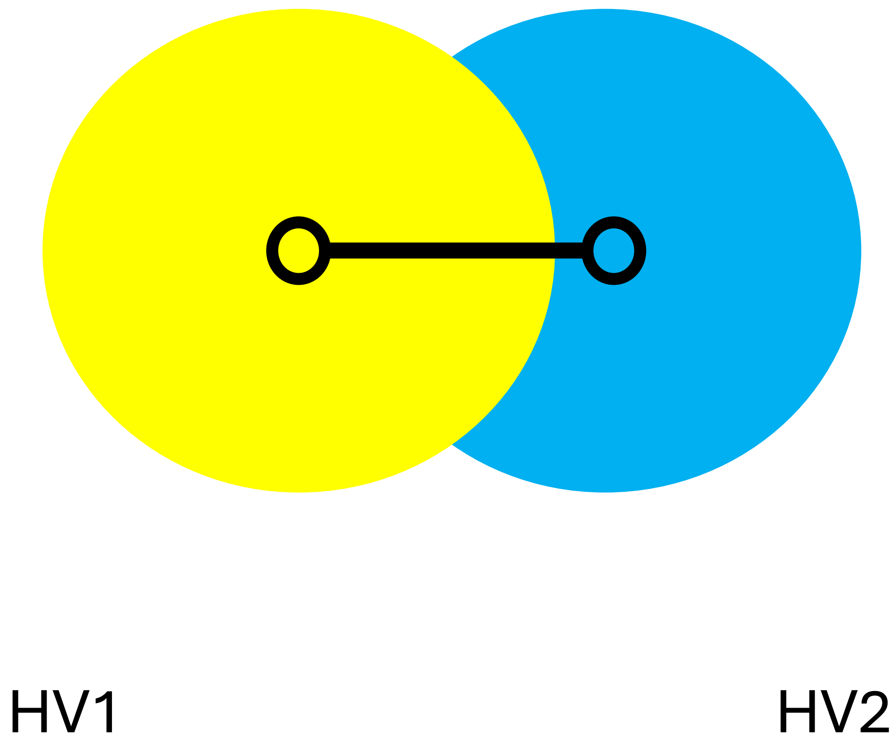


Centroid distance

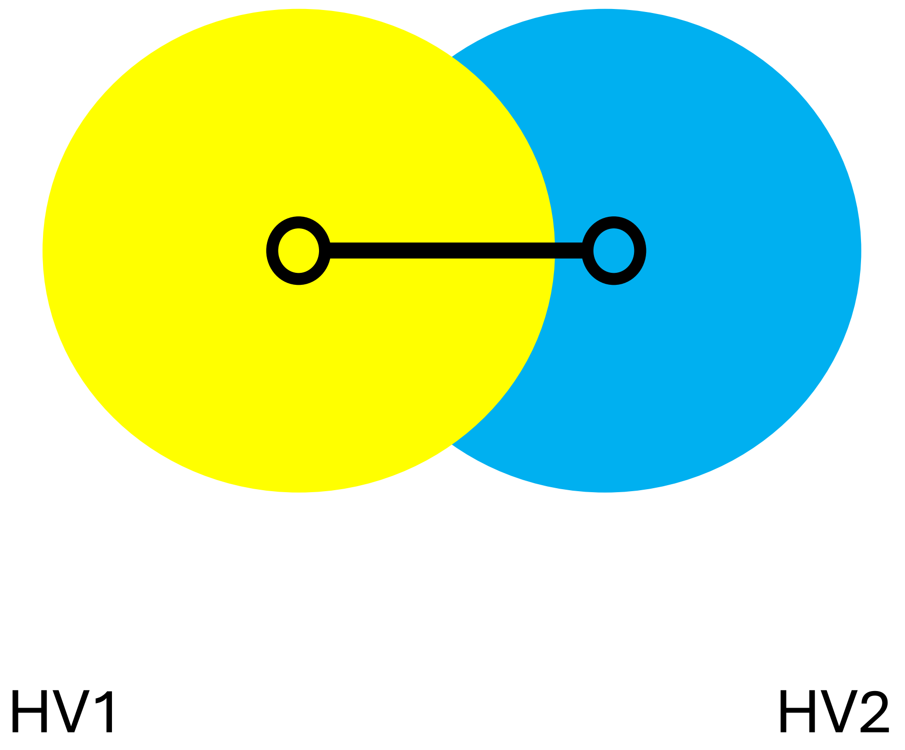


HV1 and HV2 big difference in mean conditions

Centroid distance



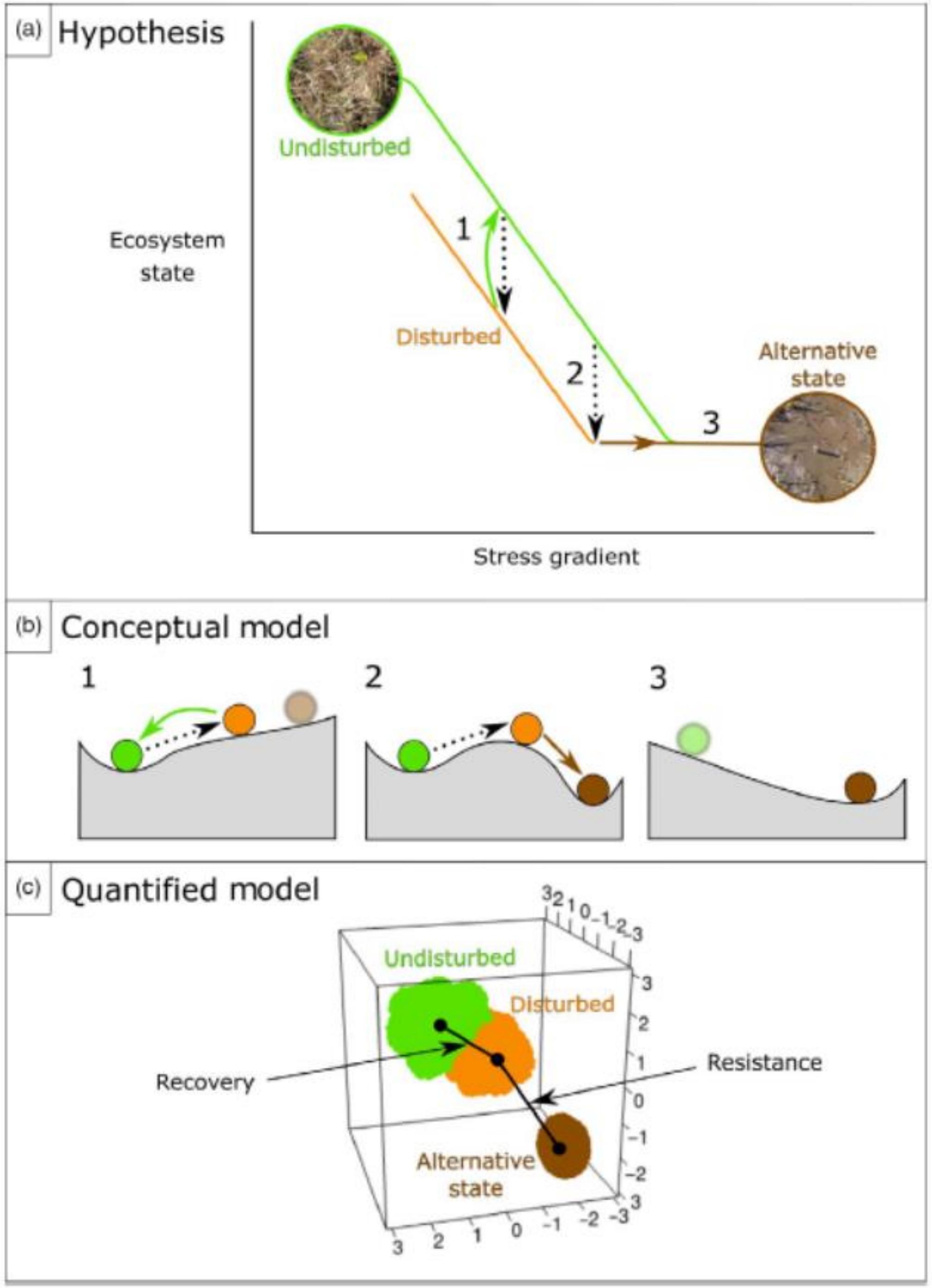
Centroid distance



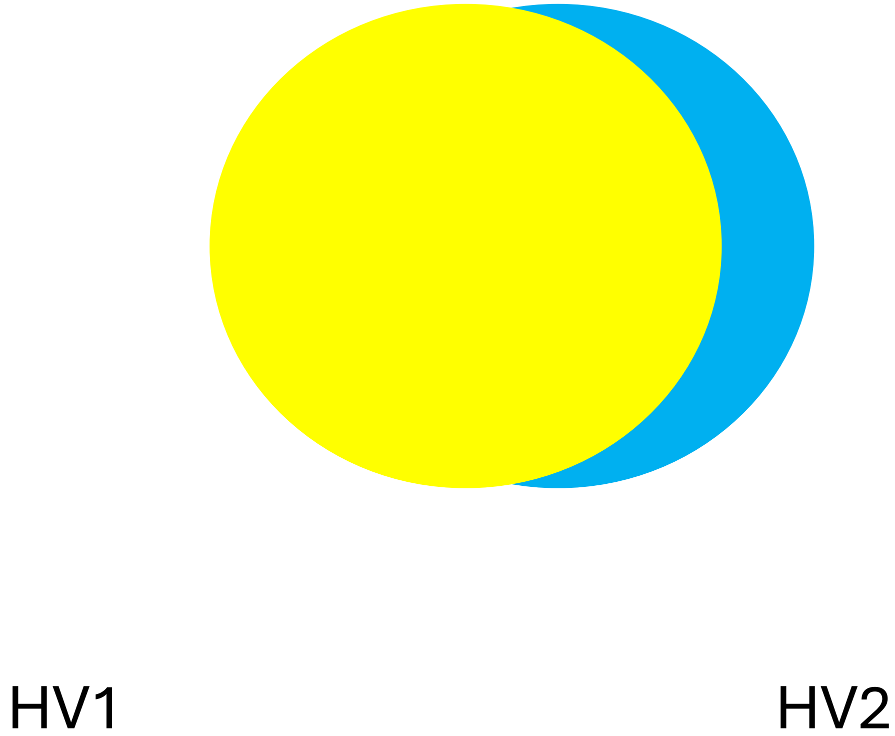
HV1 and HV2 small difference in mean conditions

Centroid distance to understand ecosystem resilience

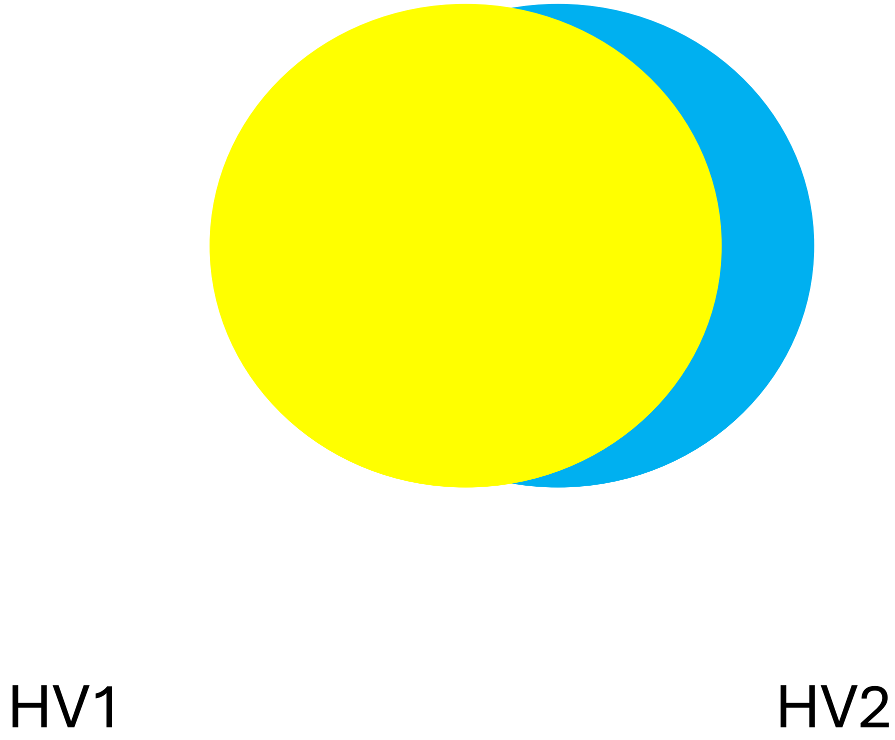
- Jones et al. 2020 *Journal of Ecology*
- Hypervolumes to quantify state and recovery of marshes along stress gradient (flooding) to disturbance
- Recovery – centroid distance from disturbed to undisturbed
- Resistance – centroid distance from disturbed to alternate state



Hypervolume overlap

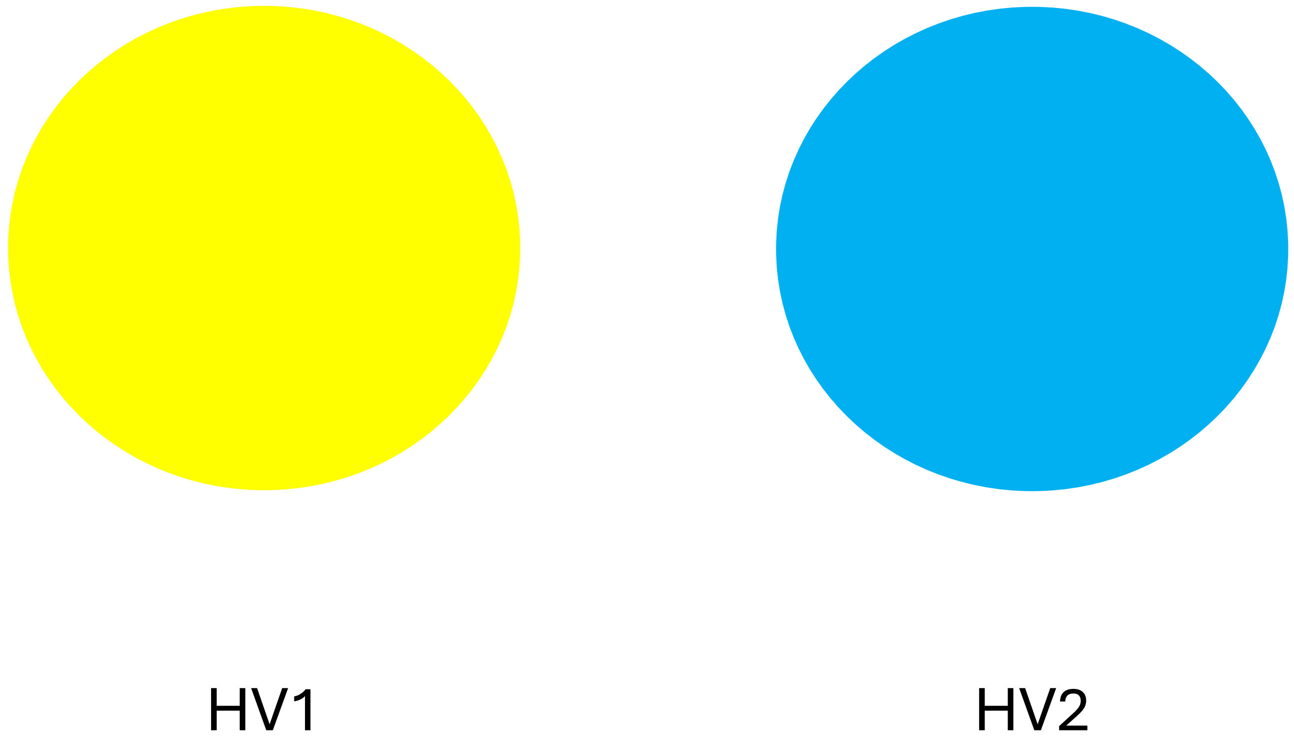


Hypervolume overlap

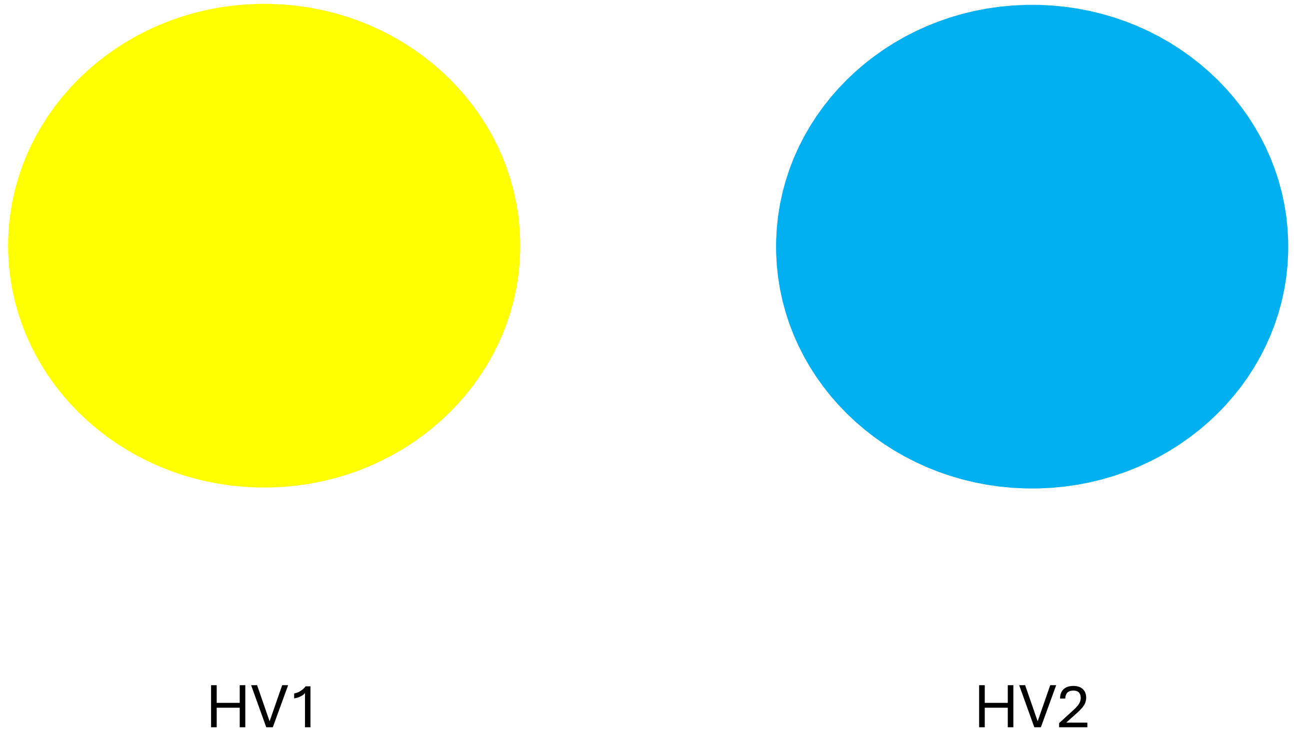


HV1 and HV2 have high similarity

Hypervolume overlap

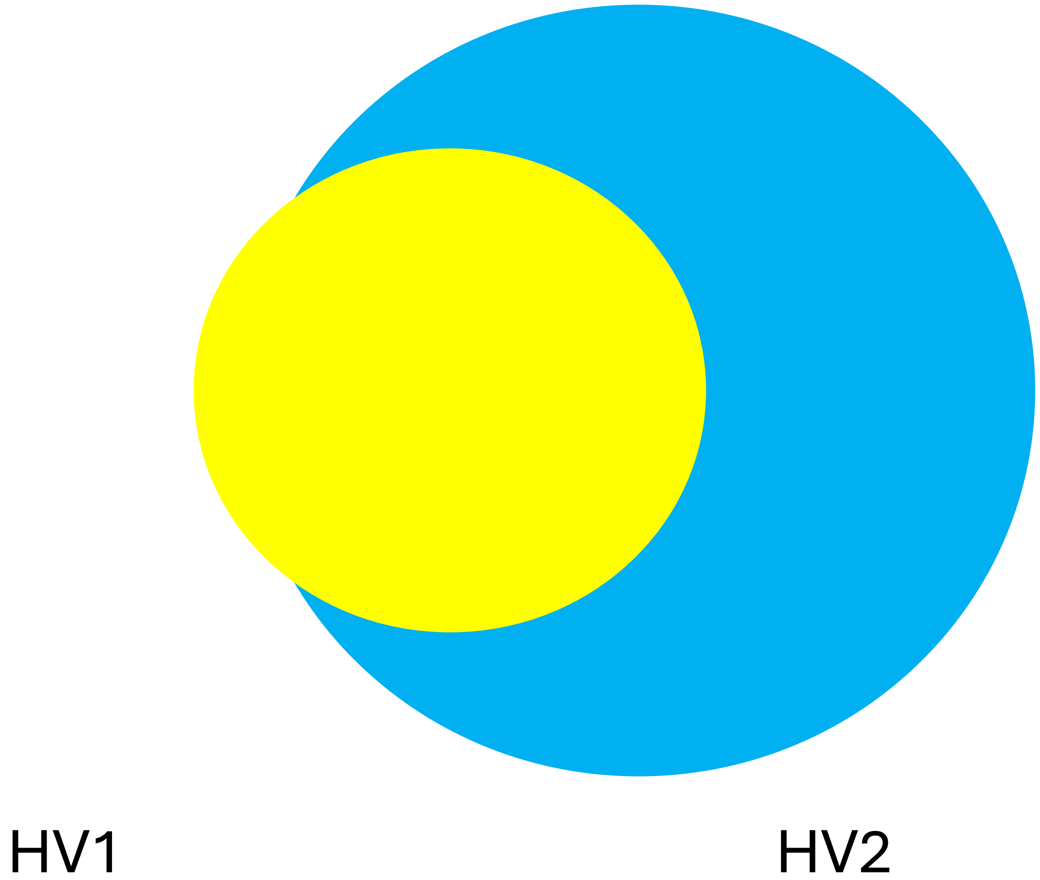


Hypervolume overlap

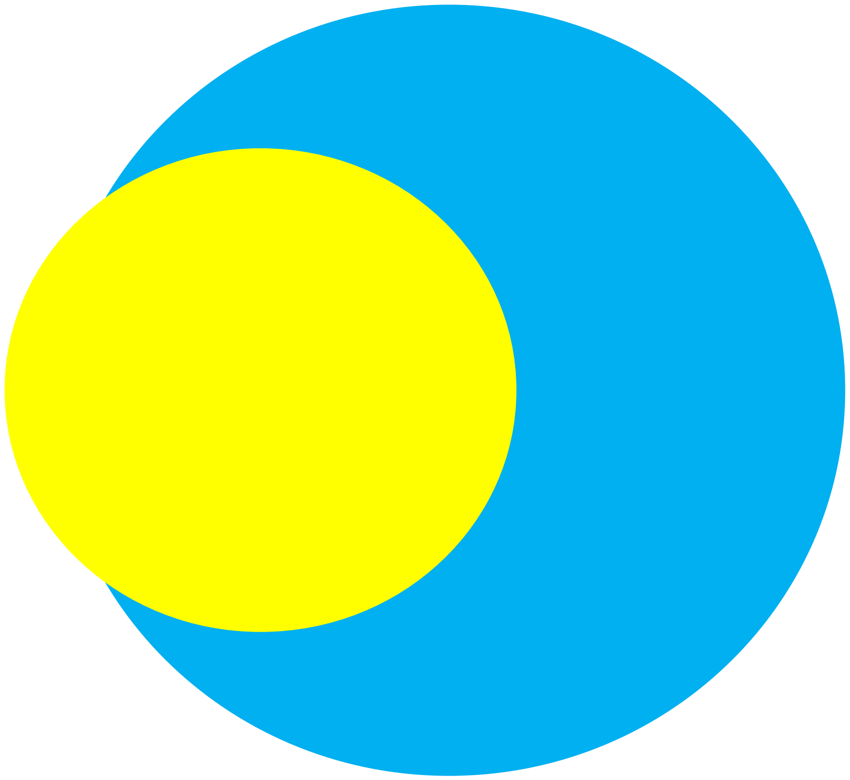


HV1 and HV2 have low similarity

Hypervolume overlap



Hypervolume overlap

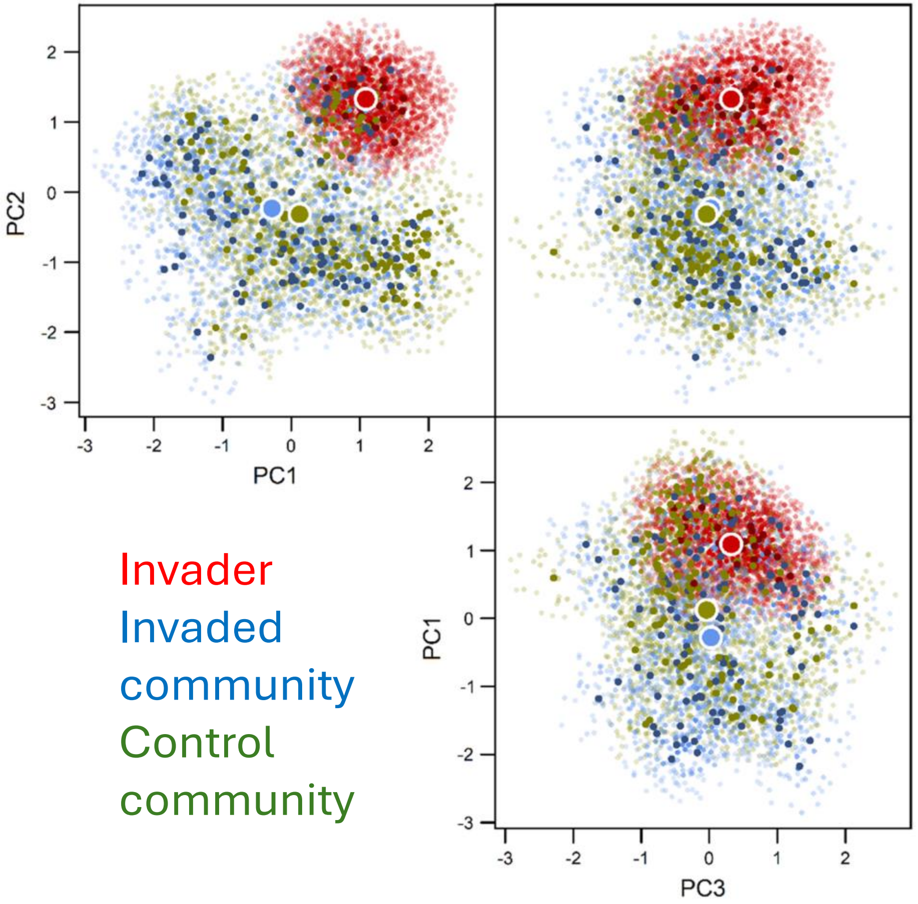


HV1 HV2

HV1 not unique and HV2 high % unique, so have low similarity

Overlap to understand trait similarity of invasive plant (Helsen et al. 2016)

- PC on traits to reduce # of axes
- Test function distinctive hypothesis
  - Invader unique part of hv
  - Community shift native to minimize overlap

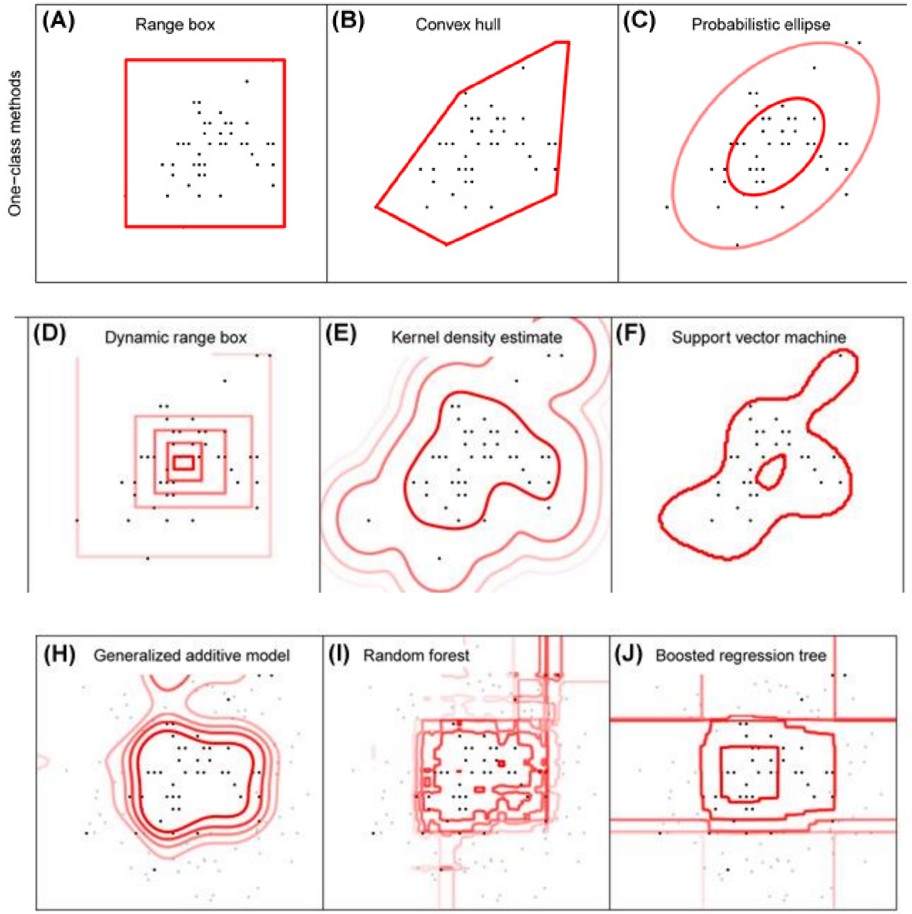


Invader
Invaded community
Control community

	Centroid distance (SD)	Jaccard similarity	Unique volume fraction (%)
Impatiens glandulifera			
NAT_C – NAT_I	0.251 (0.201–0.302)	0.529 (0.513–0.544)	27.4 (25.7–29.2) – 33.9 (32.0–36.2)
	0.217 (0.123–0.314)	0.543 (0.514–0.571)	25.0 (22.5–27.5) – 33.7 (29.9–37.2)
NAT_C – NAT_T	*0.115 (0.067–0.174)*	*0.748 (0.724–0.770)*	*15.2 (12.7–18.2) – 13.6 (11.3–16.5)*
NAT_C – INV	2.152 (2.121–2.185)	0.029 (0.023–0.033)	96.5 (96.0–97.2) – 85.7 (83.5–88.4)
	2.223 (2.165–2.285)	0.030 (0.022–0.037)	96.5 (95.7–97.4) – 83.4 (79.5–88.0)
NAT_I – INV	2.046 (2.026–2.063)	0.051 (0.047–0.054)	94.1 (93.7–94.6) – 73.3 (71.6–75.7)
	2.168 (2.109–2.212)	0.043 (0.034–0.051)	95.1 (94.3–96.1) – 73.8 (68.9–79.4)
NAT_T – INV	*2.124 (2.104–2.141)*	*0.036 (0.032–0.039)*	*95.6 (95.3–96.2) – 82.4 (81.1–84.6)*
Rosa rugosa			
NAT_C – NAT_I	0.703 (0.657–0.758)	0.461 (0.441–0.477)	28.3 (26.3–30.1) – 43.6 (41.3–46.0)
	0.471 (0.326–0.633)	0.496 (0.460–0.538)	27.8 (23.7–32.6) – 38.6 (33.8–42.9)
NAT_C – NAT_T	*0.238 (0.172–0.286)*	*0.781 (0.752–0.809)*	*9.9 (7.8–12.4) – 14.6 (11.7–18.3)*
NAT_C – INV	1.978 (1.928–2.015)	0.052 (0.047–0.057)	94.1 (93.6–94.8) – 68.1 (65.5–71.2)
	2.112 (2.027–2.212)	0.042 (0.033–0.048)	95.5 (94.8–96.4) – 66.7 (61.8–72.9)
NAT_I – INV	2.361 (2.342–2.379)	0.024 (0.021–0.025)	97.3 (97.2–97.7) – 81.7 (80.3–84.1)
	2.400 (2.311–2.487)	0.018 (0.012–0.023)	98.0 (97.5–98.6) – 82.9 (78.5–88.3)
NAT_T – INV	*2.096 (2.067–2.113)*	*0.049 (0.047–0.051)*	*94.5 (94.3–94.7) – 68.5 (67.3–69.7)*

Multivariate approaches

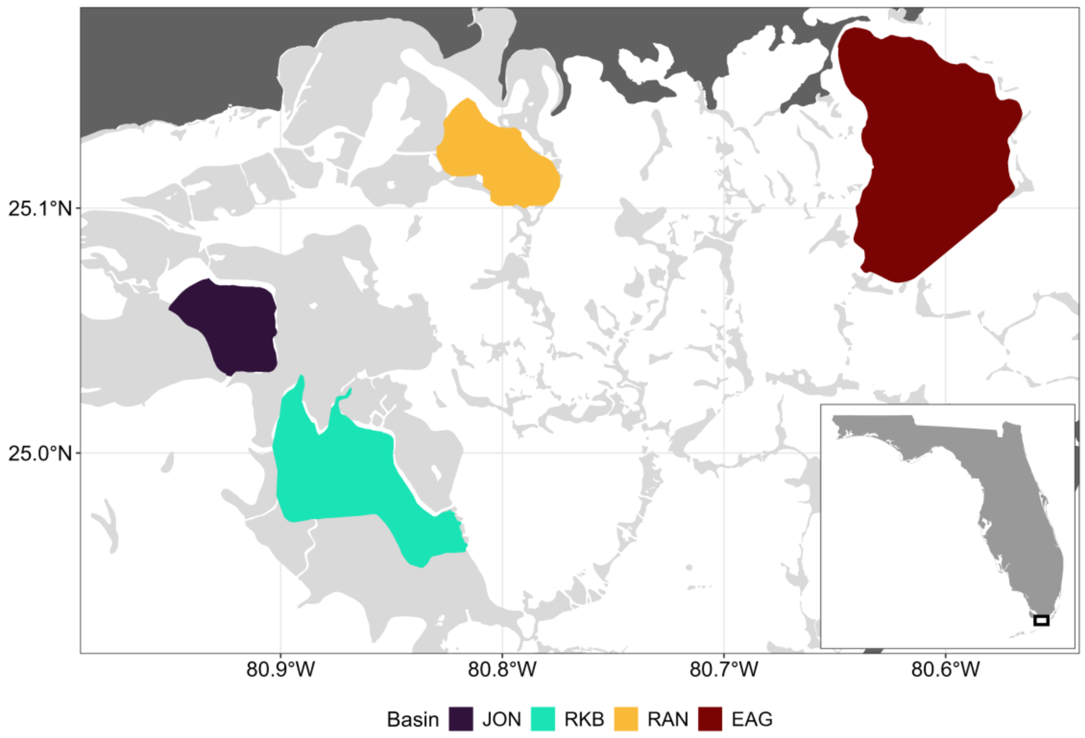
- Based on data and question
- Take advantage of variation
  - Allow for holes in data distribution
- Blonder et al. 2014 *GEB*
- Blonder et al. 2017 *Ecography*



Blonder et al. 2017. Ecography

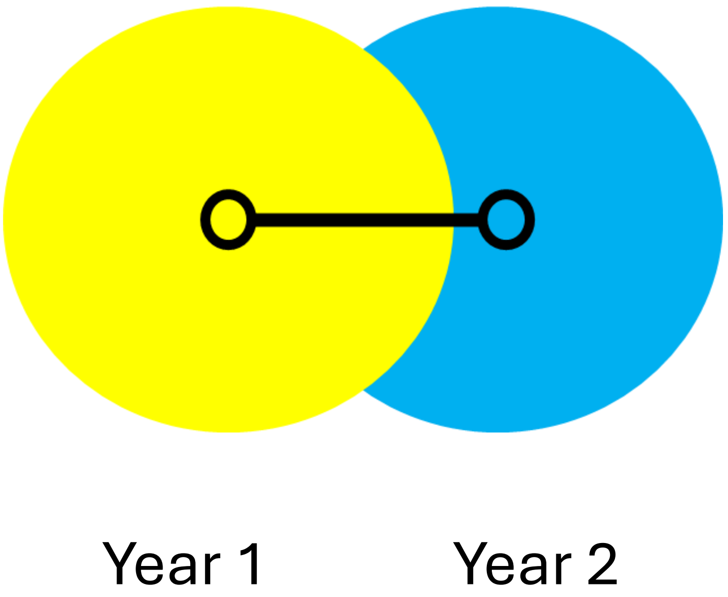
Case study 1 – Centroid distance SAV community stability

- Temporal stability of SAV communities in Florida Bay
- Monitoring data ~ 30 sites per basin
- HV – Percent cover of *Thalassia testudinum, Halodule wrightii, Syringodium filiforme,* total macroalgae, and total drift algae and seagrass richness
- Centroid distance across time (17 years)

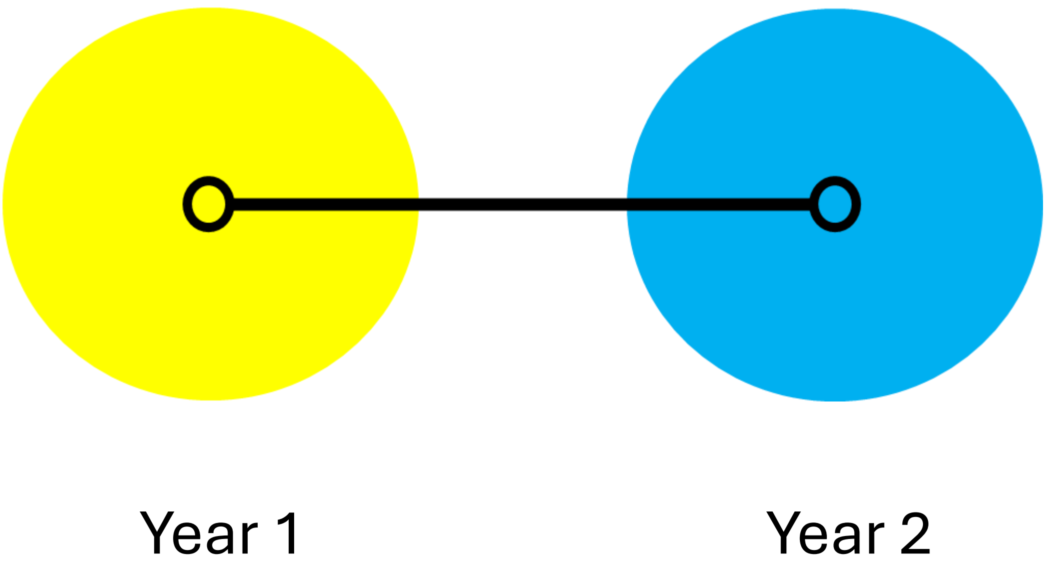


Stability – change in mean conditions

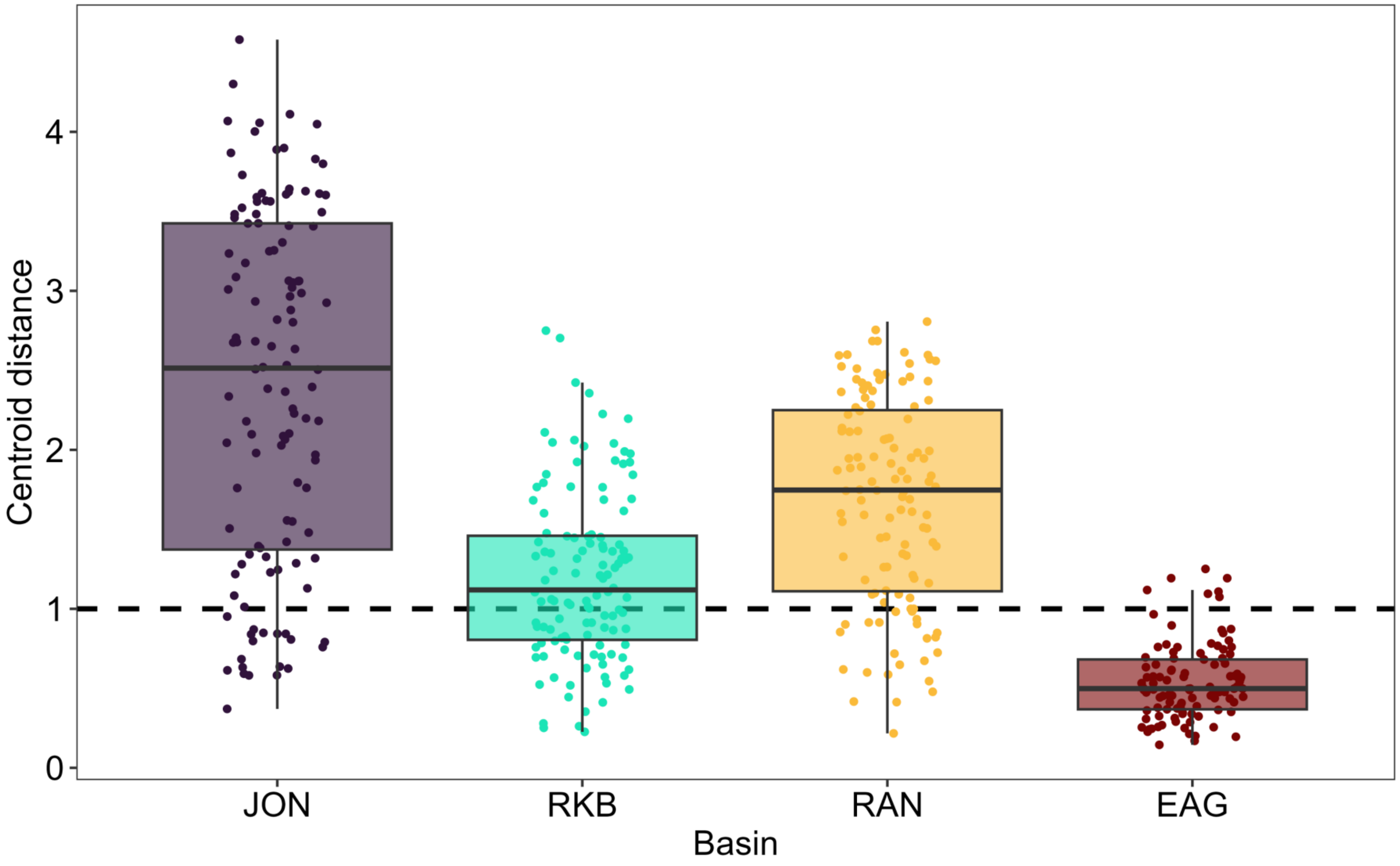
High temporal stability



Low temporal stability

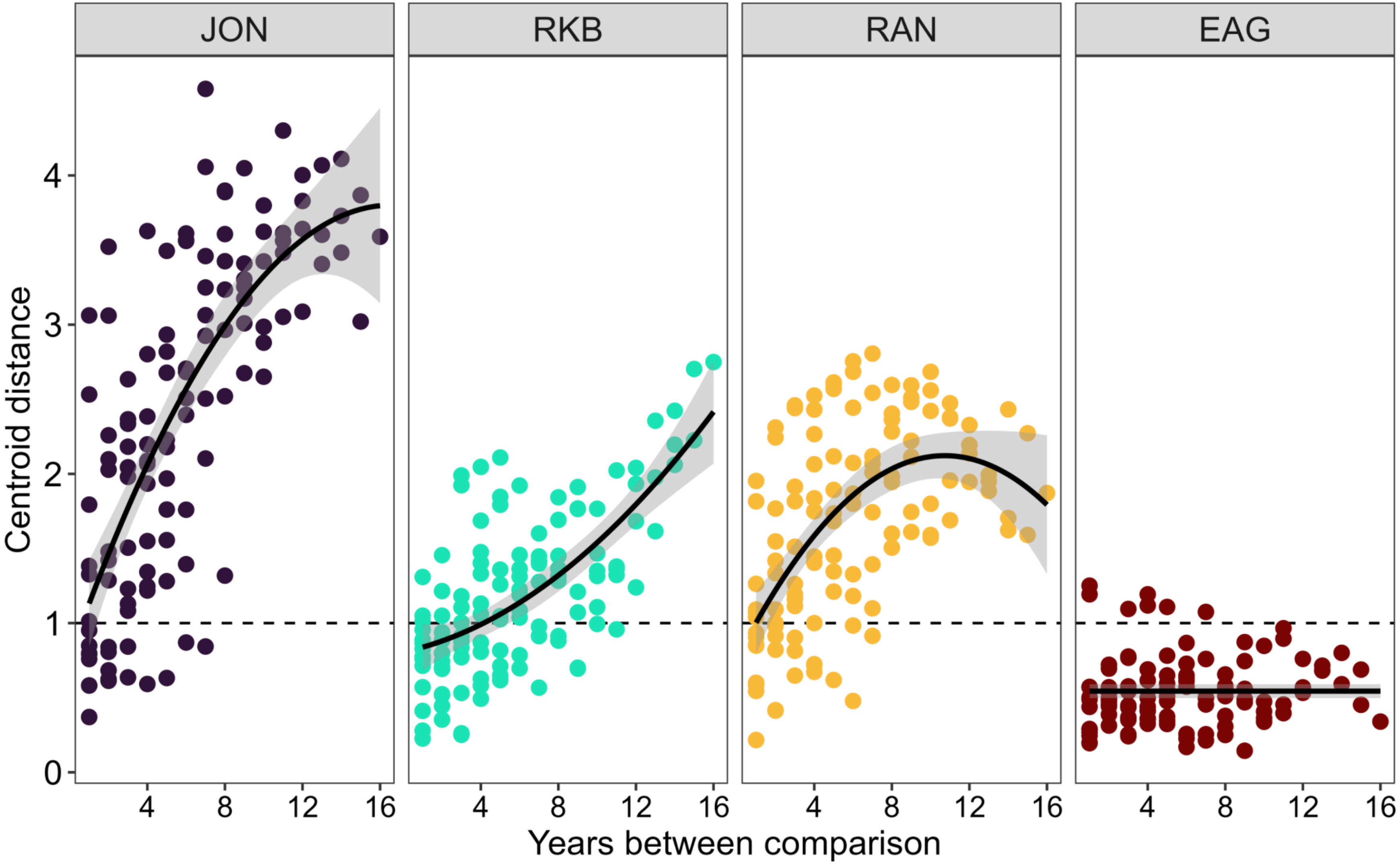


Temporal stability in mean conditions



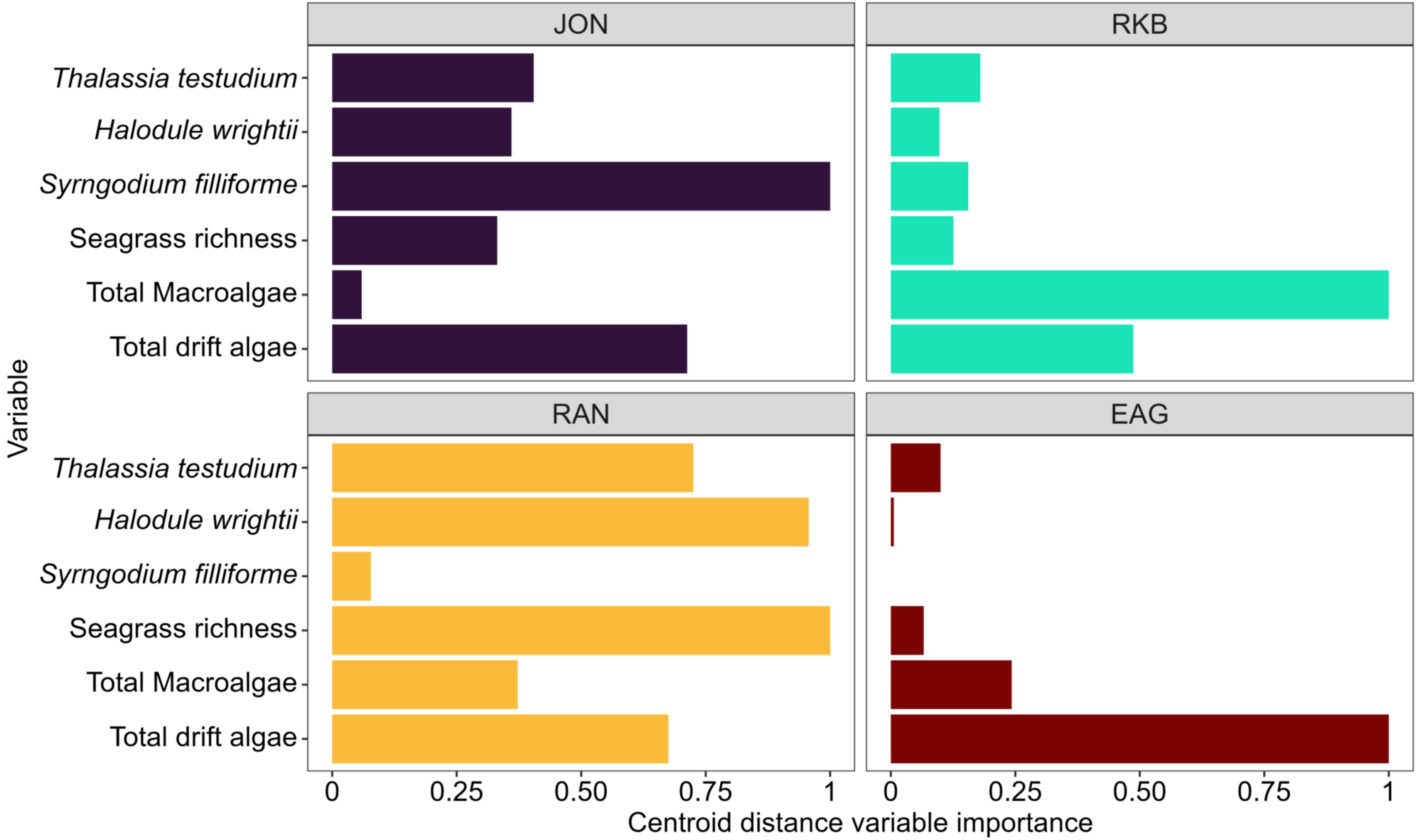
- Variation in stability over across basins

Transitions in mean conditions/state



- JON – shift with stabilization/ recovery
- RKB – shift
- RAN – recovery
- EAG – stable

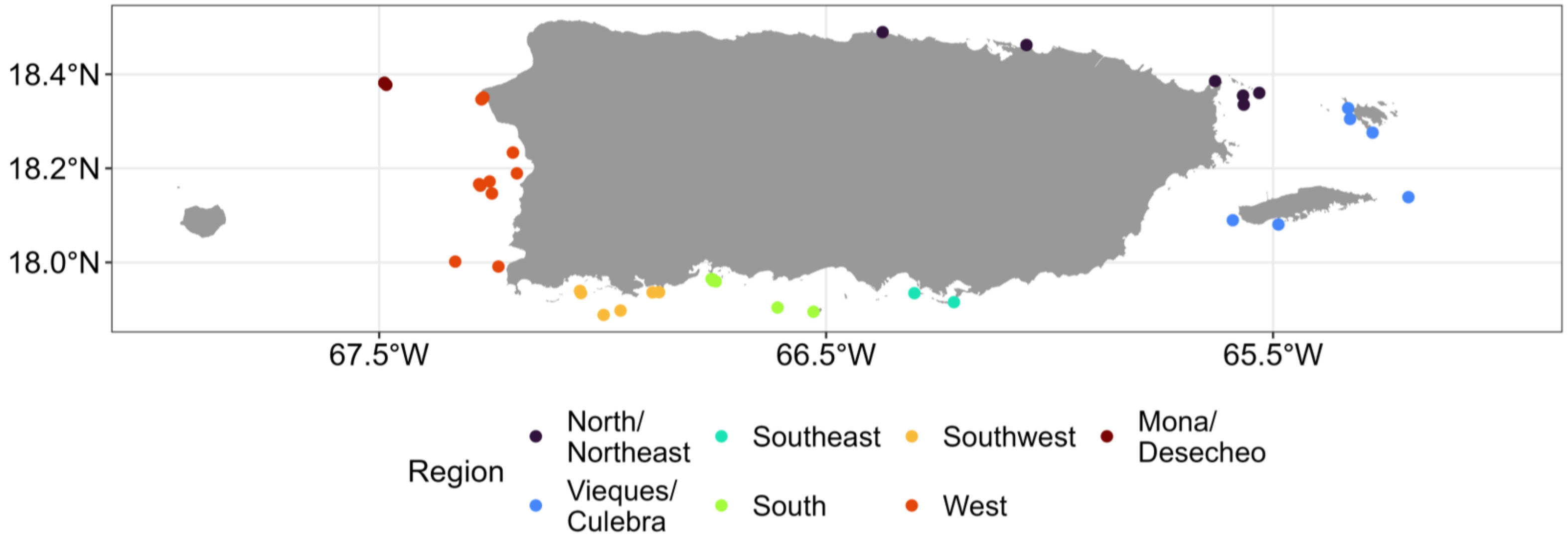
Variables contributing to state change



- Spatial variation in the variable contributing most to the centroid distance between years

Case study 2 – Hypervolume size
Coral trait diversity

- How does trait diversity vary across regions
- Benthic monitoring of coral communities combined with literature trait values
- HV – community weighted (using percent cover) for 5 functional traits based on random percent cover
- Hypervolume size for trait diversity



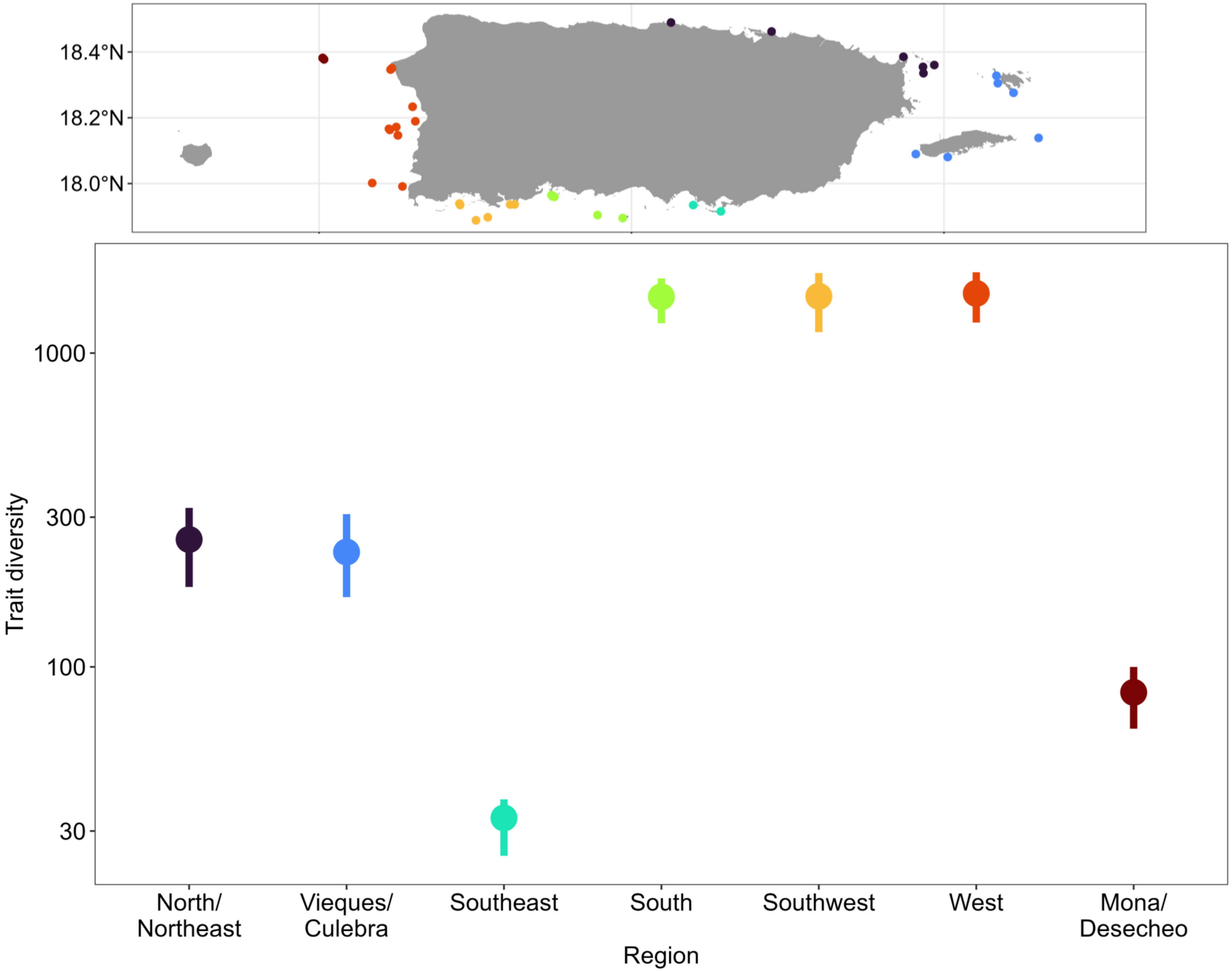
Trait diversity – variation in traits across community

High diversity

Low diversity

Region

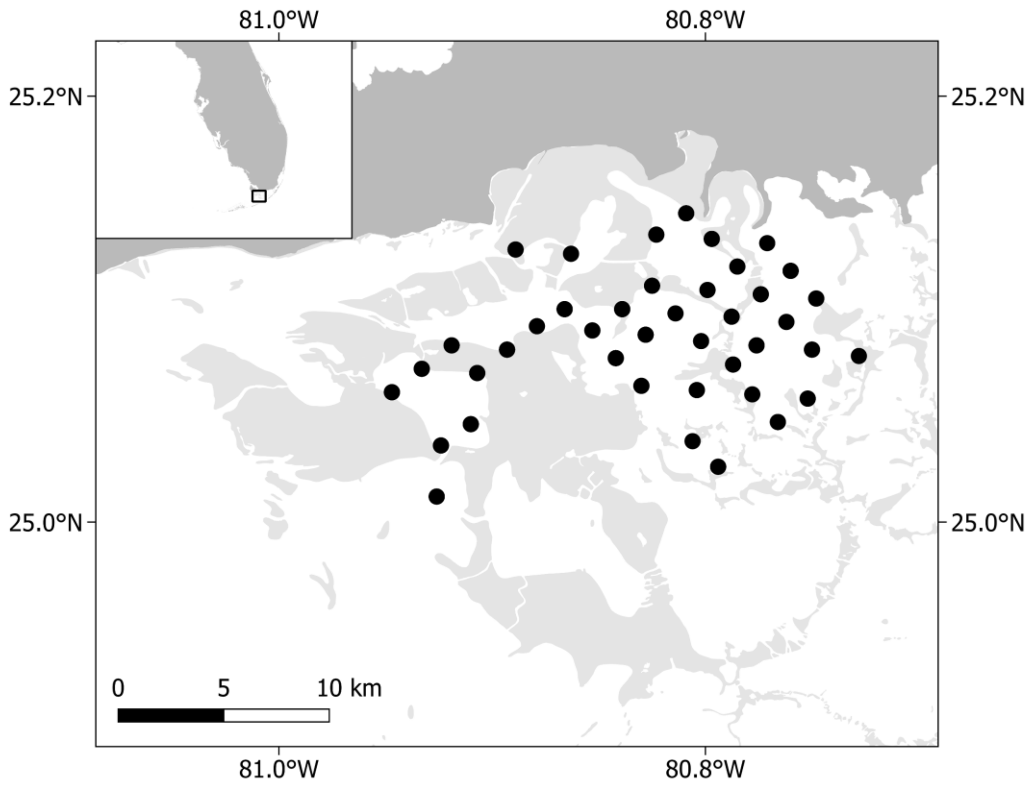
Region



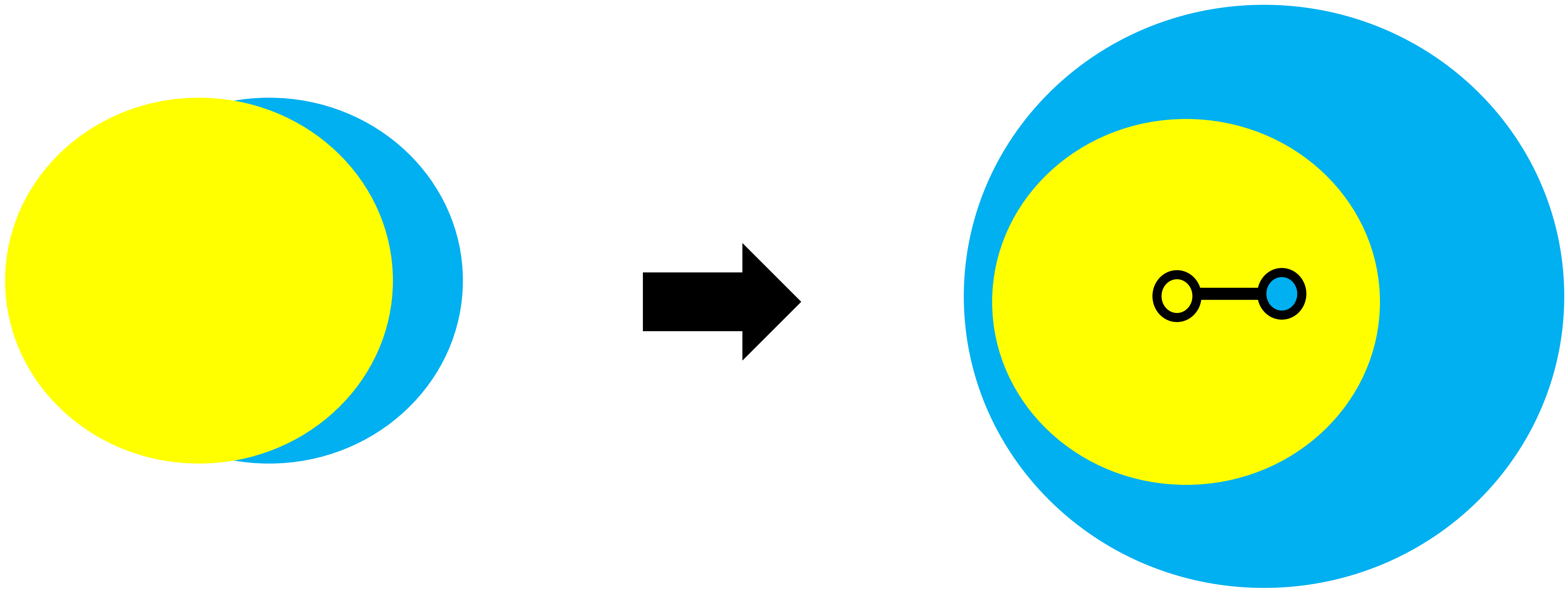
18.4°N
18.2°N
18.0°N
Trait diversity
1000
300
100
30
North/
Northeast
Vieques/
Culebra
Southeast
South
Southwest
West
Mona/
Desecheo
Region

Case study 3 – overlap
Trophic niche seagrass consumers

- Seasonal variation in trophic niche dynamics 7 seagrass consumers
- Axes – basal resource use (seagrass, epiphytes, algae, mangrove)
- HV – each species and season based on random points from mean and sd of resource use
- Overlap, size, and centroid distance

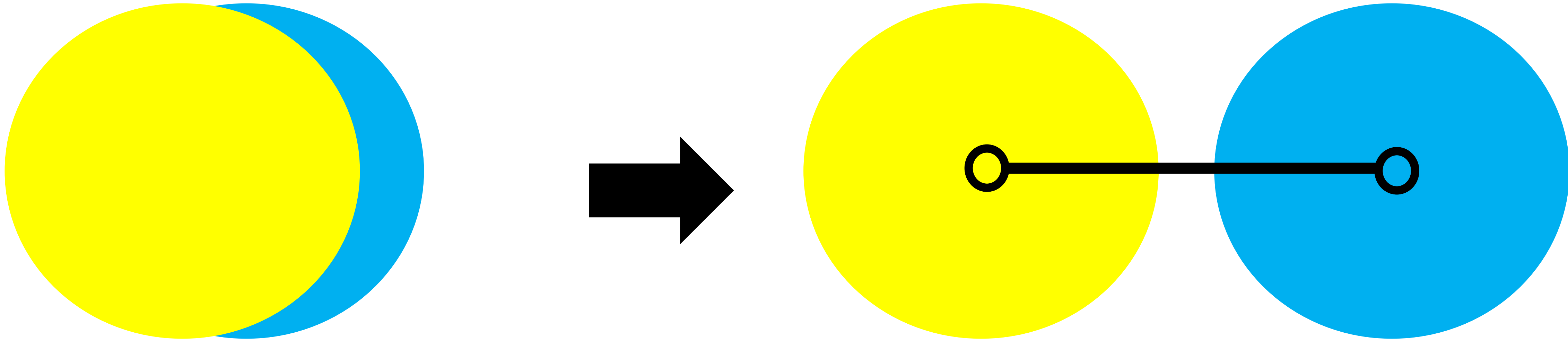


Niche expansion/contraction



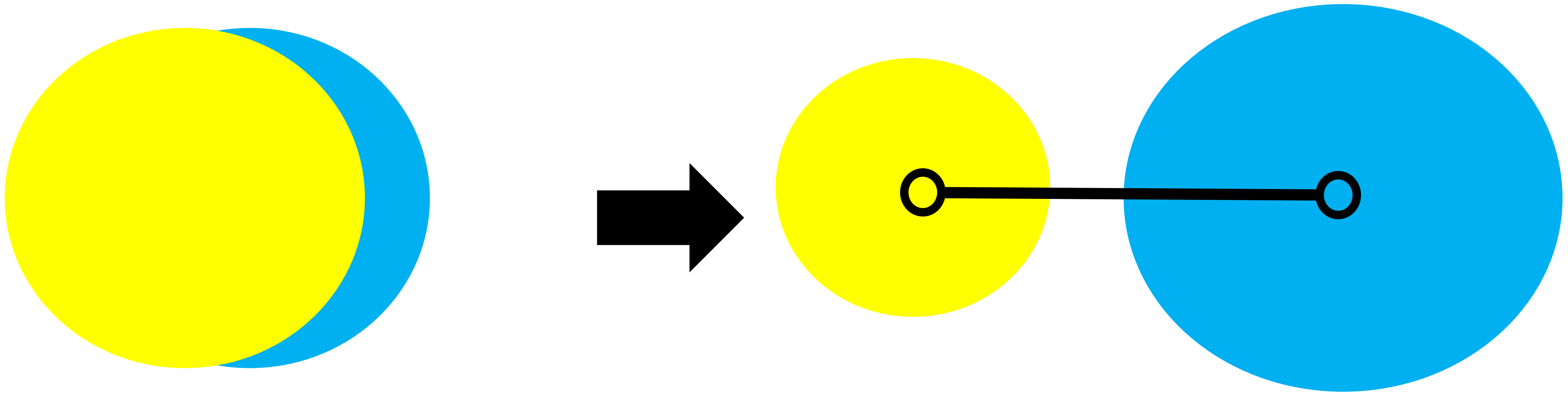
- Difference in size
- Small centroid distance
- Low overlap
- Niche unique high for hv1, low for hv2

Niche shift



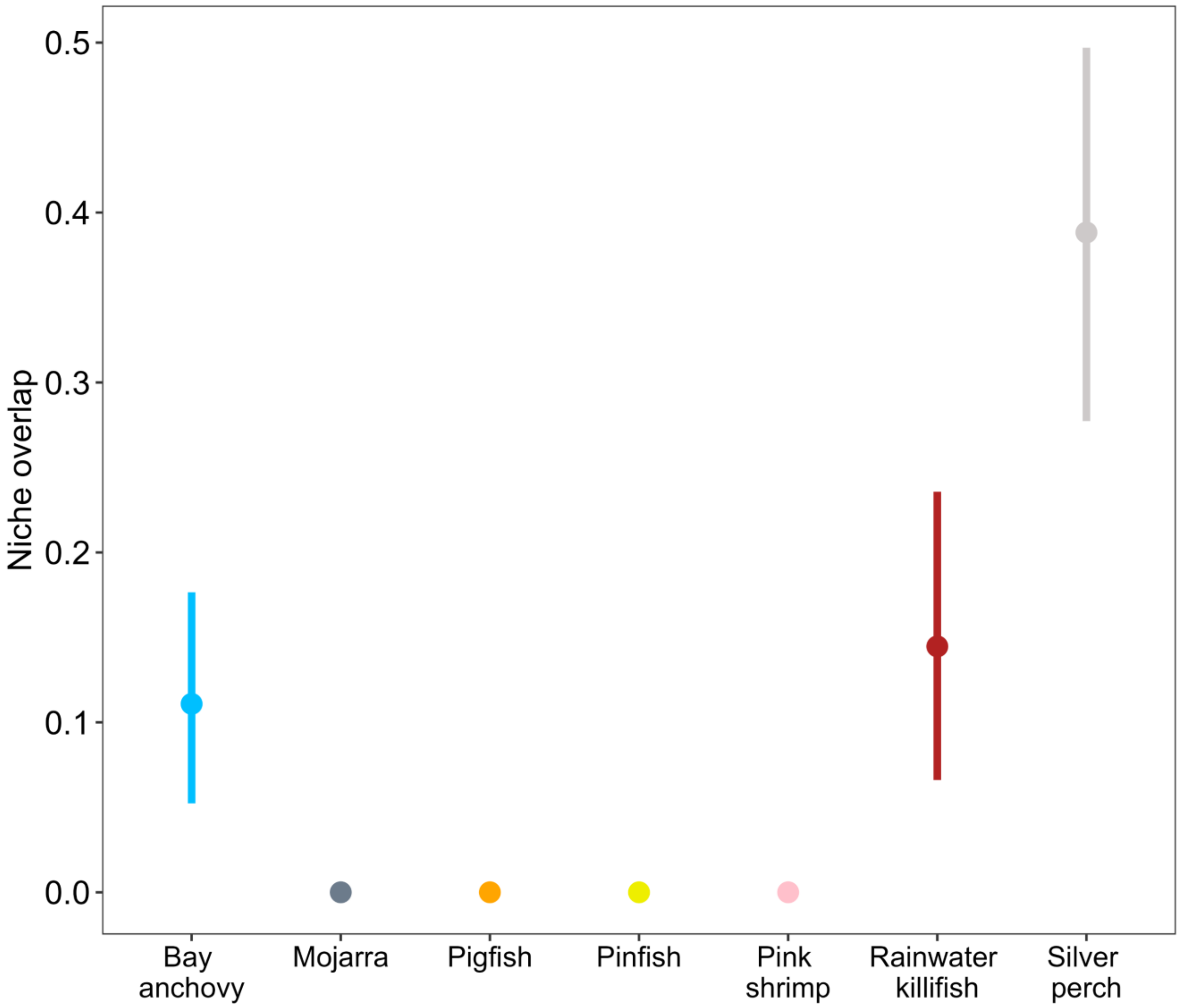
- No difference in size
- Large centroid distance
- Low overlap
- Niche unique high for hv1 and hv2

Niche expansion/contraction and niche shift



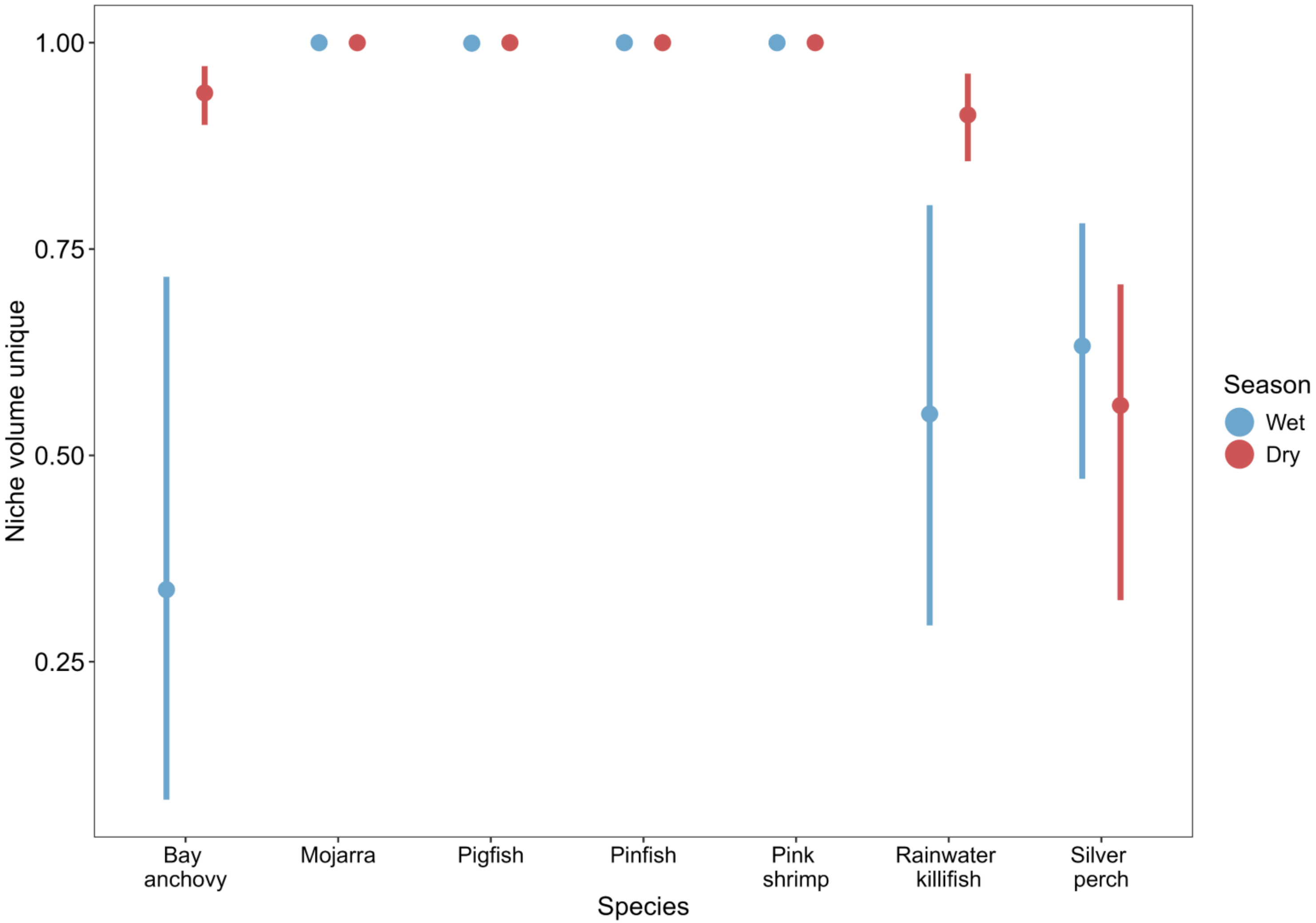
- Difference in size
- Large centroid distance
- Low overlap
- Niche unique high for hv1 and hv2

Niche similarity between seasons



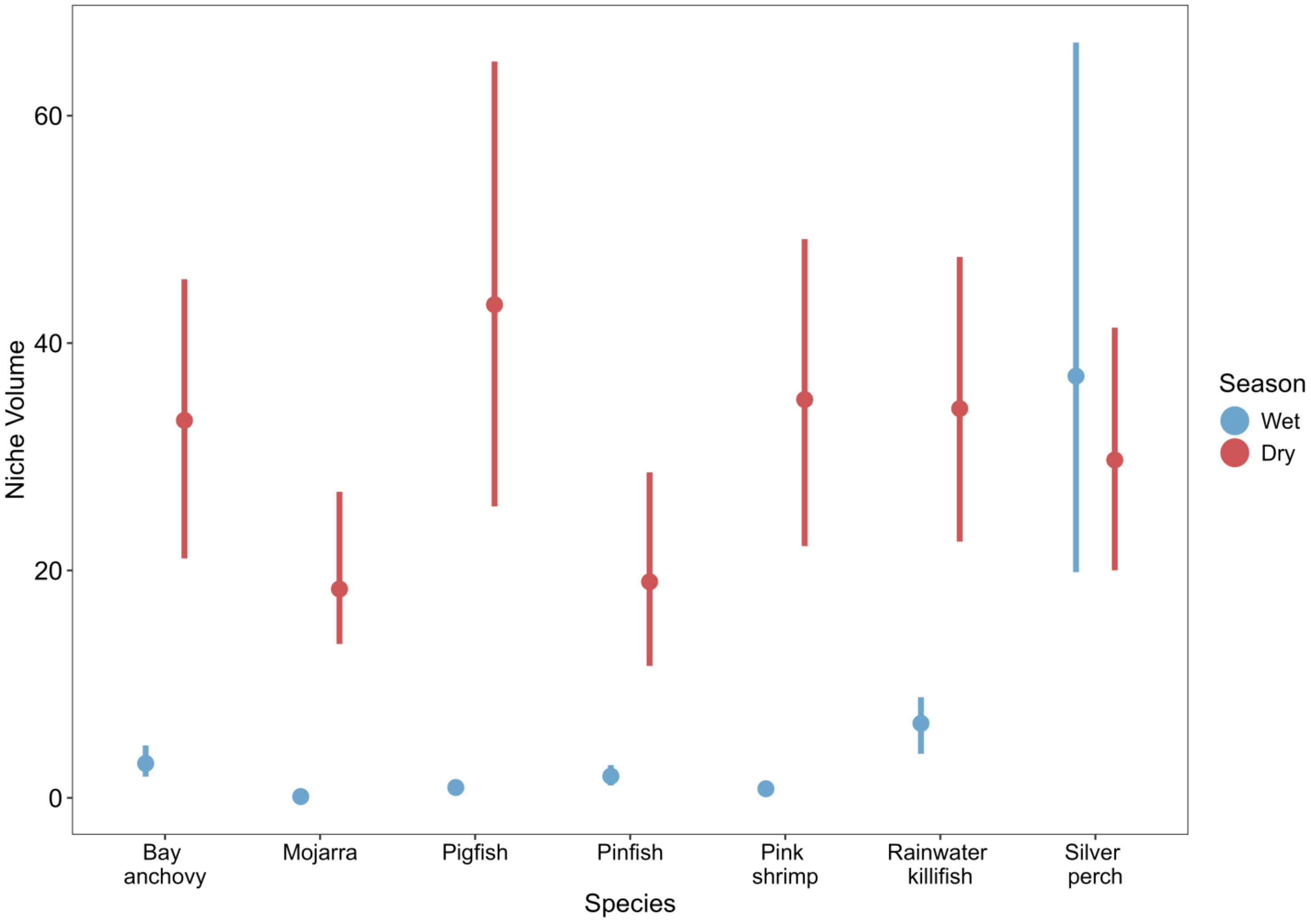
- No overlap for mojarra, pigfish, pinfish, and pink shrimp
- Intermediate/low overlap for bay anchovy and rainwater killifish
- Higher overlap for silver perch

Unique niche for each season



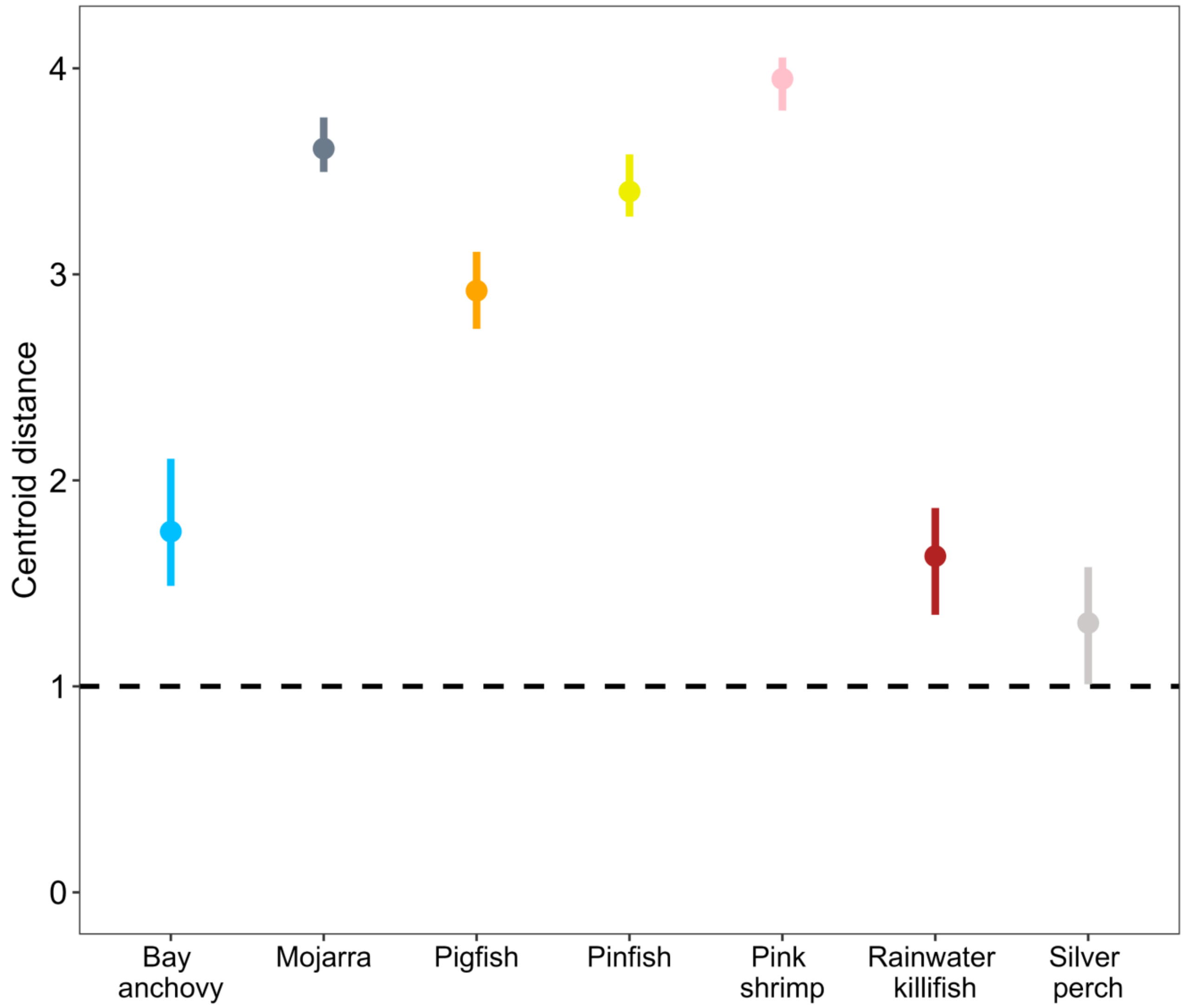
- 100% unique for mojarra, pigfish, pinfish, and pink shrimp in both seasons
- High unique for dry and low for wet for bay anchovy and rainwater killifish
- Low unique for silver perch in both seasons

Changes in trophic niche size



- Larger in dry for all species except
- Silver perch no difference between seasons

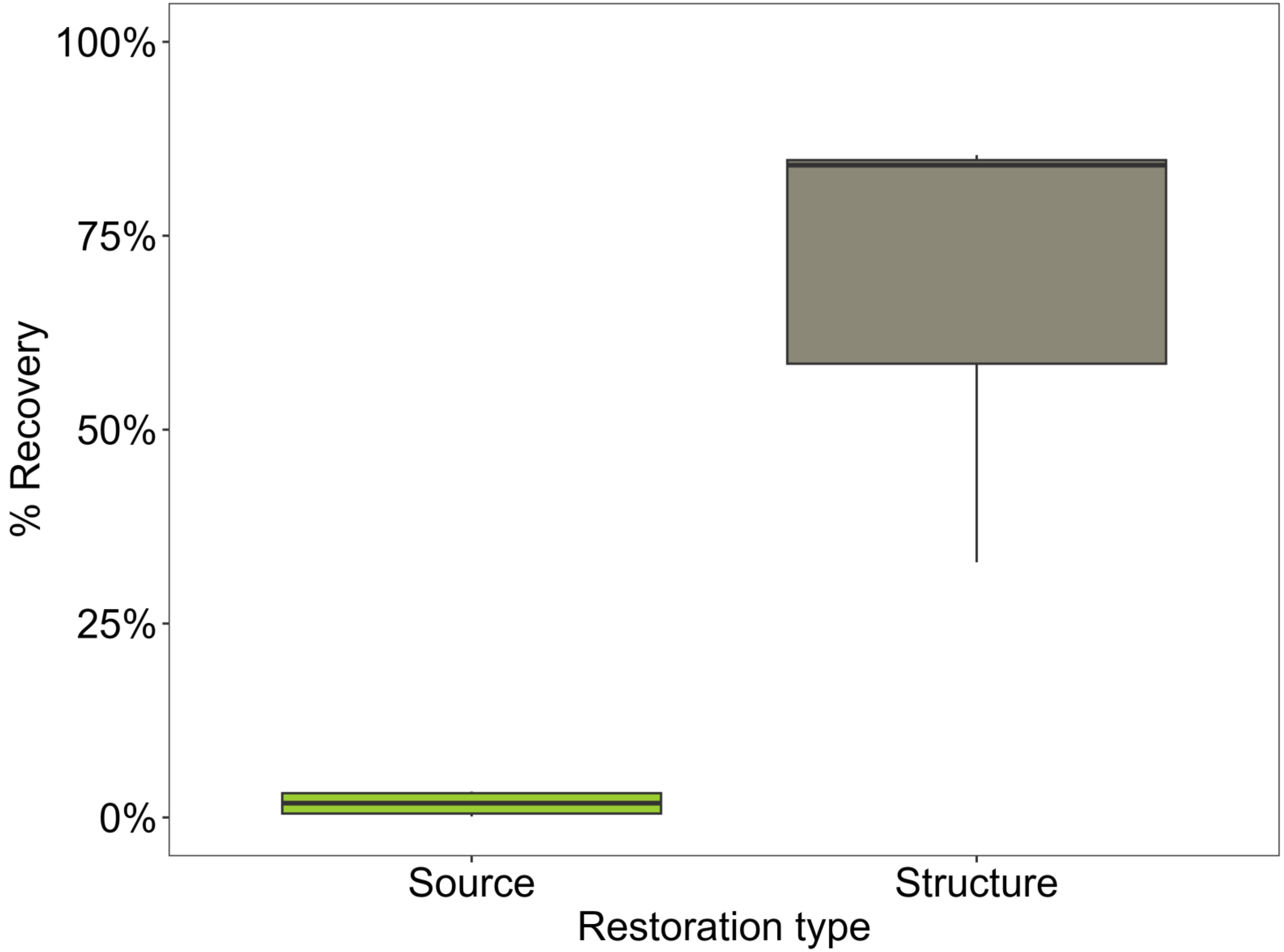
Changes in mean resource use



- Large shifts for mojarra, pigfish, pinfish, and pink shrimp

- Smaller shift for bay anchovy, rainwater killifish, and silver perch

Overlap to quantify restoration recovery (James et al. 2020)

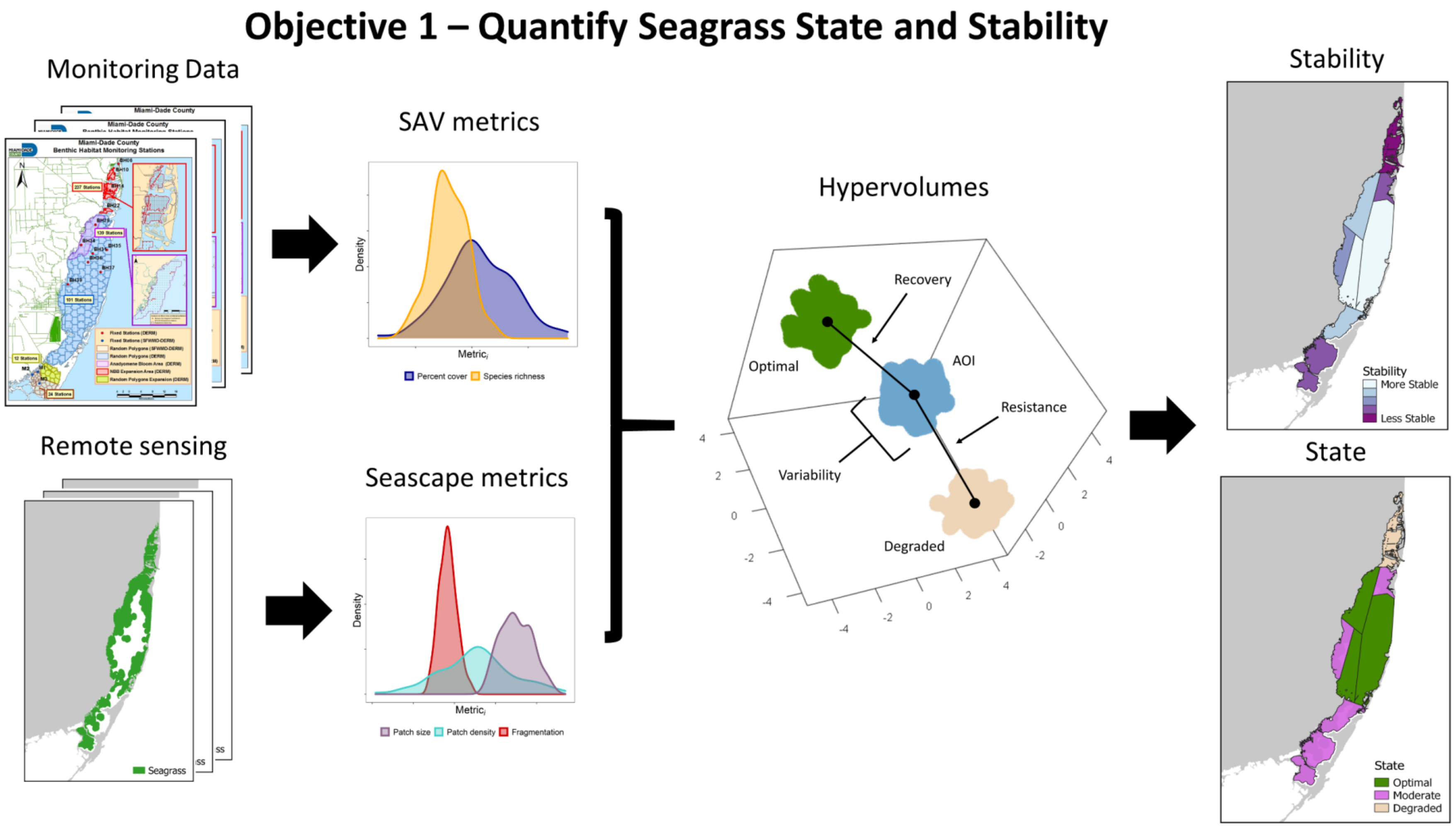


- Recovery slower in restorations of biogenic habitat than abiotic habitat structure

- Recovery of ecosystem function unrelated to age of restoration

James et al. 2020 *STOTEN*

Seagrass state



@santos_seascape_ecology

wjames@fiu.edu, rsantosc@fiu.edu