PREDICTING THE RESPONSES OF NORTHERN GULF OF MEXICO COASTAL DUNE PLANT COMMUNITIES TO CLIMATE CHANGE USING ECOLOGICAL NICHE MODELING

PRESENTER:
Justin C. Bagley, Ph.D.

ECOLOGICAL MODELS PREDICT DUNE PLANT DISTRIBUTIONS WILL BE SEVERELY LIMITED BY CLIMATE CHANGE

BACKGROUND

- Sandy dune habitats of the **Northern Gulf of Mexico (NGOM)** support diverse biotic communities and provide valuable ecosystem services to humans.
- Unfortunately, **coastal dune ecosystems are declining** globally due to multiple interacting stressors, including **global climate change (GCC)** [1].
- ***Q: How will dune plant species respond to GCC?***
- **Ecological niche models (ENMs)** predict past, present, and future distributional areas (suitable habitats) of species, thus are useful for addressing this question [2].

OBJECTIVE

- **Assess the severity of GCC impacts by modeling bioclimatic niches of 14 native dune plant species of the NGOM with overlapping distributions.**

METHODS

1. DATA COLLECTION / PREPARATION

- **Obtain species occurrences** (presence-only records) from Global Biodiversity Information Facility (GBIF) for all 14 species.
- **Clean occurrences** (remove duplicates, run *CoordinateCleaner*, and spatially thin to 10–50 km).
- Obtain environmental variable data layers, stack rasters, cut to 100–200 km buffer zone [3,4].
  - ***Current environments*:** WorldClim v2.1, 30-s data [4].
  - ***Future environments*:** CMIP5 2070 data, 30-s data (CESM1-CAM5-1-FV2 circulation model, RCP 4.5 scenario) [3].
- Assess correlations between env. predictor variables (Pearson's *r*, spoke plots); make reduced datasets of variables with $r < 0.9$.

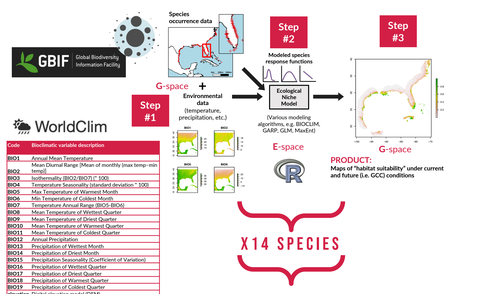
2. ECOLOGICAL NICHE MODELING (ENM) [1,5–8]

- ENM analysis – maximum entropy (MaxEnt) algorithm [2] in **R** using *dismo* [9].
- Model performance: AUC curves.
- Full (20-var.) vs. reduced (6—12-var.) models.

3. MODEL PROJECTION, TUNING, AND EVALUATION

- Project models onto current layers and future climate layers (2070, RCP 4.5).
- Compare predicted current bioclimatically suitable habitat against that under global climate change, i.e. year 2070 predictions.

Ecological Niche Modeling (ENM) Overview [2,6]



Code	Bioclimatic variable description
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp- min temp))
BIO3	Isothermality (BIO2/BIO7) * 100)
BIO4	Temperature Seasonality (standard deviation * 100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter
elevation	Digital elevation model (DEM)

Figure 1. ENM overview, including modeling process and WorldClim variable descriptions (table).

SPECIES

Table 1. Focal plant species and their most likely zone of occurrence on dunes [10].

Group	Species (Common & Scientific names)	Foredune zone	Backdune zone
Grasses			
1.	Sea oats *Uniola paniculata* L.	x	
2.	Bitter panicum *Panicum amarum* Ell.	x	
3.	Seashore paspalum *Paspalum vaginatum* Sw.	x	
4.	Saltmeadow cordgrass *Spartina patens* (Ait.) Muhl.	x	
Other herbaceous plants			
5.	Searocket *Cakile maritima* Scop.	x	
6.	Largeleaf pennywort *Hydrocotyle bonariensis* Lam.	x	x
7.	Beach morning glory *Ipomoea pes-caprae* (L.) R. Brown	x	
8.	Seapurselane *Sesuvium portulacastrum* (L.) L.	x	
Trees and shrubs			
9.	Seacoast marshelder *Iva imbricata* Walt.	x	
10.	Florida rosemary *Ceratiola ericoides* Michx.		x
11.	Sand live oak *Quercus geminata* Small		x
12.	Waxmyrtle *Morella cerifera* L.		x
13.	Gulf croton *Croton punctatus* Jacq.		x
14.	Aloe yucca *Yucca aloifolia* L.	x	

Foredune species Backdune species

RESULTS AND DISCUSSION

No	Species Name	Full model AUC	Reduced model AUC	Full model Present to 2070 Trend	Reduced model Present to 2070 Trend
1	*Uniola paniculata*	0.975	0.940	drastically reduced	expansion
2	*Panicum amarum*	0.910	0.887	drastically reduced	reduced
3	*Paspalum vaginatum*	0.964	0.953	reduced	reduced
4	*Spartina patens*	0.910	0.901	drastically reduced	drastically reduced
5	*Cakile edentula*	0.925	0.917	drastically reduced	reduced
6	*Hydrocotyle bonariensis*	0.900	0.879	drastically reduced - southern expansion/refugium	drastically reduced - southern expansion/refugium
7	*Ipomoea pes-caprae*	0.905	0.868	drastically reduced	reduced
8	*Sesuvium portulacastrum*	0.911	0.876	drastically reduced	drastically reduced
9	*Iva imbricata*	0.976	0.976	reduced	reduced
10	*Ceratiola ericoides*	0.942	0.922	reduced	reduced/equal - northward expansion/refugium
11	*Quercus geminata*	0.943	0.929	drastically reduced - northward expansion/refugium	reduced/equal - northward expansion/refugium
12	*Morella cerifera*	0.797	0.777	drastically reduced	reduced/equal - northward expansion/refugium
13	*Croton punctatus*	0.888	0.860	expansion	somewhat reduced
14	*Yucca aloifolia*	0.945	0.923	drastically reduced - northward expansion/refugium	reduced/equal - northward expansion/refugium

Table 2. Summary of model evaluation statistics and qualitative interpretations from comparing current vs. future (2070, GCC) MaxEnt model predictions. Area under the Receiver Operating Characteristic curve (AUC) statistics for each ENM are metrics for model evaluation, with higher values indicating greater predictive ability. "Present to 2070 Trend" columns describe changes in predicted habitat suitability (HS) between 'current' conditions (modern 1950–2000 data) and 2070 conditions representing GCC based on the IPCC RCP v4.5 scenario of global CO_2 emissions. Reduced models based on less correlated variables were preferred.

Mining GBIF records in **R** yielded a total of 600–11,950 raw occurrence records per species (museum specimens ≠ citizen science obs.). Data cleaning procedures reduced these to 129–438 occurrences per species with reduced spatial bias. Analyzing cleaned occurrences with either the full vs. reduced datasets yielded broadly similar models for each species with good—excellent predictive ability overall (mean AUC = 0.911, range = 0.777–0.976; **Table 2**). Projecting ENMs onto current conditions revealed good agreement with species known distributions. Model comparisons revealed <u>**four major trends**</u> **in predicted habitat suitability (HS) from current to 2070 conditions: (1) expansion** of foredune species HS (e.g. *U. paniculata*, **Fig. 2A**); **(2) reduction** in foredune species HS (e.g. *P. vaginatum*, **Fig. 2B**); **(3)** ***drastic*** **reductions** in foredune/backdune species HS; and **(4) northward or southward range expansions or shifts** in HS in backdune species (e.g. *Q. geminata*, **Fig. 2C**). However, the dominant pattern among our preferred reduced models (9/14 species, 64%) was a trend of reductions in HS under GCC (**Table 2** *above*).

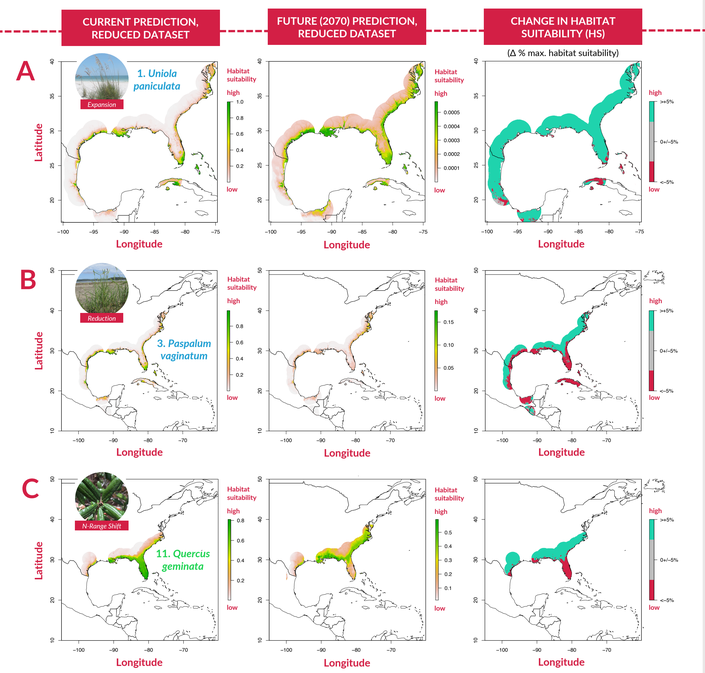


Figure 2. Exemplars of three major trends in habitat suitability predicted by our models. Continuous raw output from current ENMs (*left*) are compared against model projections onto 2070 GCC conditions (*center*). Change plots illustrate differences between these two rasters after reclassification to % max. habitat suitability (*right*; green, ≥5% expansion; red, ≤−5% reduction). See text for further details.

ENM PROBLEM FORMULATION / WORKFLOW

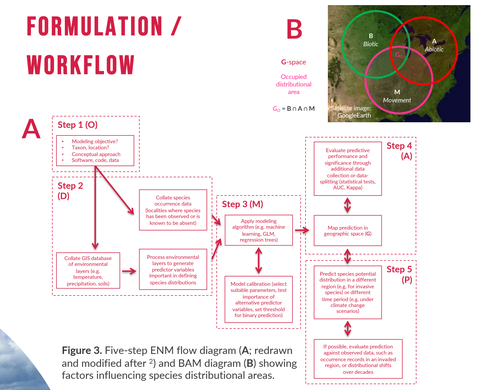


Figure 3. Five-step ENM flow diagram (**A**; redrawn and modified after [2]) and BAM diagram (**B**) showing factors influencing species distributional areas.

FUTURE DIRECTIONS

- Run ENMs using other **global circulation models (GCMs)** & IPCC representative concentration pathways (e.g. RCP v8.5).
- **Additional model evaluation and tuning.**
- **Field-based validation** of present-day ENMs to assess suitability–abundance or suitability–fitness correlations.
- **Population genomics of local adaptation.**
- **ENM prediction of future distributions of adaptive genetic variation.**
- Mapping of gene–environment match/mismatches to predict most impacted areas under **GCC** *cf.* [11].

REFERENCES

1. Defeo, O., McLachlan, A., Schoeman, D.S., Schlacher, *et al.*, 2009. Threats to sandy beach ecosystems: a review. *Estuarine, Coastal and Shelf Science*, 81, 1–12.
2. Peterson, A.T., Soberón, J., Pearson, R.G., Anderson, R.P., *et al.*, 2011. *Ecological Niches and Geographic Distributions* (MPB-49). Princeton University Press, New York.
3. Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, *et al.*, 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25, 1965–1978.
4. Hijmans, R.J., 2021. raster: Geographic Data Analysis and Modeling. R package version 3.4-13. Available at: https://CRAN.R-project.org/package=raster.
5. Elith, J., Graham, C.H., Anderson, R.P., Dudik, *et al.*, 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 29(2), 129–151.
6. Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, 190(3-4), 231–259.
7. Merow, C., Smith, M.J., Silander, J.A. Jr., 2013. A practical guide to MaxEnt for modeling species' distributions: What it does, and why inputs and settings matter. *Ecography*, 36, 1058–1069.
8. Phillips, S., 2021. maxnet: Fitting 'Maxent' Species Distribution Models with 'glmnet'. R package version 0.1.4. Available at: https://CRAN.R-project.org/package=maxnet.
9. Hijmans, R.J., Phillips, S., Leathwick, J., Elith, J., 2020. dismo: Species Distribution Modeling. R package version 1.3-3. Available at: https://CRAN.R-project.org/package=dismo.
10. Williams, M.J., 2007. Native plants for coastal dune restoration: what, when and how for Florida. USDA NRCS, Brooksville Plant Materials Center, Brooksville, FL.
11. Exposito-Alonso, M., Vasseur, F., Ding, W., Wang, G., *et al.*, 2018. Genomic basis and evolutionary potential for extreme drought adaptation in *Arabidopsis thaliana*. *Nature Ecology and Evolution*, 2, 352–358.

ACKNOWLEDGEMENTS

We thank the JSU College of Science and Mathematics for providing space, computational resources, and IT support during this project. Additionally, we thank the JSU Department of Biology for providing funding for equipment (4 TB external hard drives) used during this research.

AUTHORS
Justin C. Bagley, Ashlynn Abernathy, Lacey Bell, Rachel E. Bonner, Laura K. Dease, Collier DeVaney, Macee J. Glick, Jackson Hall, Elizabeth A. Hughston, Miles Jones, Nathan Jones, Monquita King, Kayla Morrow, Jordan Peters, Maddie Prickett, Caleb West.
Contact: jbagley@jsu.edu

WEBSITE:
bagleylab.com

Take a picture or **scan the QR** code to **download** the **full poster.**