Migrating Mangroves: Exploring the potential for pollinators to accelerate climate driven mangrove encroachment into Florida salt marsh ecosystems

Introduction: Anthropogenic climate change is altering the biogeographic patterns of species globally, often driving poleward shifts (Chen et al., 2011). A species' geographic range limits have widely been attributed to the physiological tolerance of temperature and other abiotic factors (Dillion et al., 2010). Ecological interactions may also contribute to a species' ability to match climate change velocity (HilleRisLambers et at., 2013; Jones and Gilbert, 2016). This is especially true in plants, most of which rely on animals for pollination and seed dispersal (Ollerton et al., 2011).

In order for most plants to track climate change, they must obtain adequate pollination services to ensure successful reproduction and sufficient seed set for dispersal into newly suitable habits beyond their range (Chalcoff et at., 2012). A long-held ecological theory is that reproduction at a species range margin is limited, and plant populations are expected to be isolated with suboptimal pollination conditions due to sparser floral displays and rewards. Recent studies have reported that plant-pollinator interactions do not widely limit species distributions and that pollinators may actually serve as a "biotic pull" contributing to plants' adaptation to climate change via migration (Dawson-Glass and Hargreaves, 2021). Investigations into range edge pollination biology are crucial to providing insight into how plants are able to attract and sustain quality pollination services to aid in climate change induced range expansions.

Background: Avicennia germinans (Acanthaceae, black mangrove) is an insect-pollinated flowering tree that is adapted to intertidal zones and restricted by frost to tropical and subtropical regions (Osland et al., 2020). The range dynamics and distributional limits of black mangroves are globally well-described with an extensively documented climate change-induced northerly range expansion (Cavanaugh et al., 2014; Coldren et al., 2019; Adgie and Chapman, 2021). The migration of subtropical black mangroves into temperate salt marsh ecosystems have been extensively documented in wetlands in Texas, Peru, Brazil, South Africa, Mexico, Australia, New South Wales, and the Guangdong Province of China (Saintilan et al., 2014; Loveless, 2014; Cavanaugh et al., 2019).

Over the past two centuries, the geographic distribution and abundance of Florida's black mangroves have fluctuated approximately three degrees of latitude north of their historical range in sync with decreases in extreme cold events (Cavanaugh et al., 2019; Hayes et al., 2019). Black mangroves are dispersed abiotically via water and recent extreme hurricane events have been identified as a major dispersal agent contributing to the poleward expansion of the species. However, propagule dispersal alone cannot ensure the subsequent establishment, therefore, successful reproduction is necessary (Kennedy et al., 2020). Pollinators are vital for the reproductive success of black mangroves, and significant declines in fruit set occur when pollinators are excluded (Rathcke et al., 1996; Nettel-Hernanz et al., 2013). The ecological mechanisms driving the black mangrove's range expansion are unknown. No studies to date have attempted to assess the reproductive ecology of a plant species, from range core to margin, during an active poleward expansion.

Preliminary Work: I have conducted preliminary research along a latitudinal gradient on the northeast coast of Florida within the NOAA: Guana Tolomato Matanzas National Estuarine Research Reserve and further north near the NPS Timucuan Preserve. During the summer 2022 flowering period methods were tested and data was collected on tree growth patterns, floral display, floral traits, floral resources, and pollinator interactions.

Objective: Mangrove migration has crucial and complex implications for global wetland structure and function because as mangroves migrate into higher latitudes in response to climate, they will provide countless ecosystem services to threatened coastlines while also encroaching and replace salt marsh habitats (Chapman, 2020). Understanding what may accelerate black mangrove encroachment into salt marsh wetlands, as well as shifts in the ecotone, is key to wetland conservation and making timely land management decisions. A comparative study of black mangrove reproductive ecology will be conducted from the equatorial range core to the shifting range margin along a latitudinal gradient on the east coast of Florida in order to identify potential ecological mechanisms underlying plant range expansion. The black mangrove populations at the wetland sites where I will conduct the proposed research have been genotyped and extensively studied by the advisors of this project (Kennedy, 2020b). I aim to provide the first documented in-depth account of black mangrove reproductive ecology to offer insight into how plants are able to attract and sustain quality pollination services to aid in range expansion.

Statement of Work: (1) Floral Design and Function: Throughout the 2023 summer flowering season I will measure several floral traits that directly influence the occurrence and frequency of pollinator visits. Flower size will be quantified using three measurements that are often linked to pollinator type or syndrome. To obtain a metric of reproductive potential, I will count and sum all buds, open flowers, and aborted flowers present. Floral abundance and display size will be quantified as the number of open flowers at a given time, the number of flowers per inflorescence, and the number of inflorescences per tree. I will also measure floral longevity. Collectively, these measurements will allow me to quantify the floral traits related to pollinator attraction and pollination efficiency.

(2) Floral Rewards: To accurately capture black mangrove's nectar characteristics, nectar volume, sugar concentration, sugar composition, pH, and secretion rates will be assessed. Nectar quality will be calculated as the total sugar per inflorescence and the total sugar per tree.

(3) Pollinator Interactions: I conduct an intensive observational study of visitor interactions and preferences. I will continue to work closely with entomologists familiar with this system to collect data on pollinator identity, diversity, visitation rates, the average arrival and departure times of common visitors, as well as a description of foraging behavior and flower handling for each pollinator functional group will be recorded. I will also measure abiotic and biotic covariates including percent cloud cover, wind speed, air temperature, relative humidity, conspecific density, and the dominant flower species within 5 meters.

(4) Reproductive Success and Establishment: To obtain a metric of reproductive success, I will calculate the flower-to-propagule ratio and fecundity (as measured by total propagule production) of each tree. At the end of the flowering period, mature propagules will be collected at trees that were sampled during the flowering period. Propagule length, width, and dry mass will be measured. Propagules will be placed in individual tubes and grown in topsoil and seawater for five years. Initial growth rates will be calculated using the timing of propagule abscission, leaf emergence, total root length, root surface area, and the number of root tips after a 9-month growing period.

Broader Impacts: (1) Benefits to Coastal Wetland Conservation: Mangroves are an ecologically, economically, and culturally significant species that provide vital habitats for a rich variety of wildlife that include estuarine, intertidal, and terrestrial species (Lonard et al., 2017; Friess et al., 2020). Incorporating plant-pollinator interactions, and the floral resources that mediate them, can refine and shape conservation efforts, particularly for plants that are of high ecological and economic importance like black mangroves (Friess et al., 2020). Within the wetlands of this study, multi-year datasets have been collected on a multitude of abiotic and ecosystem level traits. Reproductive and pollinator ecological data is missing from the decades of research that exist on migrating mangroves. My research will take advantage of an incredible opportunity to add novel ecological insights to a wealth of data and scientific insights on how climate change is impacting wetlands globally. By collaborating with established mangrove scientists and connecting datasets, I can drastically reduce many of the major challenges facing most ecological investigations today. There is incredible potential to expand scientific knowledge of wetland floral ecology, range edge reproduction, and shifting wetland dynamics by conducting the proposed research. This research will advance our understanding of the ecological interactions that shape species' geographic distributions, particularly during a climate change-induced range expansion. Floral design, function, and rewards have not been previously explored as a potential adaptive or acclimating mechanism of plants leveraging their mutualisms with pollinators to aid in their ability to match climate-change velocity. This study will be the first of its kind to take steps toward analyzing the direct influence pollinator mutualisms have on the reproductive success of range expanding plants. I intend to be an innovative and collaborative leader in floral ecology research, advance our understanding of the impact climate change has on black mangroves, and better protect this vital species and the wealth of organisms and coastal cities that rely on them. The GCA Coastal Wetlands Scholarship will empower me to fill a substantial gap in knowledge that is vital to wetland conservation.

(2) Community Science Initiatives: Before beginning graduate school, I spent eight years developing the skills to create intricate, hands-on, inquiry and phenomena-based science education programming for students in early childhood through high school. I have cultivated new initiatives in schools, adapted them consistently over time, and nurtured excitement and passion in children. My graduate studies thus far have positioned me to harness my expertise as an educator to do my part in filling the chasm between authentic science and students. Support from the GCA Coastal Wetlands Scholarship will also provide me access to the field experience and training to truly bring children in as collaborators in active research and empower them to expand science understanding. While completing the proposed research project I will also: (i) design research-based cross disciplinary science curriculum focused on Florida native wetland ecosystems that is differentiated to support diverse learners, (ii) craft professional development programs for Florida teachers that provide access to graduate level wetland studies and training in rigorous field and laboratory methods, (iv) develop and refine school-wide STEM enrichment programs that connect with native Florida wetlands. Currently I am spearheading a collaboration with the NOAA: Guana Tolomato Matanzas National Estuarine Research Reserve Education Coordinator to consult on and enrich their current school programs and to develop curriculum and protocols for a new NOAA wetland water quality and mangrove greenhouse satellite site project with the Florida School for the Deaf and Blind. Continuing my conduct fieldwork and grow as a scientist will allow me to contribute my experience, skills, and passions to ensuring science is a community practice.

Funding Plans: Funds from the GCA Coastal Wetlands Scholarship would be used to purchase field supplies for nectar collection and analysis as well as cover mileage traveling from Chicago, where I attend graduate school, to the wetland field sites along the east coast of Florida. An itemized budget can be made available upon request. Housing accommodations during the proposed fieldwork will be funded in part by the Northwestern University Plant Biology and Conservation Program and in part as an extension project of the NSF-funded WETFEET project led by wetland ecosystem ecologists Samantha Chapman of Villanova University.

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