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Environmental Stressors and Priority Plant Communities on Jekyll Island, Georgia:

Interacting Effects, Stakeholder Values, and Structured Decision Modeling

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SUMMARY

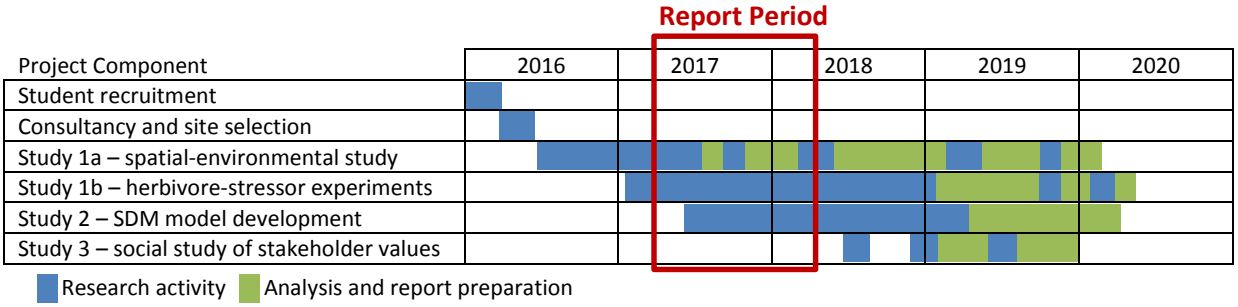
Natural areas on Jekyll Island, like many of Coastal Georgia's ecosystems, are facing a multitude of environmental stresses: sea level rise, climate change, altered hydrology, fire suppression, invasive species, and altered wildlife abundances can all affect the dynamics of vegetation communities. Jekyll Island's maritime forest communities are globally rare, unique to barrier islands, and highly regarded for their aesthetic and recreational values. This creates a strong impetus for conserving the integrity of these forests. Our four-year study investigates the effects of multiple stressors on the dynamics of Jekyll Island's maritime forests.

The research is mainly focused on live oak maritime forests: the most iconic and dominant forest type on Jekyll Island, a globally rare ecosystem, and a system that faces multiple environmental stressors that may threaten its future persistence. Oak regeneration failure is a major concern not only in maritime forests, but has been a challenge in numerous oak woodlands and forests around the world. Understanding the role of multiple stressors in shaping the future of these forests is a topic of very broad significance in environmental conservation and sustainability.

In 2018, we are expanding the scope to include a mixed oak-pine forest invaded by camphor trees. The camphor tree (*Cinnamomum camphorus*) is an introduced ornamental tree that has begun proliferating on Jekyll Island, especially in the forested area near Shell Road. The JIA conservation team is taking rapid action to eradicate the species in this area. However, it produces massive amounts of fruit, so controlling its regeneration will also be an issue. Our new study will investigate how deer browsing and heavy pine litter accumulation in this forest may affect camphor tree regeneration.

The overall research plan includes three suites of Research Studies:

1) Investigate the effects of multiple stressors on vegetation structure and dynamics using
    a. tree spatial-environmental correlations, and
    b. experimental manipulations of herbivores and stressors;
2) Integrate field and existing data on expected management outcomes into a decision support framework; and
3) Evaluate stakeholder attitudes toward management options.



According to the project timeline, Year 2 activities (April 2017-March 2018) are focused on Research Study 1a (spatial-environmental correlations), 1b (herbivore –stressor experiment), and Study 2 (decision support model development). Study 1b now also includes an herbivore-stressor experiment in the Shell Road forest. We are on schedule with the proposed activities. Our progress is reported below in five sections, elaborating on key progress elements: Study 1A, Study 1B, Study 2, Project Personnel, and Additional Complementary Funding.

RESEARCH STUDY 1A: SPATIAL-ENVIRONMENTAL STUDY

The first research activity is a **spatial-environmental study of plant community response to stressors**. The basic idea is to look at the spatial patterns of environmental conditions, then map the locations of all individual saplings and mature trees, and the density of seedlings, of different tree species. We are analyzing these data to determine whether seedlings are occurring in the same or different locations relative to the parental generation of trees, and the environmental conditions associated with observed distributions. The goal of Study 1a is to infer the relative contributions of different underlying drivers and regulators that affect oak regeneration and forest composition.

Figure 1: Macro-plot locations in the northern study site. Plot numbers refer to pairs of fenced and unfenced 10x10m herbivore plots.

Experimental Design

The northern field site is in the maritime forest between Horton House and Horton Pond. In January 2017, we established two large "macro-plots," each 100x200m, at the site. Both macro-plots span an elevation gradient and have variable densities of canopy tree species.

We have completed the first full round of data collection in the Maritime Live Oak study. We mapped the location, size, and species of every sapling and mature tree in our study plots, covering a total of 4ha (8.8 acres). We also sampled the density of live oak and laurel oak seedlings over an array of 400 points. The environmental variables assessed over the entire study area include high-resolution elevation from digital elevation models, percent tree canopy cover and light environment from hemispherical photography, and soil electrical conductivity using a 2m-long, tubular electromagnetic induction (EMI) instrument. The instrument is carried back and forth throughout an area. Every second, it sends a magnetic pulse through the soil below it, and measures how strongly that magnetic field is transmitted through the soil. It measures the conductivity at two depth ranges, 0-1m deep and 1-2m deep. It records those measurements along with the precise GPS coordinates of the instrument, allowing the generation of a two-dimensional map of soil conductivity. This measurement integrates several characteristics of soil, all of which affect the soil's ability to conduct electricity: soil moisture, soil organic matter, clay content, calcium content, and/or salinity. By taking repeated measurements on different days, and by chemical/texture analysis of soil samples from strategically selected locations, one can discern the relative contribution of moisture and other soil attributes to the overall signal. In March 2018, we conducted two surveys of soil electrical conductivity, before and after a heavy rain event. Differences in maps indicate changes in soil moisture, whereas persistent patterns that do not change following rain tend to indicate other soil characteristics. We are analyzing the resulting maps to develop a soil sampling strategy so that the maximum information about soil characteristics can be resolved.

Preliminary Findings

The analyses of the spatial distribution of live oak and laurel oak trees are preliminary at this stage, yet point to some informative trends and insights.

Live oak regeneration: We found that there were no live oak saplings (taller than 1.5m and less than 10cm in diameter) at the site. We did positively identify many live oak "seedlings." However, further investigation revealed that many, if not all, are actually sprouts emerging from the roots of mature live oak trees. Vegetative reproduction, rather than reproduction from acorns, may be the dominant strategy for live oak regeneration. If this is confirmed, the growth and survival of root sprouts may be a more important aspect of the species' life history, in terms of management, than the dynamics of acorns and 'true' seedlings.

Spatial distribution of oak species: Live oaks and laurel oaks have different distributions along the elevational gradient at the site. Live oaks are distributed rather evenly across the whole elevational gradient, while laurel oaks are concentrated at higher elevations, and do not occur at the lowest elevations (Figure 2A). Furthermore, the spatial distribution appears to vary for trees of different size classes (a proxy for age, not shown in Figure 2). The pattern could indicate that tree survival is affected by environmental conditions across the site. It may also indicate, however, that constraining environmental conditions have changed and shifted spatially over time. Since soil characteristics tend to vary with elevation, these measurements can help interpret the mechanisms by which elevation affects tree distributions. We are conducting a series of geostatistical analyses that will help identify which hypotheses best explain the observed patterns of tree distributions.

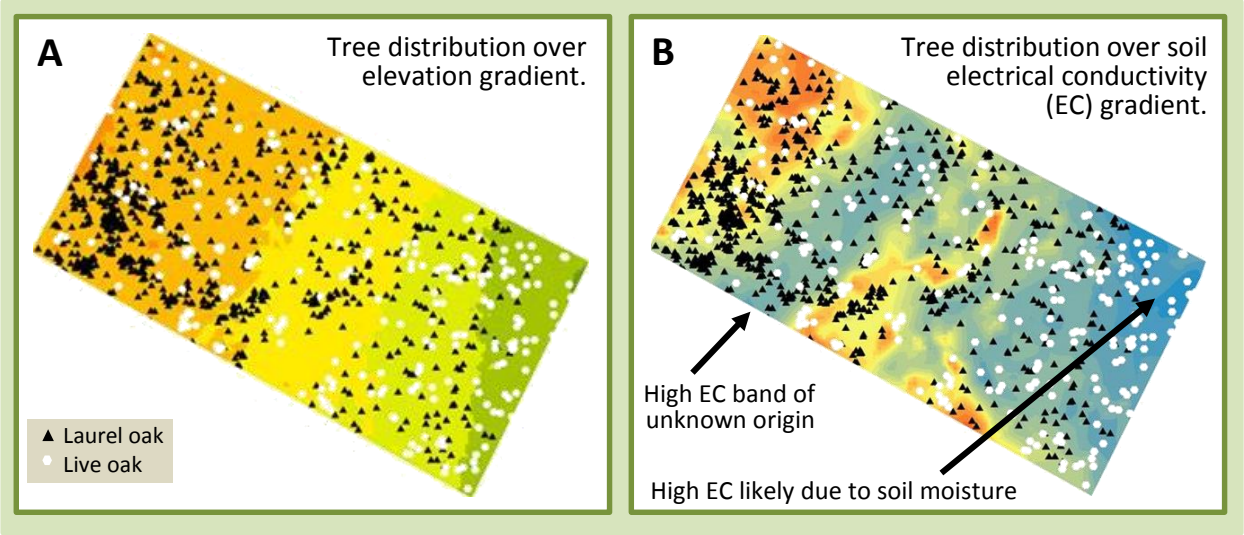


Figure 2: East macroplot, showing the distribution of all live oak (white) and laurel oak (black) trees of all sizes. The high density of laurel oaks in the southwestern corner is predominantly saplings. Color gradient in (**A) represents elevation**, from low (green) to high (orange). Color gradient in **(B) represents soil electrical conductivity at depths 1-2m below the soil surface**, ranging from low (orange) to high (blue) conductivity. Preliminary geostatistical analyses suggest that the high electrical conductivity in the lower elevations in the eastern area of the macroplot is likely due to higher soil moisture and soil organic carbon. The band of higher conductivity at higher elevation, however, is not likely due to soil moisture. It may be due to a clay layer nearer the soil surface, or potentially enhanced calcium from shell middens. Soil samples and additional analyses will be conducted in 2018 to better understand the soil environmental conditions and their correlations with the distribution of live oak and laurel oak trees of different sizes.

RESEARCH STUDY 1B: DEER-STRESSOR EXPERIMENTAL STUDY

The basic idea of these studies is to study the effects of different stressor factors on herbaceous vegetation and tree seedlings. We now have two study sites: the maritime live oak forest at the north end of the island, and the camphor tree-invaded mixed oak-pine forest adjacent to Shell Road in the center of the island.

Maritime live oak forest

In the maritime live oak forest, we are studying the effects of deer herbivory, light availability, and soil moisture on naturally occurring live oak and laurel oak seedlings, and transplanted live oak seedlings. Based on our observations during setup of the maritime live oak plots, and preliminary analysis of baseline data, our findings led us to simplify the initial experimental design, in order to increase our ability to statistically detect differences between fewer environmental stressor treatments. We now expect that deer impacts will be of a fairly small magnitude on the seasonal and yearly time scales of our data collection, and we also observed high variability in seedling condition. Smaller treatment effects and higher variability mean that larger sample sizes are needed to resolve ecological mechanisms. We have decided not to use brush pile treatments because without it, we can double our sample size to test herbivory, light, and soil moisture effects. The natural seedling study began in the maritime live oak forest in Spring 2017, and the seedling transplant study will begin in April 2018.

Hurricane Irma (September 2017) and the January 2018 ice storm caused extensive tree damage in the area, and many of the deer exclosures were hit by fallen trees and branches. Repairs were made as quickly and effectively as possible. We do not think that the periods of damage will significantly affect the results, but we will analyze any differences between affected vs. unaffected plots to confirm. Following the upcoming vegetation monitoring in May 2018, we will be able to begin preliminary analyses of treatment effects on naturally occurring vegetation.

Camphor tree-invaded forest

In the new camphor tree area study, we are manipulating deer herbivory and litter density across an elevation gradient, and will assess the effects on all herbaceous vegetation and tree seedlings, with particular interest in camphor tree seedling response to environmental stressors.

The habitat in this forest is mixed pine, oak, and other hardwood species, with a nearly continuous saw palmetto shrub layer that excludes almost all other plant species and results in greatly reduced floristic diversity. However, throughout the approximately 4ha (8.8 acre) site, there are distinct clearings in the saw palmetto, typically 3-12 m across. In these clearings, we observed very little herbaceous or shrub vegetation, yet notably thick litter layers comprised predominantly of pine needles, and we commonly observed evidence of deer utilization. Almost all of these clearings contained juvenile and/or mature camphor trees, which JIA staff treated with herbicide in 2016 and 2017. Almost all clearings had small redbay (*Persea borbonia*) and/or swamp bay (*Persea palustris*) plants, which appear to be mostly sprouts from roots of trees that died back as a result of the laurel wilt invasion that decimated Georgia coastal populations from 2004 to 2009. In about half of the clearings, there were also camphor seedlings emerging. Figure 3 shows photos of typical saw palmetto density and striking contrast to the occasional clearings in the saw palmetto matrix.

Ecologically, this site therefore contains an important set of interacting stressors of management concern. The density of saw palmetto and the very thick layer of pine litter throughout the site are likely the result of long-term fire suppression. The clearings may represent the last vestiges of open understory that the palmettos have yet to fully colonize, or they may be staying open because of some other factor that limits palmetto encroachment. In either case, the thick pine litter in the clearings may be inhibiting herbaceous and shrub growth. Alternatively, or in addition, deer utilization

of these clearings may be contributing to their low species richness and abundance. We see re-emergence of both native *Persea* species as well as the invasive camphor tree in clearings. We do not know how the combination of deer and fire suppression are affecting the relative success of these two species. Understanding which conditions favor the native species, and which favor the invasive, will help JIA conservation staff manage the area for invasive control and native plant diversity restoration.

In total, we identified 32 clearings that were at least 6m across, of which a randomly selected 24 will serve as research plots. In 12 clearings, we are erecting 6x6m deer exclosures, and the other 12 will remain unfenced. In each fenced and unfenced plot, we will clear the litter on half of the plot, and leave the litter layer intact on the other half. We will carefully monitor the response of all herbaceous and shrub species to the experimental treatments, and also track associated changes in soil moisture. Experimental setup and baseline data collection will be completed in April 2018.

Figure 3: Camphor tree-invaded site near Shell Road. Left: Masters student Dessa Dunn makes her way through the saw palmetto shrub layer, which almost entirely fills the understory. Due to its density, there is very low plant diversity in most of the forest understory. Right: There are occasional, distinct clearings in the palmetto, such as that pictured here. These commonly have invasive camphor trees (which have been killed by JIA conservation staff), as well as recovering bay trees (foreground), but a very sparse herbaceous layer and thick pine litter on the ground. These clearings are the focus of our research.

RESEARCH STUDY 2: DECISION SUPPORT MODEL DEVELOPMENT

Development of a decision support model is a complex, iterative process, which entails different forms of stakeholder participation, compiling scientific expertise, and formal model development by our research team. To date, our progress has involved four main components: 1) garnering additional external funding to expand the scope of the research to include four other Georgia barrier islands; 2) recruiting and training Masters student Dessa Dunn, and engaging postdoctoral scholar Brian Crawford

to assist with model development, and 4) conducting activities at a Maritime Forest Workshop to begin identifying salient concerns and management objectives across all five participating islands.

Expanded scope. In consultation with Ben Carswell, JIA Conservation Director, we pursued the opportunity to garner a Coastal Incentive Grant that would not only replicate the deer-stressor experiments on four additional islands (Ossabaw, St. Catherines, Sapelo, and Little St. Simons), but would also broaden the scope of the decision support modeling work. In this context, the management concerns and objectives of Jekyll Island will be one of several distinct sets of objectives included in the model. This enhancement of our research objective effectively leverages the funding from JIA to develop a decision support tool that will serve Jekyll Island but will be of much broader utility in understanding and promoting the conservation of maritime forests along the whole Georgia coast.

MS Student and Postdoc. Our decision support model team now includes MS student Dessa Dunn and Postdoc Brian Crawford, who will work with Co-PI Clint Moore to develop the model. We believe that having a larger team, with more focused interest and expertise in structured decision making, will greatly facilitate our progress toward model development as well as the depth and relevance of the model, given the now-expanded scope.

Maritime Live Oak Forest workshop. This workshop, co-sponsored by JIA and our recently acquired Coastal Incentive Grant, served many functions. One of the key functions was to initiate the stakeholder and scientific expertise gathering necessary to pursue the model development. At the workshop, we asked managers from five barrier islands, including Jekyll, were asked to present their 3 main management objectives relating to maritime live oak forests. During their presentations, Brian Crawford concatenated their objectives and led a participatory exercise, in which the whole workshop body reviewed the objectives and worked towards organizing them hierarchically to identify fundamental, overarching objectives, and "means objectives" that help achieve the fundamental objectives. This is an essential early step in structured decision making. The workshop also presented the very valuable opportunity to stimulate participant interest and willingness to continue working with us on model development.

PROJECT PERSONNEL UPDATES

In addition to the three principal investigators, we have engaged two PhD students, one MS student, one postdoctoral scholar, and a field technician to actively work on the project.

- *Hannah Morris, Warnell-ICON PhD student*. Hannah is in her third year of study, under PI King's advisement. She is leading the multi-island research questions regarding herbivory, multiple stressors, and past, present, and future forest composition (Research Studies 1A and 1B) for both the funded JIA project as well as the broader CIG project. She will also participate in Research Study 3, evaluating stakeholder perceptions and narratives regarding forest conditions.
- *Sarah Horsley, Warnell-ICON PhD Student*. Sarah is in her second year of study, advised by Dr. Gary Green in the Warnell School. She is a social scientist, conducting research on iconic species on Jekyll Island. Her preliminary research found that live oak trees were one of the two iconic species most frequently identified by Jekyll Island residents, visitors, and staff (sea turtles being the other). The third most frequently identified species was deer. Thus, her research domain dovetails with the Research Study 3 objectives of understanding public perceptions regarding Maritime Live Oak forests and deer. We are teaming up with her to conduct Research Study 3. In summer 2018, her surveys and interviews will elicit stakeholder perceptions, and very importantly, she will begin to assess how the iconic status of the concerned species may influence perceptions of management alternatives.

- *Dessa Dunn, Ecology MS Student*. Dessa began her Masters in Conservation Ecology and Sustainable Development in the Odum School of Ecology in Fall 2017. She will contribute to the Jekyll stressors project by taking the lead on the camphor tree-invaded study site for Research Study 1B, and will work with Brian Crawford and Clint Moore on the decision support model development.
- *Brian Crawford, Postdoctoral Scholar, Warnell School.* Brian conducted his masters and PhD research on Jekyll Island, studying management alternatives for the conservation of diamondback terrapins. His research included developing a structured decision making model, and its implementation to evaluate management alternatives. His expertise is thus a great asset to our team.
- *Ruth Cumberland,* field technician. Ruth was employed as a full-time research technician on Jekyll until November 2017, when she switched her employment base to the CIG grant. However, she continued to contribute to all research activities on Jekyll as part of the cooperative approach we are taking to fulfilling both research projects.

ADDITIONAL, COMPLEMENTARY FUNDING

The commitment that JIA has made to understanding the potential threats of environmental stressors on the regeneration and future condition of coastal maritime forests is a profound contribution to the larger endeavor of coastal conservation in Georgia and beyond. This study will provide management-relevant information for managing the maritime forests on Jekyll Island, but has the potential to contribute much more broadly if the research approach is replicated on other barrier islands. Each island has its own history of land use, management strategies, and environmental stressors. By extending the study, we can start to build more robust generalizations about the conditions under which forest regeneration is threatened, and by what specific stressors.

To pursue that goal, we applied for and obtained two additional grants to fund the replication of this study on Ossabaw, St. Catherines, and Sapelo Island. We received a Coastal Incentives Grant, for which JIA funding provided significant leverage as matching funds. The CIG will contribute funding to research on Jekyll by paying for a field technician to serve both projects, and also paying for live oak and sand live oak seedlings to be used in Research Study 1B. PI King also received funding through the University of Georgia, through a program that is geared to supporting junior faculty to establish robust research programs. That grant is being used to purchase a top-tier hemispherical photography camera and software suite, so that we can fully understand the complex light environment in the study forests. The funding will also pay for soil analyses from the north island Maritime Live Oak and the central island camphor tree-invaded forests.

Over 10 Georgia coastal managers and biologists have enthusiastically supported our plans, and receipt of the CIG funding represents an acknowledgement that this is a pressing, timely, and scientifically strong plan to strengthen our management of these rare treasures. In both proposals, we acknowledged JIA's critical role in instigating this important research avenue. By leveraging the JIA Research Grant to gain additional funding, our efforts will further strengthen Jekyll Island's well-deserved reputation as a leader and innovator in coastal environmental conservation and education.

ACKNOWLEDGEMENTS

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