Final Project Report 6:

Developing a decision-support tool for restoration and conservation of maritime live oak forests

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__About this report:__ This preliminary report explains our approach for compiling and building knowledge regarding maritime live oak forest demography, and for supporting decisions regarding restoration alternatives. We present our approach in four sections:

Maritime Forests: Context and Knowledge Gaps → Structured Decision Making Approach → Demographic Modelling for SDM → Application for Decision Support

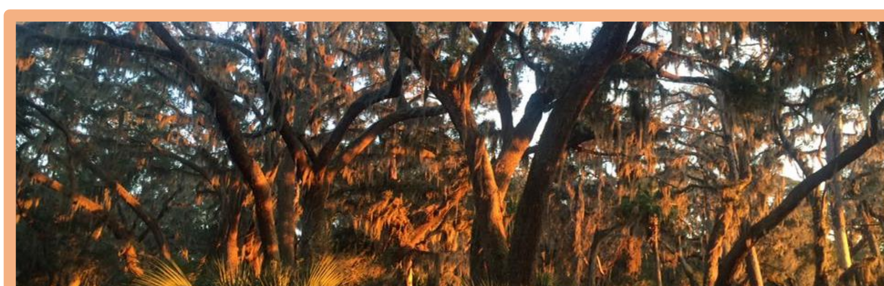
Maritime Live Oak Forests on Georgia Barrier Islands

The Georgia coast and its barrier islands are some of the most treasured landscapes in the South. Maritime live oak (MLO) forests, with canopies of graceful, spreading live oaks (*Quercus virginiana*), play a central role in supporting biodiversity and the ecological health of islands, and are globally rare ecosystems. **Jekyll Island offers unmatched opportunities for the public to enjoy the unique natural heritage of barrier island MLO forests in Georgia.**

As a result of the coast's varying geology, hydrology, ecological diversity, and human history, its MLO forests are complex, dynamic, and variable. **They are also facing many environmental stressors including climate change, land development, and altered wildlife abundances.**

Adult live oaks appear timeless and resilient, but storm damage, intense fire, and beach erosion are increasingly observed causes of mature tree mortality on barrier islands. **Meanwhile, managers on Jekyll and other islands have noticed little to no evidence of live oak regeneration.** This raises questions about the future of MLO forests facing ongoing environmental stressors:

- ***Are the live oak forests in peril?***
- ***If so, what should be done?***



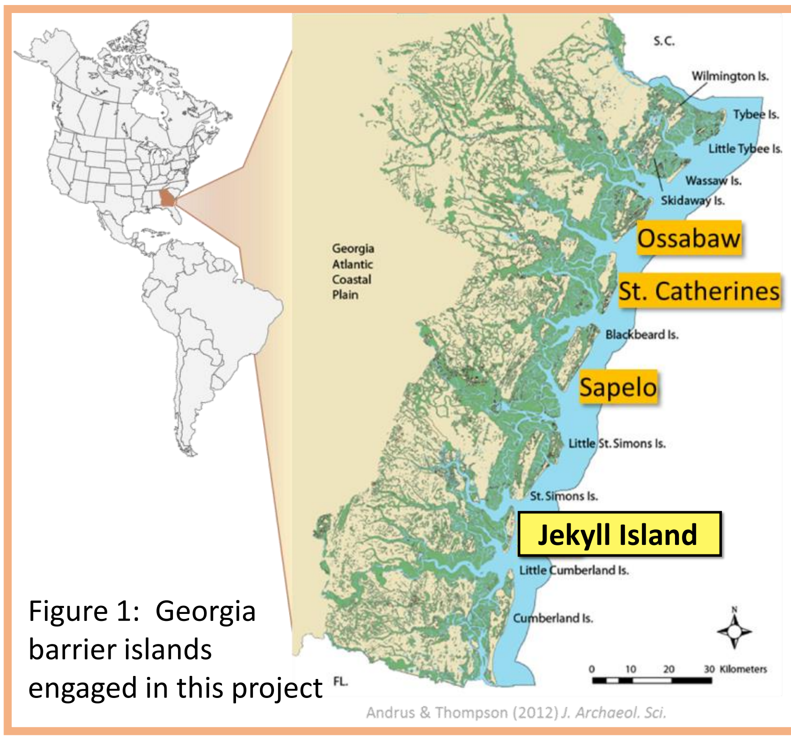


Figure 1: Georgia barrier islands engaged in this project

Andrus & Thompson (2012) *J. Archaeol. Sci.*

Addressing the first question requires ecological knowledge of the effects of environmental conditions on live oak regeneration. The second question requires an approach to identify possible management actions, and then compare their likely outcomes and costs.

We are tackling both by using a modified Structured Decision-Making (SDM) approach, described herein.

By sponsoring this research, Jekyll Island Authority (JIA) is taking a leading role in building knowledge that will benefit the conservation and restoration of MLO forest ecosystems in Georgia and beyond.

To capitalize on the support from JIA, we acquired a NOAA/Georgia DNR Coastal Incentive Grant in order to extend field research to three other barrier islands (Figure 1), and to engage a broader group of island managers and land stewards in participatory process to address these critical questions together.

Introduction to Structured Decision-Making

SDM is a six-step procedural framework, designed to integrate knowledge and uncertainties regarding the consequences of different resource management actions. SDM is used as a participatory methodology to evaluate the degree to which alternative actions will fulfill a range of objectives that may be desired by different stakeholders. Most steps are conducted with facilitated stakeholder participation.

1) A management **problem** is first identified and clearly defined**,** like low live oak regeneration.
2) Stakeholders first identify their **fundamental objectives**, typically through a facilitated workshop. These are the underlying goals and ultimate aims that people wish to realize through management.
3) Next, stakeholders identify **alternative management actions** that may potentially help them meet their objectives.
4) Scientists then construct a model that estimates the likely **consequences** of actions for achieving each of the objectives from Step 2.

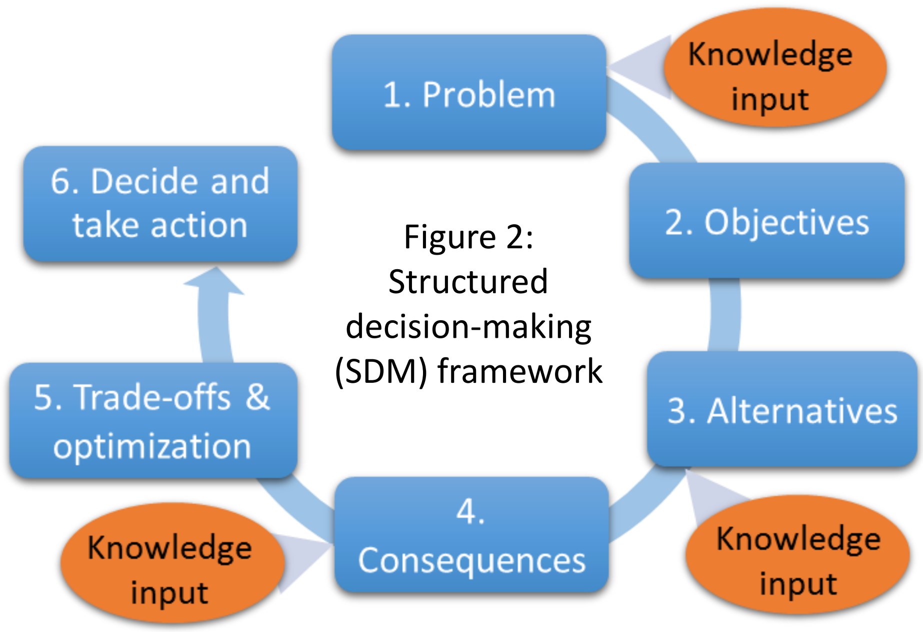


Figure 2: Structured decision-making (SDM) framework

5) Stakeholders then consider model outputs to evaluate **trade-offs**, and explore **optimizations** between actions and different management objectives.
6) Stakeholders use these evaluations to collectively **decide** on a management strategy and **take action**.

Steps 1, 3, and 4 require ecological knowledge inputs. Steps 2, 5, and 6 reflect stakeholder aims and values.

Knowledge Co-production to Inform Decision-Making

Ecological knowledge is essential for SDM models and the overall process. Prior scientific research and monitoring are usually the source of such knowledge. **Managers' and other stakeholders' direct experience and expertise are increasingly recognized as valuable sources of knowledge, which may not be documented or available anywhere else.**

Surprisingly, little is known about the life history of live oak trees or the community-level dynamics of MLO forests. While we and others have conducted some field studies on live oak seedlings, there is inadequate formal scientific knowledge to construct demographic models and make sound management decisions using SDM. The richest source of this knowledge rests with island managers and stewards themselves. They have been observing the effects of management and "natural experiments" in these forests for decades.

Land stewards, island managers, and professional nurserymen each hold distinct, unique knowledge bases. We engaged stakeholders in collaborative "knowledge co-production," by using workshops and interviews to elicit and synthesize their disparate bodies of knowledge. The co-produced knowledge is then used to inform SDM at three key input points. We also elicited stakeholder aims and values to inform SDM steps 2, 5, and 6 (Figure 2).


Field interview with land managers on Sapelo Island

Workshop #1: MLO Problems – Knowledge and Gaps

Our first knowledge co-production workshop was held in March 2018. We invited seventeen stakeholders to discuss the problem of live oak regeneration.

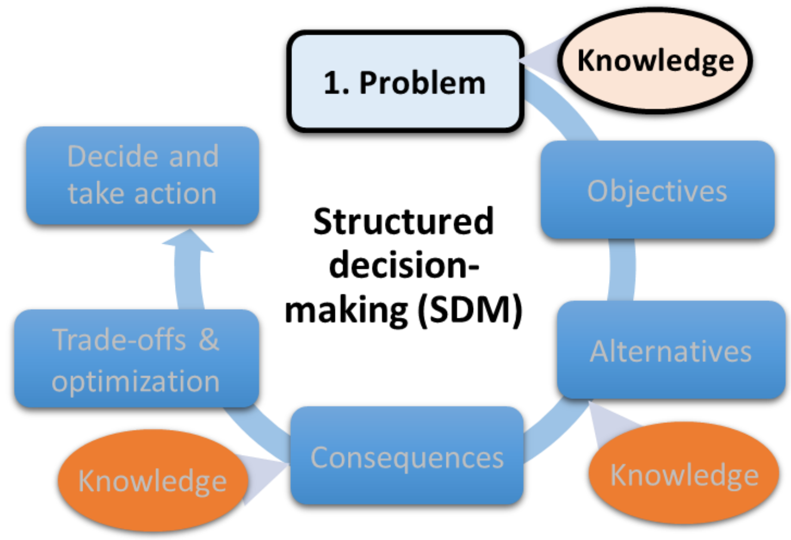
Workshop group brainstorming.

In order to build relevant knowledge for **Step 1 of SDM: Problem identification**, we conducted activities and discussions that facilitated stakeholders to:

a) Define the management problem;
b) Elicit and synthesize their knowledge regarding live oak regeneration, and
c) Identify knowledge gaps and research priorities.

Table 1: Top factors influencing live oak regeneration	
Influence Factor	% of Participants Citing
Mammal herbivory	100
Water availability	100
Herbaceous plant competition	88
Light/canopy gaps	75
Fire	75

Table 2: Salient knowledge gaps and priorities for future research		
Rank	Research Question to Address Knowledge Gap	% Citing as High Priority
1	Oak-herbivore interactions:	100
2	Define landscape-level restoration/management targets:	94
3	MLO as habitat for species of concern	88
	Effects of loss of redbay midstory.	88
4	Fire & saplings: How big do they need to be to survive?	82
5	Effects of precipitation and storm frequency on demography	77



We first asked participants to write lists of ecological factors that they thought could influence live oak regeneration. We compiled their lists and found that participants had collectively identified 18 distinct factors. We then tabulated how often each factor was mentioned by participants on their individual lists. The the five most commonly identified factors are shown in Table 1.

Participants also worked in small groups to brainstorm about existing gaps in current knowledge, which they felt posed important questions for future research. Combined, their lists identified 25 different knowledge gaps/research questions. We considered each gap/research question in a full-group discussion. Participants then voted on the priority level of each research question. The top five are shown in Table 2, ranked according to the percentage of participants who identified them as top priorities for research.

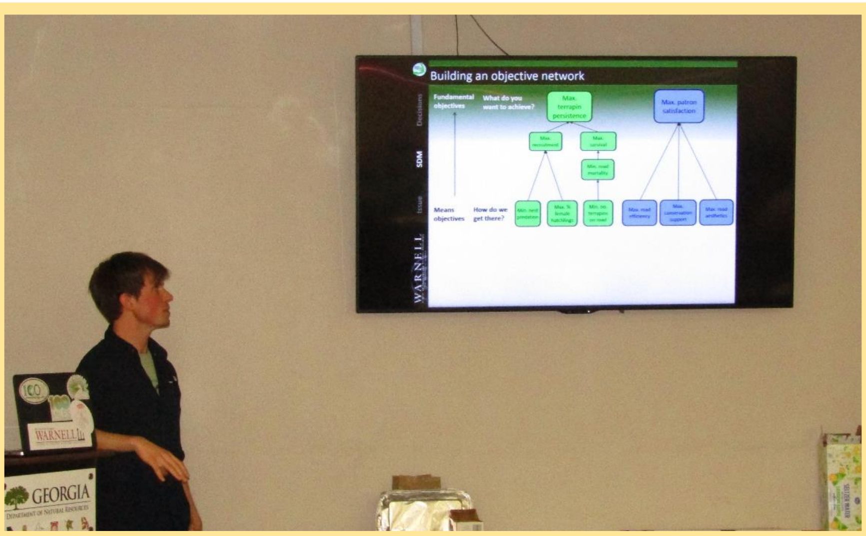
This co-produced knowledge was the basis for Step 1: Problem Identification, and it also provided critical guidance for Step 4: Modeling consequences of management alternatives.

The consensus from stakeholder knowledge was that **the impacts of current live oak regeneration, wildlife, hydrology, fire, and storm damage trends are still uncertain, but are likely to result in declines in MLO forest conditions and cover in the future.**

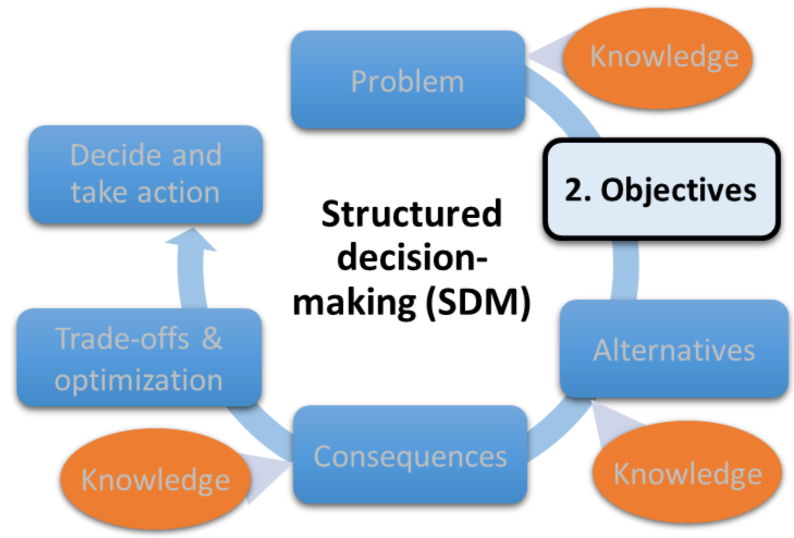
Workshop #1: MLO Forest Management Objectives

Another aim of the first workshop was to facilitate the participants to define their **fundamental objectives** relating to MLO forest management. In SDM, fundamental objectives are the ultimate goals of management; they reflect stakeholders' values and the underlying reasons why they would prefer certain management outcomes. These are distinguished from *means objectives*, which describe aims and outcomes that would contribute toward fundamental objectives.

In Workshop #1, we asked managers from Jeyll Island and three other islands (Ossabaw, St. Catherines, and Sapelo) to share their key management objectives for MLO forests. Through facilitated discussion, stakeholders were able to clarify some fundamental objectives that motivated the management goals for each island. The fundamental objectives tended to reflect different mandates of the stewarding agencies and different conservation philosophies.



Facilitated interactive process of identifying fundamental and means objectives for different islands and coastal MLO forests.



Ossabaw and St. Catherine's Island managers stated that they favored a more passive management approach to the live oak regeneration problem, allowing forest processes to occur naturally and evolve (Table 3).

On the other hand, Jekyll Island and Sapelo managers were more concerned with maintaining specific conditions in their MLO forests in the future and favored active management to do so. Given the uncertainty as to whether current regeneration trends would lead to decreased MLO forests in the future, they were motivated to take bet-hedging action now by planting young live oaks. They were interested in continuing with the SDM process to support decision-making about methods and site prioritization for restoration via live oak planting.

Active live oak restoration became the focus of the subsequent steps in the SDM process.

Table 3: Key Management Objectives of Four Barrier Islands

Ossabaw	St. Catherine's	Sapelo	Jekyll
Maintain and allow landscape to exist as it would naturally occur	Allow forests to evolve with minimal intervention	Maintain and enhance existing maritime live oak forests	Maintain maritime live oak forest composition
		Identify and prioritize sites for maritime live oak restoration	Manage fire risk

Passive management (Ossabaw, St. Catherine's)

Active management through restoration (Sapelo, Jekyll)

Workshop #2: Live Oak Restoration Objectives

We conducted a second workshop in April 2019, which focused on active live oak restoration. We polled participants from the first workshop to determine who was interested in evaluating live oak seedling or sapling planting as a restoration strategy. Nine of the original participants took part in the 2nd workshop, including Ben Carswell, Joseph Colbert, and Cliff Gawron from Jekyll Island.

For Step 2 of the SDM process for active restoration, the facilitated workshop elicited individual feedback and group discussions in order to:

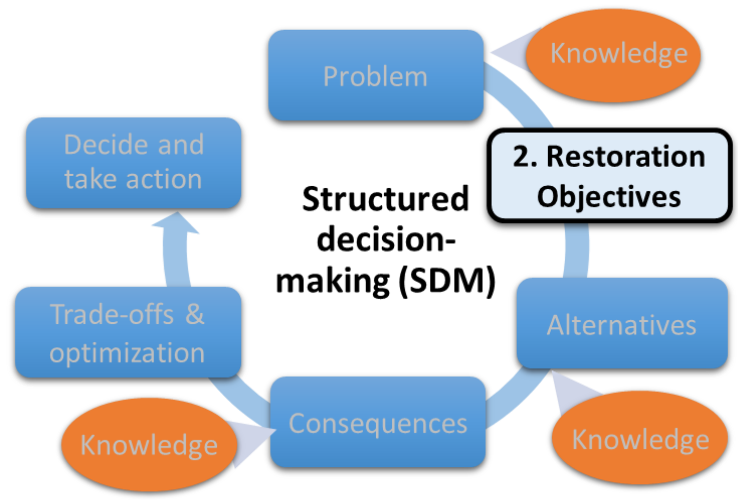
a) Revisit and clarify the range of stakeholders' fundamental objectives for live oak restoration;

b) Identify desired future conditions as long-term goals;

c) Identify conditions to achieve within 10 years, which would indicate progress toward long-term goals.

Table 4: Desired future condition (long-term means objective)		
Rank	Condition	% of Participants Citing
1	Diverse age structure	100
2	Diverse under and mid-story density and species	75
3	Healthy shrub and grass component	63
	Canopy dominated by live oak	63

Table 5: Desired condition within 10 years (short-term means objective)		
Rank	Condition	% of Participants Citing
1	Reduced invasive exotic species	75
2	Seeing successful live oak saplings and seedlings	63



Among several fundamental objectives, stakeholders identified two in particular – *cost-effectiveness* and *maximum seedling survival* – that are likely to generate tradeoffs in their choice of management alternatives.

Model development in Step 4 of the SDM process will provide the means to evaluate those tradeoffs in Step 5.

Tables 4 and 5 list stakeholders' long- and short-term desired future conditions, ranked by percentage of participants who cited them.

Most participants' desired conditions reflected concern about the age or vertical structure of live oaks in their MLO forests, as well as forest composition and plant diversity. Thus, **the desired conditions captured both compositional elements of forest ecology as well as indicators of continued regeneration through time.**

Workshop 2 stakeholders discuss future desired conditions.

Workshop #2: Live Oak Restoration Alternatives

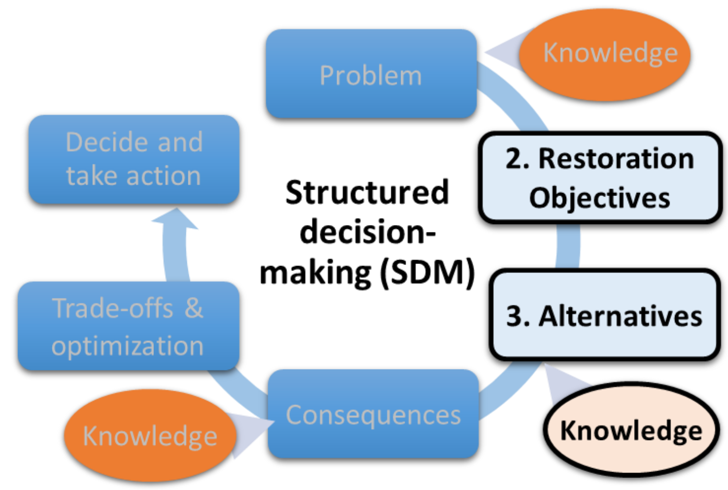
Workshop #2 stakeholders were generally concerned by the lack of juvenile live oaks in the maritime forests they managed. Without juveniles, there is no future potential for trees to augment current populations or to replace mature trees that may die.

In the workshop, we sought to Identify a range of potential, practical management actions that could help ensure that some young trees would be available to ascend to the canopy and replace existing mature trees. These alternatives would then be evaluated using modeling, in Step 4 of the SDM process, to estimate the extent to which each alternative would achieve managers' various fundamental objectives.

The stakeholders had identified two fundamental objectives – cost-effectiveness and high seedling survival – which helped guide a brainstorming session about different arrangements, conditions, or manipulations that could be enacted while planting live oaks. We asked questions like how many to plant, where to plant, what accompanying treatments might enhance survival, and whether treatments were too costly to be practical.

As we considered what factors might significantly influence the success of planted seedlings, we reviewed our list of 18 factors that influence live oak regeneration from our first knowledge co-production workshop (Table 1; Table 6). Although many conditions affect oak seedling growth and survival, they are not all feasible to control as a management action. We then discussed which of these factors would be most practical to control and potentially result in highest seedling survival.

Table 6: Factors influencing live oak regeneration	
Influence Factor	% of Participants Citing
Mammal herbivory	100
Water availability	100
Herbaceous plant competition	88
Light/canopy gaps	75
Fire	75



Workshop 2 stakeholders consider alternatives for achieving live oak restoration objectives.

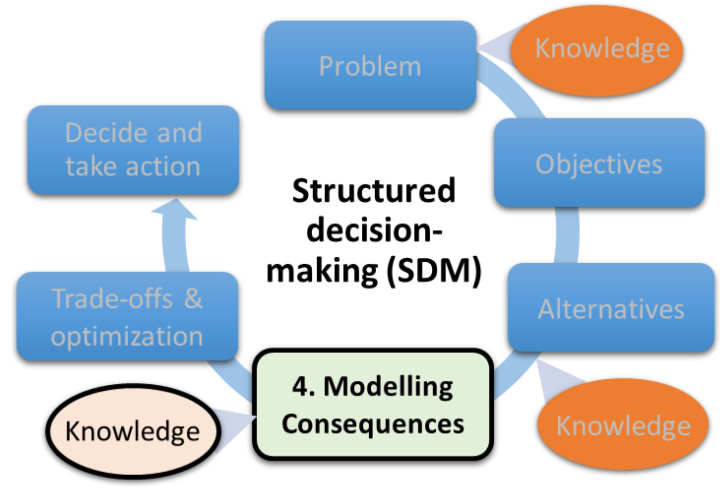
Stakeholders identified three factors that would both influence seedling survival, and be practical to manipulate: herbivory, neighboring plant competition, and light conditions.

These were selected as potential restoration treatments to explore further in Step 4: Modeling Consequences.

Modeling in SDM Step 4 will explore three management actions that are practical to implement, likely to influence seedling performance, and will impose varying costs:

- **Limiting mammal herbivory**
- **Limiting plant competition**
- **Creating / planting in canopy gaps**

Demographic modelling of live oak seedling growth and survival

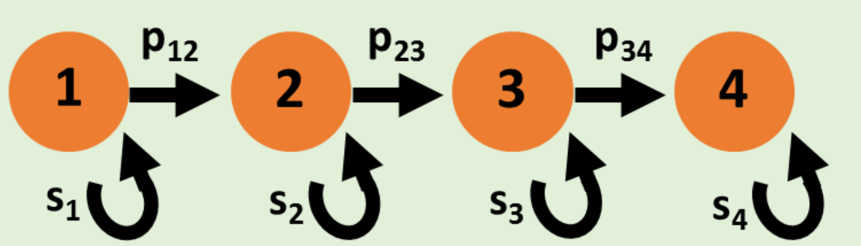


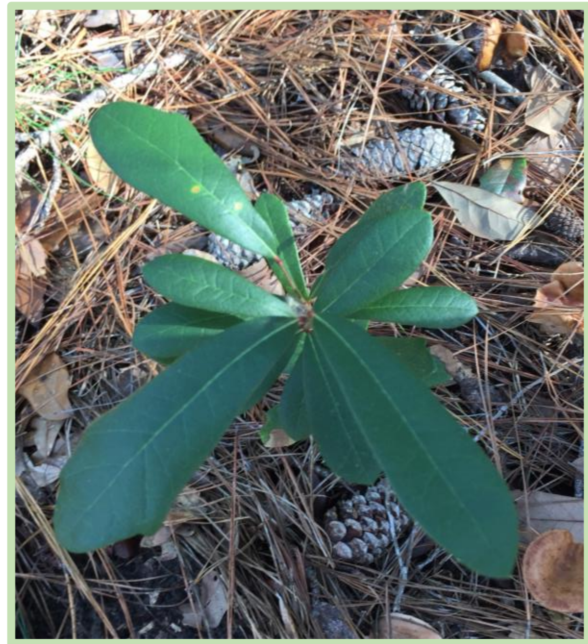
After identifying potential restoration treatments In Step 3, Step 4 of SDM is to evaluate the consequences of these alternatives for achieving stakeholder objectives. For this, **we are constructing a model that projects how treatments will affect live oak seedling growth and survival**.

A plethora of computer models exist to simulate forest-level dynamics. We conducted a systematic review and found that none were appropriate for the scale and nature of restoration treatments. Instead, individual-leve demographic transition matrix models are the most suitable tool for such projections.

Transition matrix models project population growth based on the probabilities that individuals will survive and stay (s) in a certain size or stage class (s_1,s_2,..), or survive and grow (p) from one size or stage class to another (p_{12}, p_{23},…). **Building a model with estimated growth and survival probabilities under different alternative treatments will help us project success rates for seedlings reaching the sapling stage.**

Figure 3: Example of a demographic transition matrix model





Planted live oak seedling in experimental plot on Sapelo Island

Our field experiments are generating some parameters for the model, but for estimates over longer periods and under more conditions than found in our experiments, we again look to expert knowledge as a source for model parameterization.

Knowledge co-production: Expert-derived parameters

Additional demographic knowledge is held by stakeholders who have propagated and grown live oaks for years. We have interviewed coastal managers, nurserymen, and restoration professionals to elicit their expert opinion on live oak survival and growth rates under hypothetical restoration conditions:

- High and low mammal herbivory;
- With and without herbaceous vegetation control;
- Under shaded or light-gap conditions.

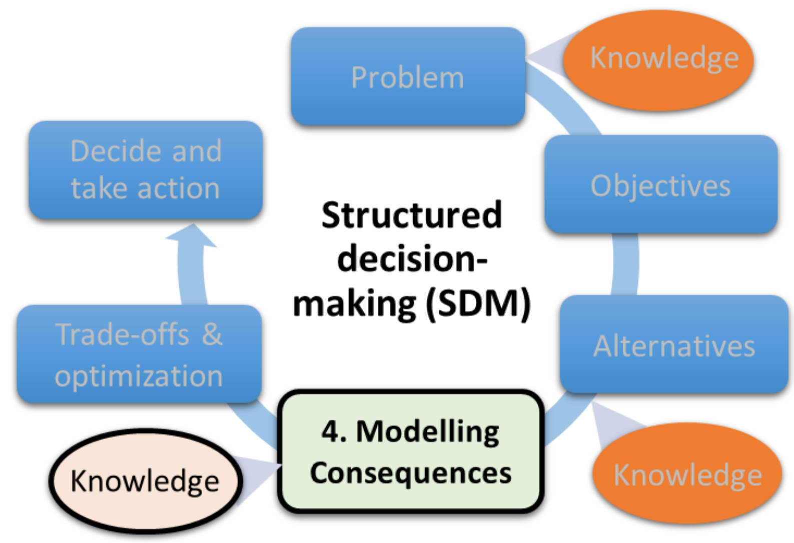
The demographic modeling is progressing well and will be strengthened by additional interviews.

Figure 4: Graphical template used for eliciting knowledge from stakeholders to estimate survival and growth parameters. Dashed lines are drawn by interviewees. Interviewees are asked to make estimates under alternative growing conditions.

Coupling demographic model with management objectives

The demographic model is being parameterized to project seedling growth and survival rates, and expected number of years until saplings are well established, under the selected range of management alternatives. This will allow us to project the degree to which different alternative plans will achieve objectives related to maximizing restoration success.

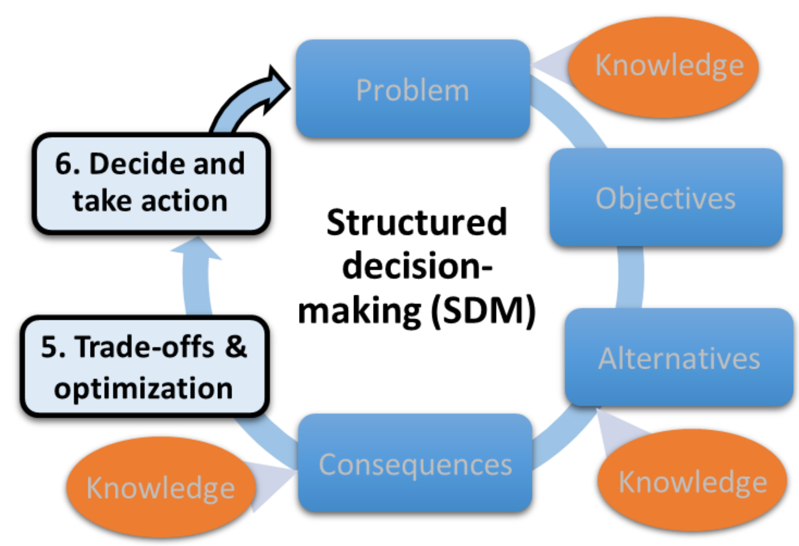
We will also estimate the financial and time costs to implement each of the scenarios on Jekyll Island, to estimate the consequences of each alternative for the other key fundamental objective, minimizing costs.



Application for Decision Support

The full decision-support model, including both demographic parameters and costs, will be run with different management scenarios selected by stakeholders. In Step 5, we will present modeling outcomes to JIA managers and stakeholders, and facilitate their evaluation of alternatives.

Tradeoffs will inevitably arise regarding the costs associated with creating the most favorable conditions for seedling success. Our aim will be to facilitate the managers' use of modeling outputs to find optimal combinations of actions for their budget, risk tolerance, and priorities for certainty and time frames for realizing restoration success.



Erecting short term deer exclosures may be a cost-effective way to improve seedling success in areas with high herbivory.

Our ongoing commitment to supporting restoration decision-making on Jekyll Island will include:

- **Updating our models with emerging research findings;**
- **Technical advice on logistics and methods for sourcing and planting seedlings, controlling vegetation, and different ways of excluding herbivores;**
- **Developing monitoring plans for restoration actions.**

Conclusions and Key Insights

To date, we have progressed through Steps 1 to 3 in the SDM process. We used workshops and a co-production approach to: compile knowledge regarding the live oak regeneration problem, identify fundamental objectives, refine objectives to concentrate on active live oak planting for restoration, and identify management alternatives to help meet those objectives.

Key insights:

- **There is not sufficient research-based knowledge to fulfill the informational needs for SDM.**
- **Diverse, in-depth stakeholder knowledge helped clarify the ecological dynamics surrounding live oak recruitment limitation.**
- **For Jekyll Island, active live oak planting was seen as desirable to ensure live oak recruitment under uncertain natural regeneration conditions.**

We are currently engaged in Step 4 of the SMD process, eliciting expert knowledge to complete the demographic transition matrix model with critical model parameters.

Key insights:

- **Stakeholders identified herbivore control, vegetation control, and planting in light gaps as potential management actions to explore with the model.**
- **A transition matrix model of growth and survival probabilities under different restoration treatments will project success rates for planted live oak seedlings.**
- **Incorporating Jekyll Island-specific cost estimates for alternatives will enable the model to be used in tradeoff analysis and decision support.**

We will facilitate Jekll Island's use of modeling outputs to analyze tradeoffs and find optimal combinations of actions for their restoration priorities and budget.

Key insights:

- **Beyond evaluating model outputs, decision support to JIA will include technical advice and monitoring plan recommendations**
- **The SDM process supports adaptive management, in which monitoring data from management actions is used to update the models and improve outcomes.**
- **JIA's research-oriented Conservation Program has exceptional capacity to use adaptive management to accelerate restoration success.**