FINAL PROJECT MEMORANDUM

1. ADMINISTRATIVE:

Understanding Conservation Management Decisions in the Face of Sea-Level Rise Along the U.S. Atlantic Coast (Project 018)

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2. PUBLIC SUMMARY: Coastal ecosystems in the eastern U.S. have been severely altered by processes associated with human development, including drainage of wetlands, changes in hydrology, land clearing, agricultural and forestry activity, and the construction of structures that "harden" the coast. Sea-level rise and the changing frequency of extreme events associated with climate change are now further degrading the capacity of those ecological and social systems to remain resilient. As custodians of ecological goods and services valued by society, coastal National Wildlife Refuges (NWRs) have an especially important role to play in helping socio-ecological systems adapt to global-change processes. To help refuges address this challenge, we articulated a two-track decision problem faced by coastal refuge managers. The first track focuses on efficient allocation of limited staff time and budgets for management of existing programs under the current refuge design. The second track recognizes the negative impacts of global-change processes on the ability to maintain societal values derived from the existing refuge configuration. Over the long term, refuge managers must decide when and where to acquire or protect new land/habitat to supplement or replace the existing refuge footprint to sustain values as the system evolves over time. Each track suggests a unique set of alternatives to represent differences in the identity of the decision maker(s) and in the spatial, temporal and governance scales of the decision problem. We developed a prototype decision structure by describing how a hierarchical set of objectives and alternative actions can be used to explore the tradeoffs inherent in making short and long-term adaptation decisions. The prototype attempts to characterize a balance between decisions within the purview of the refuge itself and decisions made at higher organizational levels concerning reconfiguration of the refuge, which may be required to ensure the long-term persistence of societal values.

3. TECHNICAL SUMMARY: In cooperation with the North Atlantic and South Atlantic Landscape Conservation Cooperatives (LCCs), the Southeastern Climate Science Center (SECSC) funded this project for fiscal years 2013-2014 to understand decision-making problems faced by National

Wildlife Refuges in the Caribbean and along the Atlantic Coast that are susceptible to sea level rise (SLR). We focused on developing a generally applicable framing of decision problems faced by refuge managers, and on understanding the extent to which those decisions might be influenced by other agents who have either common or competing interests. The goal was to develop a problem framing that would broadly reflect the type, scale and scope of SLR-adaptation decisions faced by refuges in general, and that could be used by individual refuges to help understand how their specific problems fit into a larger context of SLR planning and implementation. We assisted refuge managers in developing a common frame of reference for some shared SLR-related management problems, while also facilitating communication about these problems with other refuges and with surrounding jurisdictions.

4. PURPOSE AND OBJECTIVES: Coastal ecosystems in the eastern U.S. have been severely altered by processes associated with human development, including drainage of coastal wetlands, changes in hydrology that alter sediment and freshwater delivery to the coast, land clearing, agricultural and forestry activity, and the construction of seawalls and other structures that "harden" the coast. Sea-level rise and the changing frequency of extreme events associated with climate change are now further degrading the capacity of those ecological and social systems to remain resilient in the face of disturbance. As custodians of ecological goods and services valued by society, coastal National Wildlife Refuges (NWRs) have an especially important role to play in helping socio-ecological systems adapt to the global-change processes of sea-level rise, climate change, and changing land use. But the challenges for these refuges can be daunting, and the resources available for conservation limited. Thus, it is imperative that scarce conservation resources be used as efficiently as possible as refuges struggle with a mission that has gradually gotten much harder.

This project was principally a scoping exercise, intended to explore a management-research collaboration that would help NWRs make more informed decisions about how to plan for and adapt to sea-level rise and related global-change processes. In the uncertain world of climate change, good decisions don't guarantee good outcomes, but a systematic process, in which decision makers (managers) and scientists are fully engaged in all aspects of the problem, should enhance the likelihood of good outcomes. In pursuing this management-research collaboration, the SECSC began working with NWR staff to develop and fund a portfolio of adaptation decision projects at coastal refuges that meets the following objectives:

1) improve the capacity of refuges to make smart adaptation choices in the face of sea-level rise and other global change processes, with a focus on the following areas:
    a) understanding stakeholders' values, perceptions of tradeoffs, and tolerance of risk
    b) exploring how the ability of refuges to meet their objectives is influenced by the larger socio-ecological system in which they are embedded
    c) using state-of-the-art science to help predict the consequences of alternative adaptation strategies and to understand the implications of uncertainty in those predictions
    d) designing or redesigning monitoring programs to support decision making and learning

2) advance the development and application of decision-science in some or all of the following areas:
   a) eliciting stakeholders' values, and understanding how the costs and benefits of adaptation activities are distributed among stakeholders
   b) understanding how to use vulnerability assessments to predict the consequences of adaptation choices and to support decision making
   c) identifying and addressing scale mismatches (scale mismatches occur when the scale of environmental variation and the scale of the social organization responsible for environmental management are not aligned)
   d) developing decision-analytic tools appropriate for problems with deep uncertainty, conflicting values, and multiple decision makers

5. ORGANIZATION AND APPROACH: Our intent was to better understand the perspectives of refuge staff and what they see as key challenges in dealing with global change processes. In particular, we explored the following questions:

- How are local scale (refuge level) and broader scale (regional, flyway) refuge management objectives defined and to what extent are they coherent? Are these static (i.e., the traditional mission of a refuge) or can they evolve? Who decides? What triggers this decision or re-evaluation? Can the refuge mission evolve to reflect changing resources (e.g., disappearing barrier islands), or changing values assigned to local or broader scale objectives?
- How are the multiple objectives of refuges valued relative to each other? Who makes the determination? Is there room for negotiation? How do the stakeholders who determine the refuge's mission account for the impact of global change processes on the mission of a refuge? How is the mix of local and broad-scale objectives used to make resource allocation decisions at the refuge scale? Is this allocation coordinated in any way across multiple refuges?
- Is the individual refuge the right scale to think about and make resource allocation decisions that address a mix of local and broad-scale conservation objectives? Should the refuges (as they exist now and after the realization of a variety of global change scenarios) be thought of as a portfolio of assets that can be managed together, at least to accomplish some broader scale conservation outcomes? If so, how are individual refuge objectives valued relative to collective (system-wide) outcomes?
- What is the basis for deciding it is time to start transitioning from the current mission (or refuge "footprint") to a new mission, given uncertainty about the trajectory of some of the large-scale drivers (e.g., drought, sea-level rise, saltwater intrusion) and uncertainty about what future objectives can be achieved at or near a refuge?

To explore these questions we followed general guidelines for the framing of decision problems provided by Keeney (1992). We used a decision-analytic approach, meaning that decision problems are explicitly structured in terms of choices, outcomes, and values in order to identify the choice that is most likely to meet stated objectives. Decisions involve both predicting outcomes from alternative choices and valuing those outcomes. The first part is the (objective) role of science and the second part is the (subjective) role of the decision maker (and, ultimately, society). Discussions were "values focused" (Keeney 1992) in the sense that the ecological, social, and economic values the refuge supports were recognized as the key to developing and evaluating adaptation choices. Objectives (values) are discussed first, and drive the rest of the decision analysis. Emphasis was placed on the recognition that "the decision context and the fundamental objectives that frame a decision situation must be compatible" (Keeney 1992); i.e., objectives should be sufficient to fully evaluate all the alternatives and alternatives should be sufficient to describe all the various ways in which the objectives could be achieved.

6. PROJECT RESULTS: Although some of the particular elements will vary across individual refuges, we ultimately embraced a two-track decision problem (i.e., short and long-term) articulated by coastal refuge managers. The first track focuses on efficient allocation of limited staff-time and budgets for management of existing programs and resources under the current refuge design. Acknowledged as a near-term solution, refuge managers must make informed resource-allocation decisions to minimize loss in the capacity to meet the refuge mission within the current refuge footprint. Impacts of global change processes are contributing to this decline. Assessment of the impacts of alternative management actions on achieving these goals, and subsequent allocation decisions, are implemented largely at the refuge level, constrained by an annual operational budget (i.e., objectives are primarily determined by local refuge leadership, although possibly informed by stakeholder input).

The second track recognizes the negative impacts from global-change processes on the ability to achieve social and ecological values derived from the existing refuge configuration. Over the longer term, refuge managers must decide when and where to acquire or protect new land/habitat to supplement or replace the existing refuge footprint and sustain refuge values as the system evolves over time. Creating and implementing a strategy for expanding refuge capacity to sustain the refuge mission is likely to involve capital-allocation decisions out of the direct control of the staff of an individual refuge. It is also unrealistic to expect that a major refuge expansion could be accomplished solely using federal funds (such as the Land and Water Conservation Fund). Therefore, efforts to expand refuges to meet these changing needs will require the creation of partnerships and the identification of a set of common objectives and funding sources that the partners, including the refuge, are willing to bring to bear in a collaborative manner.

The theme common to both of these problems is developing an approach to minimize the cumulative loss of value over time as conditions change in the refuge and surrounding landscape. Each track suggests a unique set of alternatives to represent differences in the identity of the decision maker(s) and in spatial, temporal and governance scales of the decision problem. Minimizing loss associated with coastal refuge objectives is tied to decisions made within the context of a refuge system that is created and constrained by a combination of social, physical, chemical, and biological processes operating at a variety of scales. We have developed a prototype decision structure by describing a hierarchical set of objectives, performance metrics, and alternative actions, which can be used to explore the tradeoffs in making short and long-term adaptation decisions. Thus, the prototype attempts to characterize a balance between decisions within the purview of the refuge itself and the actions (i.e., refuge expansion) needed to ensure the long-term persistence of societal values when actions are not under the full control of the refuge.

7. ANALYSIS AND FINDINGS: Decision analysis has been widely used in business and government decision-making, but its application to problems in natural resource conservation has mostly been a phenomenon of the last two decades. Traditional approaches to decision making, which tend to focus mostly on alternatives and predicted outcomes, can be distinguished from modern methods that emphasize fundamental values and the multiple-objective tradeoffs inherent in natural resource management. The emphasis on values rather than outcomes helps decision makers and stakeholders understand whether disagreements are over predicted outcomes or how those outcomes are valued (i.e., subjective preferences). It also helps promote a role for analysts and scientists in conservation decision making as "honest brokers" (Pielke 2007) rather than as advocates for a particular course of action. Multi-criteria decision analysis that accounts for outcomes and values is now widely used in conservation, and is seen as contributing to better decisions through a formal structuring of decision problems that accommodates conflicts in fundamental values among stakeholders.

Despite its appeal, however, the application of decision science to complex, real-world problems can be quite challenging. Difficult questions arise about how to design processes to formulate, evaluate, and modify environmental policies in which the engagement of stakeholders, scientists, and decision makers can be nurtured and sustained, and in which governing bodies and institutions can promote discourse, transparency, accountability, learning, and a shared stewardship of the environment. Indeed, much of the recent literature in natural resource management focuses on the need for so-called "double-loop" and "triple-loop" learning (Pahl-Wostl 2009), in which extant problem formulations, laws and regulations, institutional norms, and power relationships are called into question. Beyond questions about institutional and governance structure, many conservation problems involve multiple decision makers, often acting more or less independently in pursuit of their own agendas. Add to this complexity the presence of various sources and degrees of uncertainty in outcomes, and it's perhaps easy to understand why some have questioned whether decision analysis can be successfully applied to such "wicked" problems (Ludwig 2001). The challenge for this project has been to frame coastal-wetland conservation in a way that promotes a shared understanding of the problem among diverse decision makers, to understand how key environmental drivers and outcomes are linked across a range of spatial and temporal scales, and to develop approaches appropriate for coping with "deep uncertainty" in the future and our collective ability to influence it.

In spite of these difficulties, we believe the application of decision science (Skinner 2009) shows great promise for addressing the adaptation problems faced by refuges. So-called structured decision making (SDM) (Gregory et al. 2012) is a method for analyzing decisions by breaking them into their essential components and then reassembling them to identify a preferred course of action. The SDM process includes: eliciting management objectives, identifying potential management actions, developing relevant system models that predict the outcomes of those actions, selecting an optimization method to identify optimal choices with respect to the objectives, and designing a monitoring program to keep track of the state of the system and evaluate progress (Williams et al. 2002, Skinner 2009). SDM is grounded in modern decision theory, which provides a robust framework for making decisions about the management of complex systems under uncertainty (Williams et al. 2002, Burgman 2005).

A week-long workshop with Cape Romain NWR demonstrated that refuge staff and scientists can work together successfully to identify objectives, specify management alternatives, predict the consequences of those alternatives, and identify preferred alternatives, at least for the set of objectives currently being considered by the refuge (migratory birds in decline, threatened and endangered species, waterfowl, and public recreation and education). The challenge remains to broaden the objectives to include other ecosystem goods and services that traditionally have not been explicitly considered by refuges in their management decisions (e.g., protection from storm surge). This broadening of objectives complicates the decision-making process, but also provides opportunities for collaboration with stakeholders who may have agendas different from the refuge and opportunities for addressing problems across scales (i.e., addressing issues of scale mismatch). We make some recommendations on how to proceed in this endeavor in the following section.

Although partnerships are an important component of current refuge operation and sustainability, partnerships with, and public support from, other decision makers and stakeholders are critical for any expansion of a refuge and, therefore, for the longevity of the refuge. Examples of the kinds of actors whose interests and decisions may directly or indirectly influence the outcomes for fundamental resource objectives (waterfowl, threatened and endangered species and migratory birds in decline) include: commercial fishers; large private landowners; large public landowners; NGOs; public agencies that enforce state or federal laws/regulations that affect habitat; Friends of the Refuge groups; volunteers; state/federal Depts. of Transportation; local and county governments; and small businesses such as lodging and restaurant owners who benefit from ecotourism. Decisions and actions by these actors may influence the availability of habitat in a positive or negative way. Thus, broad-based political support is a crucial component for implementation of any expansion plan, regardless of the availability of land and willingness of potential sellers. Engendering support will likely be most effective if the objectives of these decision makers are considered when quantifying the value of the refuge or refuge system. This understanding presents an opportunity to reframe the metrics used for appraising the value of the refuge; i.e., scaling the evaluation of benefits to match the decision context of a broader set of stakeholders whose interests are focused on those goods and services that meet greater public benefit.

8. CONCLUSIONS AND RECOMMENDATIONS: Refuge resource-allocation decisions are often complicated by a mismatch between the scale of environmental variation (processes) and the spatial and temporal scale at which management actions can influence the attainment of refuge objectives (Iguchi 2011). A significant number of the challenges and, presumably, failures in conservation and management are attributable to poor understanding of, and response to, the interaction of socio-ecological processes across scales and levels (Cumming et al. 2006, Cumming and Norberg 2008, Guerrero et al. 2013). A refuge has limited control, authority and resources to fully realize conservation objectives for wide-ranging, migratory species that may only spend a portion of their complete lifecycles in refuge habitats and whose migratory pathway may eventually be altered by changing climate and habitats. Although the governance structure of the regional NWRs may result in an appropriate matching of scales for some decisions (e.g., resource allocation at region or flyway perspective), many decisions are made at the refuge level where the likelihood of scale-mismatch are increased. NWRs face a considerable challenge in defining achievable yet meaningful objectives while, at the same time, expanding the scale of the decision context by considering a broader set of stakeholders and expressing the significance of the refuge in terms that engender broader societal support.

Here we provide some recommendations for carrying this research-management collaboration forward, should the SECSC decide to do so. We focus on what we see as critical needs in terms of the assessment of the values of ecosystem goods and services, and on the development of optimization approaches appropriate for dynamic problems.

<u>Resource valuation</u>. – The SECSC should consider working closely with social scientists and natural resource economists to help identify relevant stakeholders, to quantify objectives, and to value the provision of ecosystem services under current and future refuge designs. Many management actions that impact the quantity and quality of ecosystem services provided by refuges have benefits and costs whose values accrue outside traditional markets, such as increased flood protection, decreased nutrient cycling, and increased recreational quality for visitors. Nonetheless, these values are critical to understanding how scarce management dollars should be allocated among competing demands. A host of economic valuation tools exists to quantify these nonmarket benefits and costs, such as choice experiments, contingent valuation, hedonic property value models, and recreational demand analysis. Benefits-transfer techniques provide a reasonable and efficient approach to quantify the value of a great many different ecological services (Bergstrom and Taylor 2006). In addition to employing standard economic valuation methods, the use of both monetary and nonmonetary valuation approaches could be explored and so that the implications of using a nonmonetary valuation framework over a traditional monetary approach could be evaluated. Relevant questions for further exploration include: whose objectives must be considered and what are the associated effects on management decisions? At what temporal and spatial scales should benefits be evaluated? How does one account for temporal changes in values as the stock of resources changes? How is uncertainty in valuation best incorporated in the analytical framework and are there significant limitations of nonmonetary over monetary valuation approaches? How are traditional conservation benefits (e.g., biodiversity, species persistence) weighed against metrics of ecosystem services, and do these represent fundamentally distinct objectives (i.e., intrinsic wildlife value versus goods and services for human benefit)?

<u>Dynamic reserve design</u> - Reserve design is the generic problem in conservation concerned with identifying those parcels of land in need of protection in order to sustain fish, wildlife, and other natural resources and their value to humans. Parcels that are identified as priorities may then be secured through purchase, easement, or other conservation instrument, with the goal of securing sufficient quantity, quality, and connectivity of habitat to meet conservation objectives. The reserve design problem has traditionally been treated as a static problem, in which it is assumed that all priority parcels will eventually (or, in many cases, all at once) be added to the reserve. The treatment of the reserve problem as static may be entirely appropriate in the design of marine

reserves, where jurisdiction authority exists to implement the reserve within a short period of time. But a static approach may not be appropriate in terrestrial systems, where many parcels may be in private ownership and must be secured on the open market. Thus, it is likely that a reserve design will have to be implemented incrementally, which then exposes the decision maker to resource, environmental, and socio-economic conditionals that can change dramatically over time. To date there is a limited body of theory and methods available for calculating optimal solutions to dynamic problems of spatial prioritization. There has been some notable work recently (McDonald-Madden et al. 2008), but much remains to do in terms of problem formulation and algorithm development. Several heuristic methods have been developed for large problems (Moilanen and Cabeza 2007), but none provide the generality necessary to account for multiple and diverse management objectives. An algorithm that shows promise belongs to the class of approximate dynamic programming methods (Powell 2010). More precisely, it uses the concept of value function approximation (Szepesvári 2010) and simulation, and is inspired from the Least Squares Dynamic Programming algorithm (Bonneau et al. 2014).

Adaptive asset allocation (portfolio management) – There is increasing interest in combining both short and long-term decision making problems into a common analytical framework. Suppose the decision maker can allocate varying resources to adaptation/relocation or protect/defend actions (a portfolio). Both actions incur an immediate cost, but protect/defend actions have an immediate payoff, whereas the payoff of adaptation/relocation actions occurs in the future. How should the mix of the portfolio change over time as sea level rises in order to maximize the temporal sum of returns? What if the decision maker is highly uncertain about how fast and how much sea level will rise? Modern portfolio theory, which is based on the idea that it is both the *expected* return and the *deviation* from the expectation (i.e., risk) that are important (Ando and Mallory 2012, Hoekstra 2012), might provide a useful analytical framework. A portfolio diversifies risk onto a variety of assets making it less sensitive to deviations in expectations. Key elements are the expected return of individual assets, their deviations (uncertainty), and the correlation in expected returns among assets. Low (or even negative) correlation among assets reduces risk. We suggest the analytical framework of Marinoni et al. (2011), in which the expected return and risk of a portfolio p comprised of assets $i, ...I,$ given climate scenarios $k = 1,...K$ are:

$$E\left(R_p\right)=\sum_{i=1}^{I} w_i E\left(R_i\right)$$

and

$$\sigma_p = \sqrt{\sum_{i=1}^{I} w_i^2 \sigma_i^2 + \sum_{i=1}^{I}\sum_{j=1}^{I} w_i w_j \sigma_i \sigma_j \rho_{i,j}}$$

with correlation

$$\rho_{i,j} = \frac{\sigma_{i,j}}{\sigma_i \sigma_j}$$

where

$$\sigma_{i,j} = \sum_{k=1}^{K} p_k \left(E\left(R_{i,k}\right) - E\left(R_i\right) \right) \left(E\left(R_{j,k}\right) - E\left(R_j\right) \right)$$

and where w_i is the proportion of the total portfolio comprised of asset *i*, and $\rho_{i,j}$ is the correlation in return between assets. What is missing from this approach is the fact that asset allocation can change over time. In particular, returns will depend on both the current and future sea level (system is non-stationary). While current sea level is known, future sea level is uncertain. In a dynamic setting, risk changes as uncertainty is reduced. A productive line of inquiry would be to determine how to optimize a state/time-specific portfolio in response to changing system state *and* to our understanding of how that state may change in the future (i.e., adaptive portfolio optimization). This approach might be demonstrated using investment decisions in tidal wetlands. Tidal wetlands and associated submerged aquatic plant beds are important spawning nursery, and shelter areas for fish and shellfish, including commercially important species like the blue crab. Investment decisions might include barrier-island re-nourishment, repairing/raising impoundment levees, deepening freshwater wells, plugging ditches, installing/repairing water control structures, securing new property upslope, building new impoundments, raising wetlands (dredge and fill), or purchasing rolling easements.

9. MANAGEMENT APPLICATIONS AND PRODUCTS: An important milestone in this project was a two-day multi-refuge workshop held at Alligator River NWR, March 5-6, 2014. An important outcome from the workshop was the recognition that refuges are currently being subjected to regional workforce planning due to fiscal constraints. Budgets are to be allocated across refuges in terms of their ability to address four priorities: (1) the North American Waterfowl Management Plan, (2) threatened and endangered species; (3) declining migratory bird species; and (4) public engagement (e.g., education, recreation). A shared problem statement that emerged from the workshop was to minimize or reduce the loss of these valued resources by balancing short and long-term strategies for mitigation and adaptation. Workshop participants recognized that values will necessarily be refuge specific, and that effective strategies to minimize their loss will depend heavily on the development of effective partnerships with other stakeholders and institutions. As a result of this workshop, the Southeast and Northeast Climate Science Centers are pursuing the development of multi-year SLR-adaptation projects at four coastal refuges: Alligator River, Cape Romain, Blackwater, and Parker River NWRs.

10. OUTREACH: This project involved a number of face-to-face meetings with coastal NWRs on the Atlantic and Gulf Coasts, as well as two workshops involving managers, scientists, and decision analysts. Our team visited Alligator River, Cape Romain, Savannah, Lower Suwannee, and St. Marks NWRs during the autumn of 2013. Following these visits, we conducted a two-day workshop involving staff from the Climate Science Center and four coastal refuges: North Carolina coastal refuges, and Cape Romain, Chesapeake Marshlands, and Parker River NWRs. The objectives of this workshop were to: (1) develop a shared understanding of the adaptation problems faced by coastal refuges; (2) explore the utility of structured decision making (a.k.a. decision analysis or decision science) as a framework for attacking these problems; and (3) identify the social and environmental science necessary to support an informed approach to decision making. The intent was to use the outcomes from this workshop to advance one refuge decision problem to a week-long Structured Decision Making workshop at the National Conservation Training Center (NCTC). Ultimately, Cape Romain NWR was chosen as the subject of the NCTC workshop.

The NCTC workshop focused on two key aspects of adaptation decisions by refuges: (a) values and objectives; and (b) the issue of scale. Questions concerning values and objectives serve as a basis for exploring "decision opportunities" in addressing the impacts of global change on NWRs. Sometimes "decision problems" are obvious (what drawdown schedule should I use for this managed impoundment?), but in many contexts decision opportunities must be created from identification of one or more concerns (e.g., erosion of barrier islands) and a thorough examination of the values (or objectives) in play (e.g., sea turtle conservation). Because of the many and diverse objectives embraced by coastal NWRs, a large portion of the workshop was devoted to identifying and structuring objectives. In particular, there was a focus on both strategic and fundamental objectives and how they shape particular decision contexts. By decision context we simply mean the specific nature of the decision that must be made (e.g., what lands should be prioritized for acquisition?).

This workshop was held June 2-6, 2014 and was attended by refuge staff Raye Nilius, Sarah Dawsey, Suzanne Baird, Mike Bryant, Steven Seibert, Pamela Wingrove, and Nancy Pau. USGS representatives were Mitch Eaton, Jerry McMahon, Mary Ratnaswamy, Stephanie Romanach, and Nate Wood. Also participating were Julien Martin (Florida Fish and Wildlife Conservation Commission), Dave Case (DJ Case & Assocs.), and Elizabeth Pienaar (University of Florida). Although some of the particular elements will vary across individual refuges, the workshop characterized a common two-track decision problem (i.e., short and long-term) articulated by coastal refuges. Cape Romain NWR served as the focal site for developing the specific considerations of this decision prototype, with the desire that the general methodologies, as well as inference and learning, can be applied to coastal refuges elsewhere.

Several information products for this project were developed or are in preparation. We have prepared a draft whitepaper describing our framing of adaptation decision problems for coastal refuges; we expect to submit this as a manuscript to a peer-reviewed journal in the near future. We also have made progress on developing an efficient computing algorithm for dynamic reserve design and have begun to explore an analytical framework for dynamic portfolio design. We hope to prepare at least two manuscripts describing this work for refereed journals. We also developed data products and analysis for Cape Romain NWR (CRNWR), including:

- Imagery - NAIP, 2013, for three counties around CRNWR
- Elevation - 10m NED grid for the NWR area and 3m NED grid for areas more inland (e.g., Francis Marion NF).
- National Hydrography Dataset - vector
- National Wetland Inventory - vector
- National Land Cover Dataset, 2006, 30m grid cell

- NOAA Shorelines (merged vector)
- USDOT roads and streets - vector
- Land ownership - vector
- 2010 Census blocks - vector
- Hurricane storm surge (i.e., slosh) zones for Cat 1-5 from SC Emergency Management
- Jurisdictional boundaries (easements, incorporated cities, places) - vector
- Draft FORESCE models of urbanized land change out to 2050 (250m grid cell)
- Various SC Dept. of Health and Environmental Control layers -- agricultural facilities, hazardous waste treatment storage, leaking underground tanks, mins, ports, shellfish harvest sites - vectors
- CRNWR layers - boundaries, potential parcels for Preliminary Project Proposal (i.e., the parcels being considered for expansion), soil types, water control structures – vectors

Radley Horton and colleagues at Columbia University, who are members of the Northeast Climate Science Center Consortium, developed and shared with the Cape Romain group low, middle, and high range sea level rise estimates for the Cape Romain area for 2020, 2050, and 2080. Chris Neill and Greg Fiske of the Woods Hole Marine Biological Laboratory developed and shared a preliminary report showing predicted inundation of uplands adjacent to the refuge under various sea-level rise scenarios. Finally, we have prepared a summary of the Cape Romain NWR workshop held at NCTC and this will be made available in the near future on their website.

11. LITERATURE CITED

Ando, A. W. and M. L. Mallory. 2012. Optimal portfolio design to reduce climate-related conservation uncertainty in the Prairie Pothole Region. Proceedings of the National Academy of Sciences 109:6484-6489.

Bergstrom, J. and L. Taylor. 2006. Using meta analysis for benefits transfer: strengths and weaknesses. Ecological Economics 60:351-360.

Bonneau, M., S. Gaba, N. Peyrard, and R. Sabbadin. 2014. Reinforcement learning-based design of sampling policies under cost constraints in Markov random fields: Application to weed map reconstruction. Computational Statistics & Data Analysis 72:30-44.

Burgman, M. 2005. Risks and Decisions for Conservation and Environmental Management. Cambridge University Press, Cambridge, U.K.

Cumming, G. S., D. H. M. Cumming, and C. L. Redman. 2006. Scale mismatches in social-ecological systems: causes, consequences, and solutions. Ecology and Society 11:14.

Cumming, G. S. and J. Norberg. 2008. Scale and complex systems. Pages 246-276 *in* J. Norberg and G. S. Cumming, editors. Complexity theory for a sustainable future. Columbia University Press, New York, NY.

Gregory, R., L. Failing, M. Harstone, G. Long, T. McDaniels, and D. Ohlson. 2012. Structured Decision Making: A Practical Guide to Environmental Management Choices. John Wiley & Sons, Ltd., West Sussex, UK.

Guerrero, A. M., R. R. J. McAllister, J. Corcoran, and K. A. Wilson. 2013. Scale Mismatches, conservation planning, and the value of social-network analyses. Conservation Biology 27:35-44.

Hoekstra, J. 2012. Improving biodiversity conservation through modern portfolio theory. Proceedings of the National Academy of Sciences 109:6360-6361.

Iguchi, J. 2011. Improving the Improvement Act: Climate change management in the National Wildlife Refuge System. Environs 34:247-269.

Keeney, R. L. 1992. Value-Focused Thinking: A Path to Creative Decisionmaking. Harvard University Press, Cambridge, MA.

Ludwig, D. 2001. The era of management is over. Ecosystems 4:758-764.

Marinoni, O., P. Adkins, and S. Hajkowicz. 2011. Water planning in a changing climate: Joint application of cost utility analysis and modern portfolio theory. Environmental Modelling & Software 26:18-29.

McDonald-Madden, E., M. Bode, E. T. Game, H. Grantham, and H. P. Possingham. 2008. The need for speed: informed land acquisitions for conservation in a dynamic property market. Ecology Letters 11:1169-1177.

Moilanen, A. and M. Cabeza. 2007. Accounting for habitat loss rates in sequential reserve selection: Simple methods for large problems. Biological Conservation 136:470-482.

Pahl-Wostl, C. 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Global Environmental Change-Human and Policy Dimensions 19:354-365.

Pielke, R. A., Jr. 2007. The Honest Broker: Making Sense of Science in Policy and Politics. Cambridge University Press, Cambridge, U.K.

Powell, W. B. 2010. Approximate Dynamic Programming: Solving the Curses of Dimensionaility. 2nd edition. John Wiley & Sons, Inc., Hoboken, NJ.

Skinner, D. C. 2009. Introduction to Decision Analysis. Probabilistic Publishing, Sugar Land, TX.

Szepesvári, C. 2010. Algorithms for reinforcement learning. Synthesis Lectures on Artificial Intelligence and Machine Learning 4:1-103.

Williams, B. K., J. D. Nichols, and M. J. Conroy. 2002. Analysis and management of animal populations. Academic Press, San Diego, CA.