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Employing an Ecosystem Services Framework to Deliver Decision Ready Science

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Abstract: Public land managers have limited information to allow for integration and balancing of multiple objectives in land management decisions including the social (cultural and health), economic (monetary and nonmonetary), and environmental aspects. In this article, we document an approach to consider the many facets of decision making by incorporating them into a decision context using an ecosystem services framework. This analysis is based on a multi-partner project led by the US Geological Survey and the US Fish and Wildlife Service to provide land management decision support for the Great Dismal Swamp National Wildlife Refuge. It is an integrated ecologic-economic analysis of baseline (current) and potential future quantities, qualities, and values of selected ecosystem services in the refuge. Alternative management scenarios are modeled to consider the impact of specific management actions or natural disturbances on priority ecosystem services. We examine the benefits and challenges of using this framework. Key lessons learned from this effort include the mismatch in timing between physical and social science; the challenge of integrating methods from multiple disciplines; the importance of frequent communication to overcome siloed research; and the utility of an integrating framework such as ecosystem services and supporting tools such as the dynamic ecosystem model.

Keywords: Ecosystem services, decision science, environmental economics, environmental management, carbon sequestration

1. Background: Why Use an Ecosystem Services Framework?

The natural environment provides indispensable benefits or 'ecosystem services' that support our economy and protect human needs including provisioning (e.g., food and water), regulating (e.g., climate

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mitigation and flood protection), cultural (e.g., cultural and recreational), and supporting (e.g., nutrient cycling) services (www.millenniumassessment.org/). The ability of the natural environment to provide ecosystem services varies depending on human land use and management decisions, and is threatened by development, pollution, fragmentation, resource overuse, and climate change. By assessing, quantifying, and valuing ecosystem services, they may be used to inform land use and land management activities and decision making. Doing so may enable both decision makers and the general public to better understand the tradeoffs associated with decisions and their implications on the wellbeing of people. This paper examines the use of an ecosystem services framework to inform federal land management decision making. Our research and project design were informed by several related efforts, including:

- Duke University's National Ecosystem Services Partnership (NESP; https://nicholasinstitute.duke.edu/focal-areas/national-ecosystem-services-partnership). The NESP provided a Federal Resource Management Guidebook (https://nespguidebook.com/) that offers a framework on how to incorporate ecosystem services into federal resource management decisions.
- EnviroAtlas (https://www.epa.gov/enviroatlas). The EnviroAtlas was developed by the US Environmental Protection Agency and is an interactive platform for exploring ecosystem goods and services (EGS) to better understand the potential impact of various decisions.
- Integrated Valuation of Ecosystem Services and Tradeoffs (INVEST; http://www.naturalcapitalproject.org/invest/). INVEST is a suite of open source models developed by the Natural Capital Project (http://www.naturalcapitalproject.org/) and includes models for a number of ecosystem services that may be used to quantify ecosystem services and assess tradeoffs associated with alternative management choices.
- The Social Values for Ecosystem Services (SolVES) model (https://solves.cr.usgs.gov/). The SolVES model is geographic information system (GIS) based and incorporates quantified and spatially explicit measures of social values into ecosystem service assessments.

These existing efforts informed the integrated approach we use for the ecosystem services assessment in our study area, the Great Dismal Swamp National Wildlife Refuge (GDSNWR). This paper describes the lessons learned in the GDSNWR application and how we apply the GDSNWR conceptual model as a framework for incorporating ecosystem services and tradeoffs in federal land management decision making.

2. The Great Dismal Swamp National Wildlife Refuge (GDSNWR) and Its Management

The GDSNWR is a peatland ecosystem comprised of approximately 45,000 ha of forested wetlands located on the coastal plain in southeastern Virginia and northeastern North Carolina (Figure 1). It was formerly privately-owned forest that was logged and ditched beginning in the 1700s. The extensive ditch system (shown in Figure 1) has altered the natural flow of water across the swamp and led to drier conditions (Lichtler and Walker, 1974; Ferrell et al., 2007). This has reduced the ecological health of the wetland ecosystem and supported the dominance of a non-desired vegetation community, specifically mixed red maple (Acer rubrum)/blackgum (Nyssa sylvatica), currently at more than 60% cover in the Refuge. The increased red maple/blackgum forest type is at the expense of native, peat-forming communities of Atlantic white cedar (Chamaecyparis thyoides) and tall pond pine pocosin (Pinus serotina). The forest vegetation in different areas of the swamp reflects previous disturbances (e.g., fire, storms) and hydrologic management. In additional, draining of the swamp has shifted fire dynamics by exposing organic peat soils to a higher probability of wildfire and increasing the frequency and intensity of large fire events (Akerman 1923; Frost 1987). Sleeter and others (2017) characterize the soil type, forest communities, and associated ecological functions.

Research has shown that the level of soil saturation is especially important for native vegetation and to reestablish pre-disturbance soil and peat conditions (Dabel and Day, 1977; Carter et al., 1994). Additionally, this promotes protection of carbon (C) resources, provides habitat conditions suitable for native species, reduces the risk of catastrophic wildfire, promotes nutrient cycling, and provides flood prevention services to nearby urban and agricultural lands. The GDSNWR management is employing several actions including hydrologic modifications, selective tree logging and planting, herbicide application and prescribed fire to promote ecological integrity and improve the provision of ecosystem services (US FWS, 2006). Hydrologic management to increase soil saturation to more closely resemble historic conditions is the primary focus and is intended to support the restoration of the wetland ecosystem by reestablishing Atlantic white cedar and pine pocosin.

A key objective of the habitat restoration actions is the focus on native species. The unique ecosystem of the GDSNWR provides habitat for species including the federally listed endangered species the red-cockaded woodpecker (Leuconotopicus borealis). In 2015, the refuge reintroduced red-cockaded woodpeckers after an absence of forty years (US FWS, 2015). The abundance of species (in particular birds) combined with the location of the Refuge which is in close proximity to 1.6 million people makes the Refuge an excellent recreational opportunity. In 2014, 63,750 people visited GDSNWR for recreation including viewing of birds, butterflies, bears, turtles, snakes, wildflowers, and dragonflies (US FWS, personal communication, 2015). The quality of habitat and recreational access are both management considerations. An ecosystem services framework informs managers on the multiple benefits provided by the Refuge under both current conditions and how those benefits may change under future conditions.

3. Building an Ecosystem Service Assessment for the GDSNWR

Our research in the GDSNWR centered on how land management affects the ecosystem service of C sequestration while quantifying ecosystem service tradeoffs, with the goal of making ecological research directly relevant and usable for decision making. The project was organized in four elements: (1) strong multidisciplinary/interdisciplinary and interagency partnerships, (2) natural science: C research and remote sensing (3) economic research and valuation, and (4) dynamic ecosystem modeling. These elements will be described in more detail in the following text. The project actively ties the components together to integrate the field work, lab work, and remote sensing using an ecosystem services framework, model, and assessment; while still retaining ecological studies that independently provide useful information. All elements were initiated in March 2014 by bringing the multidisciplinary and interagency groups together in person to share ideas, needs and expectations. Meetings (via phone, email, and in person) were held regularly throughout the project to continue the focus on communication.

(1) Multidisciplinary/Interdisciplinary and Interagency Partnerships

Interdisciplinary and interagency projects are typically established to integrate expertise from multiple disciplines to solve complex scientific issues while leveraging expertise across agencies. By examining and quantifying the relationship between ecosystem function and human well-being, ecosystem service assessments are inherently at least multidisciplinary, and ideally interdisciplinary. While multidisciplinary work combines knowledge from different disciplines, researchers stay within their disciplinary boundaries. Interdisciplinary work is integrative rather than just additive; a synthesis of approaches is created to address the scientific problem at hand through active interaction between disciplines (Klein, 1990; Choi and Pak, 2006). Interdisciplinary science, in particular the coupling of ecology and economics, identifies system dynamics that may be fundamentally different from those found through isolated disciplinary research (Kinzig, 2001).

Implementing an interdisciplinary project is challenging for a number of reasons. Roy et al. (2013) found the primary barriers to interdisciplinary science include tension with departments or institutions (i.e., the strong bias towards established single discipline methods and a lack of rewards for multi-disciplinary work), communication difficulties (i.e., the challenge of understanding a different discipline's technical language), differing disciplinary approaches, and institutional barriers. Geographic proximity of collaborators and decision-makers, and the co-location of multidisciplinary research groups has been shown to contribute to successful interdisciplinary research collaborations (Rekers and Hansen, 2014).

Carpenter et al. (2009) emphasized that to actualize the concept of ecosystem services that supports development of management tools and informs policy, current gaps in knowledge must be addressed through interdisciplinary science focused on social–ecological systems. A primary goal of using an ecosystem services framework for the GDSNWR project was to provide decision-ready science; as such, the framework in conjunction with a dynamic ecosystem model was designed to directly integrate analyses from our multidisciplinary team.

Often, ecosystem service assessments do not integrate physical and economic science. Studies frequently rely on existing land use/land cover data and apply benefits transfer which assumes parallel ecological function and/or economic value (e.g., Ingraham and Foster, 2008; Patton et al., 2012; Richardson et al., 2015). While this may be necessary due to a lack of resources, time, or expertise, and these analyses make an important contribution to the literature, the comprehensive integration of physical and economic science we describe here can further advance the state of ecosystem service knowledge.

The GDSNWR project was designed to leverage strong multidisciplinary and interagency partnerships. It was conducted collaboratively by a team of scientists, technical staff, managers, and students from the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (US FWS), the Nature Conservancy (TNC), and George Mason, Clemson, East Carolina, Christopher Newport, and Southern Methodist Universities. The project developed a good multidisciplinary synergy, but found barriers to true interdisciplinary work, including institutional challenges such as differing funding structures within the team. In addition, project development and momentum were driven by the expectation of current practices. That is, scientists are comfortable with, and often appreciate contributing their expertise to multidisciplinary projects. While there was interaction across disciplines and with Refuge management at all stages of the project, research questions were largely developed in disciplinary silos and additional integration at the early stages of design could have improved the process. The time and effort required to truly integrate at the interdisciplinary level is often not realistic given project timeline and product expectations and is not the way scientists are trained or are accustomed to working.

Perhaps the most challenging barrier to the true integration of natural and economic science was simply the timing of completion of the research results from the different disciplines involved in the work; one part of the team would find themselves waiting for results from a different part. Indeed, the initial version of the dynamic ecosystem model that was designed to incorporate the natural science data from all components of the GDSNWR project was populated with literature values for the field components, as the model was needed to drive other parts of the project (such as the ecosystem service assessment) well before the natural science data collected in this project were available (see Sleeter et al., 2017). Although this was sufficient to develop an initial version of the model, collection and interpretation of site specific natural science data is at the heart of good decision support. However, it may be difficult for projects to plan enough time to accomplish that in a multi- or inter-disciplinary setting. These barriers to true interdisciplinary work (i.e., functioning as a single unit with researchers from different disciplines) are consistent with and expand on those reported in Roy et al (2013), who found the efforts at truly integrative, interdisciplinary research often resulted in merely additive research that preserved the typical separate concerns of each one.

(2) Natural Science: Carbon (C) Research and Remote Sensing

The natural science research focuses on quantifying C storage and the ecological processes that drive the ecosystem service of C sequestration. Peatlands are recognized to be important for sequestering C from the atmosphere, primarily due to the development of large belowground C stocks as vegetation that has removed C from the atmosphere very slowly decomposes and re-releases that C due to the high soil saturation and litter quality typical of peatland ecosystems (Bridgham et al., 2006; Day, 1982). Indeed, peatlands hold 16-33% of global soil C stocks but are just 3% of the land surface (Bridgham et al., 2006).

The natural science research quantified C processes in three dominant vegetation communities that represent natural and degraded vegetation in the GDSNWR (Figure 2). Two of the vegetation communities, Atlantic white cedar (Chamaecyparis thyoides) and tall pond pine pocosin (Pinus serotina), cover limited areas within GDSNWR but are among the vegetation community types desired and targeted for restoration of the swamp. The third community, mixed red maple (Acer rubrum)/blackgum (Nyssa sylvatica), covers a majority of the swamp but reflects the drier hydrologic conditions of the currently degraded swamp and is not a desired vegetation community type for swamp restoration. The natural science research objectives were: in-situ C research to characterize potential C sequestration in the representative GDSNWR vegetation communities via gaseous and water-based C fluxes and C storage in biomass and soil pools and remote sensing to quantify vegetation biomass and C stock.

In-situ Carbon (C) Research: Nine local scale study sites (3 each in Atlantic white cedar, tall pine pocosin, and red maple/black gum) were used to quantify C storage and flux in soils and groundwater, water table levels, vegetation biomass, and soil moisture (Figure 2). In general, these natural science data were used to measure GHG fluxes from the land surface and vegetation, surface elevation change due to C sequestration, C storage in soils (Drexler et al, 2017), and the hydrologic parameters that drive those processes. These analyses were designed to be directly integrated into the landscape level vegetation-based ecosystem model (discussion forthcoming), and explicitly used with the socioeconomic work for the ecosystems services assessment, while also retaining the ability to be published as stand-alone studies. More information on these studies will be published separately; for this paper, the focus is on how these data are used as part of the interdisciplinary / multidisciplinary effort.

Remote Sensing: Remote sensing with field work in 76 study plots was used to estimate Refuge-wide biomass, above and below ground C stock, and selected soil properties such as peat depth (using peat probes). This component supports the expansion of the local level in-situ C balance and hydrologic measurements to a Refuge and regional level. This work used airborne light-detection and ranging (LiDAR) imagery both pre - and post-fire to quantify elevation changes because of peatland fire and derive total soil carbon loss; results indicate fires in drained peatlands can result in substantial amounts of belowground C loss that could potentially be avoided by restoring drained and protecting existing peatlands (Reddy et al., 2015).

(3) Economic Research and Valuation

The GDSNWR provides significant contributions to recreation, air and water quality, climate regulation, public health, and tourism in addition to its primary responsibility for habitat management. An ecosystem services approach to land management decisions supports assessment of these co-benefits (Scarlett and Maillett, 2014). The economic research in this work focused on valuation of stakeholder-identified key ecosystem services for GDSNWR.

Substantial stakeholder input was obtained from a diverse group with interests in the GDSNWR through stakeholder meetings held near the Refuge. These meetings were designed to assess community and other stakeholder priorities and values, to elicit input for the selection of services for assessment, and for the development of alternative management scenarios to be analyzed in the dynamic ecosystem model.

A meeting held at project onset was used to provide stakeholders information on ecosystem services and describe the ecosystem service assessment process, and to determine their priority services for the GDSNWR by offering an extensive ‘menu’ of services and developing a prioritized list. A second interactive session was held to develop and prioritize management scenarios, during which participants commented on strawman scenarios, developed new scenarios, and provided input on how scenarios might impact the landscape.

Table 1 provides a synopsis of the outcome of the identification of ‘priority’ services from the initial stakeholder meeting. Some of the items listed in the ‘ecosystem services’ column are actually intermediate services or related ideas, while others are final ecosystem services (see Boyd and Krupnick 2009 for discussion of final ecological endpoints). After the initial stakeholder meeting, the project team organized the list by merging some items to preserve the ideas contributed by the stakeholder group while focusing on quantifiable ecosystem service endpoints. Because it is outside the scope of the project to assess every possible service, the top five were chosen. The final set of ‘priority’ ecosystem services for assessment is wildlife viewing (incorporating biodiversity), nutrient cycling, flood protection, C sequestration, and fire mitigation.

We later found that the literature and the physical research did not provide the information necessary to analyze nutrient retention and flood protection services from GDSNWR. Economic valuation of the remaining prioritized list of ecosystem services (wildlife viewing, C sequestration, and fire mitigation) was completed using a suite of methodologies most appropriate to each service. Ideally, the economic analysis would derive consumer surplus (i.e., the difference between what consumers are willing to pay (WTP) and what they actually pay) for each of the final ecosystem services. Project resources did not allow for a survey to collect primary data on peoples’ preferences for the ecosystem services provided by GDSNWR.

Therefore, we utilized benefits transfer and revealed preference techniques to estimate WTP.

Wildlife Viewing: To estimate the economic value associated with wildlife viewing, we used a benefit transfer approach. The FWS’s most recent Net Economic Values of Wildlife-Related Recreation survey (Aiken, 2016) provides estimates of consumer surplus for travel-costs related to wildlife watching. We used values from the survey for wildlife watching activities that took place in Virginia. Values for in- and out- of state wildlife watchers vary due to the differences in preferences to travel to view specific wildlife; however, the 2011 survey did not have a sample size robust enough to estimate the difference in these values and we therefore used a single value. In 2011, Virginia wildlife viewing had an estimated median value of $32 (mean equals $66) per day (Aiken, 2016). This can be escalated to 2017 USD using Bureau of Labor Statistics inflation factors (BLS, 2018); the result is $36 (mean equals $73) per day. To the extent that wildlife viewers visit the GDSNWR for unique viewing opportunities, the actual value for the Refuge may be higher or lower than the state estimate and the valuation could be improved from a Refuge specific survey. GDSNWR maintains records on the number and types of visitation via visitors self-reporting the primary purpose of their trip. Refuge staff provided information on visitation for 2014. Total visitation was 63,750 unique visits during 2014, with 44,417 reporting their primary purpose was wildlife viewing (FWS Refuge staff, personal communication, 2015). The analysis quantifies the annual value of wildlife viewing for the Refuge simply by multiplying the per day value by wildlife viewing visitation numbers. This yields a median value for wildlife watching of $1,421,344 (using the mean per day value, the result is $3,242,441). Other types of recreation on the refuge such as fishing and hunting would further increase this annual value.

Fire Mitigation: The hydrologic restoration of the GDSNWR could decrease the frequency and/or duration of ‘catastrophic fires’. We considered the litany of impacts associated with large, deep peat burning fires including carbon emissions, lost recreation, tourism impacts, and human health effects. To estimate economic benefits of the ecosystem service provided by a restored swamp, we used the damages avoided technique and focused valuation on the human health effects. Parthum et al. (2017) provides details on our approach which utilized geospatial data, primary emergency department visitation data, and cumulative relative risk functions. We valued health effects avoided using regional cost of illness values for the region (BenMAP model framework; EPA, 2007) and lost wages. If hydrologic restoration reduced annual catastrophic wildfire incidence from 2 to 1%, it would be associated with a benefit of $37 thousand in terms of avoided health effects (Parthum et al., 2017).

C Sequestration: The quantity of C sequestration in the GDSNWR was derived using literature values and validated with initial field estimates for the C sequestration valuation. As additional information from field research becomes available, this part of the economic analysis can be updated. We apply the Social Cost of Carbon (IWG, 2013; IWG, 2016) to estimate the monetary value of this ecosystem service. For C sequestration, we not only consider the current annual production of the service, we also model and estimate values associated with C sequestration under a set of varied management action scenarios. If current management is maintained, we estimate that 9.9 million tons of carbon dioxide emissions will be avoided (via sequestration) over the next 50 years with an NPV of $326 million (assuming a 3% discount rate) (Pindilli et al., 2018). The average annual value of C sequestration fluctuates from −$5 million to $24 million due to variation in annual emissions/sequestration, the increase in damages associated with an incremental ton of CO2 in future years, and discounting (Pindilli et al., 2018); over the entire period the average of all years is a $13.7 million benefit.

Ecosystem Services Portfolio: The GDSNWR provides numerous ecosystem services of which we only quantified and monetized a select few. To begin to understand the flow of services that the Refuge delivers annually, we sum the three ecosystem services: wildlife viewing, fire mitigation, and C sequestration. The physical processes and human outcomes of these three services are quite dissimilar; however, using an ecosystem services framework and economic techniques to monetize the services we are able to provide a single metric ($) that informs decision-making. In 2017, the wildlife viewing benefits are estimated at $1,421,344; if we assume current management is reducing the frequency or duration of catastrophic wildfires the health benefits of fire mitigation are estimated at $37,000; and the social cost of carbon avoided is estimated at $13,700,000 (note this value is a global benefit). This amounts to a $15,158,344 benefit each year. The people impacted vary, from local bird enthusiasts enjoying recreation on the Refuge to downwind communities avoiding health effects associated with peatland fire conditions to global citizens that are benefiting from the incremental reduction in carbon dioxide emissions. The portfolio of services provides an increased understanding of the benefits of the refuge and of the impacts on people of land and resource management decisions.

(4) Dynamic Ecosystem Modeling

In this research, the dynamic ecosystem model allows for ecosystem service assessment through time and space under a suite of management scenarios (Sleeter et al., 2017). The model is used as an interactive tool to simulate temporal changes in biophysical production of the stakeholder-identified ecosystem services as a function of future climate and management strategies. Project collaborators perform plot and Refuge level carbon research (e.g., storage, sequestration, greenhouse gas flux, biomass, peat analyses, remote sensing, and hydrology) in representative vegetation communities in the swamp. This research is integrated using a fine-scale spatial modeling framework centered on assessment of ecosystem C balance (Sleeter et al., 2015; Sleeter et al., 2017). The ecosystem model framework spatially organizes the landscape into a grid of 30 m simulation cells that represent current conditions as a combination of dominant vegetation community, age, and nominal soil moisture (‘wet’ vs. ‘dry’ strata). Ecosystem model parameterization includes C biomass and flux rates; fire probabilities; nominal soil moisture; probabilities of vegetation response to disturbance, restoration, or management; and vegetation age for every 30 m simulation cell as different probabilities apply at differently aged vegetation classes (Sleeter et al., 2017).

Net ecosystem C balance is estimated by considering current vegetation cover and condition, and effects of disturbances and/or land management and restoration actions that cause transitions to new vegetation cover and condition (Figure 2). These transitions reflect the complex spatial relationships associated with disturbances due to drainage, logging, catastrophic fire, climate variability including hurricanes and drought, and nutrient inflow; and/or to management or restoration actions including rewetting, replanting desired species, herbicide and selective logging or thinning targeting undesired species, prescribed fire, and nutrient routing. Changes in vegetation and C biomass, soil moisture, natural disturbance, and management activities are estimated temporally using user-defined scenarios (Figure 3; Sleeter et al., 2017). The resultant effects on habitat, fire, and C cycling are modeled as a function of the future modeled vegetation and soil moisture conditions. Valuation is done as a comparison of initial and future states of the ecosystem. Future improvements in the ecosystem model should strive to directly include stakeholder input (in addition to identification of priority services and scenarios), biophysical research (already directly included) and socio-economic research together in the decision support model.

This landscape vegetation-based modeling framework was designed to directly integrate stakeholder input to inform land management decisions by estimating the effects of Refuge management and/or natural events on the ecosystem services of C sequestration, fire and flood management, and establishment of desirable types of vegetation communities that promote the services of habitat provision and water quality improvement (Figures 2 and 3). Landscape changes are simulated through time using Monte Carlo methods to characterize the effects of land management and disturbance on ecosystem services (Figure 3).

This ecosystem service assessment provides land management decision support by integrating prioritization from stakeholders and partners, quantification via biophysical research, valuation using socio-economic research, and spatio-temporal modeling to help understand complex system dynamics over time (Figure 4). This provides an assessment of the quantity, quality, and value of the stakeholder-selected priority GDSNWR ecosystem services, and how those services change with management actions. The overall approach provides GDSNWR specific quantities and values while also providing a framework that could be applied to similar peatland ecosystems.

4. How Can We Improve? Recommendations for Future Projects

The GDSNWR project represents an example of a multi-organizational and science-public land management partnership, where active natural science research with economic research are brought together to produce an ecosystem services assessment and tool for decision support. This work made progress towards the aim of a truly interdisciplinary ecosystem services assessment and demonstrated the value of projects that integrate approaches from multiple disciplines for land and resource managers. Experiences gained from the GDSNWR application suggest an enhanced focus on interdisciplinary integration and communication to further strive towards providing decision-ready science.

In addition, there is a need for place-based natural and socio-economic science measurements and observations as input into an ecosystem services model. By using remote sensing as well as spatially-explicit modeling to map and simulate vegetation types and surface water distribution now and into future, this framework is spatially relevant which is critical for land and resource managers. Information on visitation and other socio-economic factors that are place-based were incorporated when available; however, this analysis could be improved with additional primary economic research.

While we ultimately quantified three ecosystem services, there is ample room for improvement by adding the values associated with additional services. In addition, a better understanding of the impact of management actions on ecosystem services – in particular when services are degraded – and the tradeoffs would improve the decision-relevance of this type of research. It was a challenge considering the incremental value of ecosystem services and that is key for the decision context. This is clear in the fire mitigation analysis which had robust methods to estimate the health effects from a single fire, but understanding and estimating the annual flow of service requires additional knowledge and/or assumptions.

Using the dynamic ecosystem model, realistic scenarios allow managers to consider the impacts of management actions on future outcomes. Additionally, this modeling provides an improved understanding of the baseline changes that will occur on the Refuge due to endogenous and exogenous factors outside of the control of mangers. Similarly, the accuracy of the ecosystem service values is increased by mapping of wildfire extent and burn depth, measuring surface and ground water flow, and estimating the rate of C sequestration by the peatlands by measuring above and below ground carbon pools.

Active integration of all project components and participants at the onset of work including land managers, stakeholders, on the ground research, and socio-economic analyses is strongly recommended with an explicit stated goal to strive for interdisciplinary work. This is an important goal as interdisciplinary and interagency projects provide insight from many different experts and disciplines and foster the ability to translate the intensive natural science monitoring and assessment from numbers that may be nearly abstract to decision makers into decision-ready science.

Regular group communication, ideally in person, throughout the project is needed. Specifically, it is important to encourage more interdisciplinary communication. For example, feedback from economists on ecological data collection plans could be beneficial for encouraging interdisciplinary work (e.g., if data are collected in a slightly different way, perhaps could value more of the ecological processes). While there was interaction across disciplines and with Refuge management at all stages of the GDSNWR project, research questions were largely developed in disciplinary silos and additional interdisciplinary integration at the early stages of design could have improved the process. However, the time and effort required to truly integrate at the interdisciplinary level is often not considered to be realistic given project timeline and product expectations, and is not the way scientists are trained or are accustomed to working. This is a paradigm that needs to change.

5. Summary and Conclusion

Without improved knowledge of the dynamics of social–ecological systems and their effect on the provision of ecosystem services, it is difficult to develop appropriate management tools or inform policy and management (Carpenter et al., 2009). Ecosystem services must be identified (stakeholders), quantified (biophysical), and valued (economics and social) to allow identification of service tradeoffs given alternative management actions and to address this growing demand for more sophisticated analysis of the social and economic consequences of biophysical land management decisions. Directly integrating stakeholder input, biophysical research, socio-economic research and modeling at project onset provides the basis to consider the impacts and tradeoffs associated with land management decision making. The research reported in this paper recognizes that the use of an ecosystem service framework to guide federal decision making is still being developed and optimized. However, this effort represents an important shift in focus towards the recognition and incorporation of the importance of nature to human wellbeing and the economy.

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Tables and Figures.

Table 1: Ecosystem services identified by local and regional stakeholders as priorities for GDSNWR. This original list of ideas was merged where appropriate to preserve stakeholder ideas while focusing on quantifiable ecosystem service endpoints. The final set of 'priority' ecosystem services for assessment is wildlife viewing (incorporating biodiversity), nutrient cycling, flood protection, C sequestration, and fire mitigation.

Ecosystem Service	Stakeholder Rank	Assumptions in Quantitative Assessment
Biodiversity	1	Biodiversity (species abundance and variety) is important factor in visitation; incorporated into 'Wildlife Viewing' service.
Wildlife Viewing	2	Focused on "non-consumptive" visitation, primarily bird watching as this is the main recreation action in GDSNWR (GDS, 2014; FWS, 2009).
Education	3	Education is, in itself, not an ecosystem service. It is a benefit of, and contributes to, all other ecosystem services.
Nutrient Cycling	4	Contributes to water quality.
Flood Protection	5	Flow control / flood probability (magnitude and/or frequency) as a function of hydrologic management.
Carbon Sequestration	6	C storage and sequestration as a function of vegetation community using biomass and soil and water gas flux data.
Fire Mitigation	7	Annual probability, magnitude and/or effects of catastrophic fire with mitigation via management actions (primarily hydrologic balance).
Non-consumptive Recreation (biking, hiking, boating)	8	Not selected for quantitative assessment
Cultural Heritage	9	Not selected for quantitative assessment
Consumptive Recreation (hunting)	10	Not selected for quantitative assessment
Aesthetic	11	Not selected for quantitative assessment
Recreational Fishing	12	Not selected for quantitative assessment
Timber	13	Not selected for quantitative assessment
Fresh Drinking Water	14	Not selected for quantitative assessment

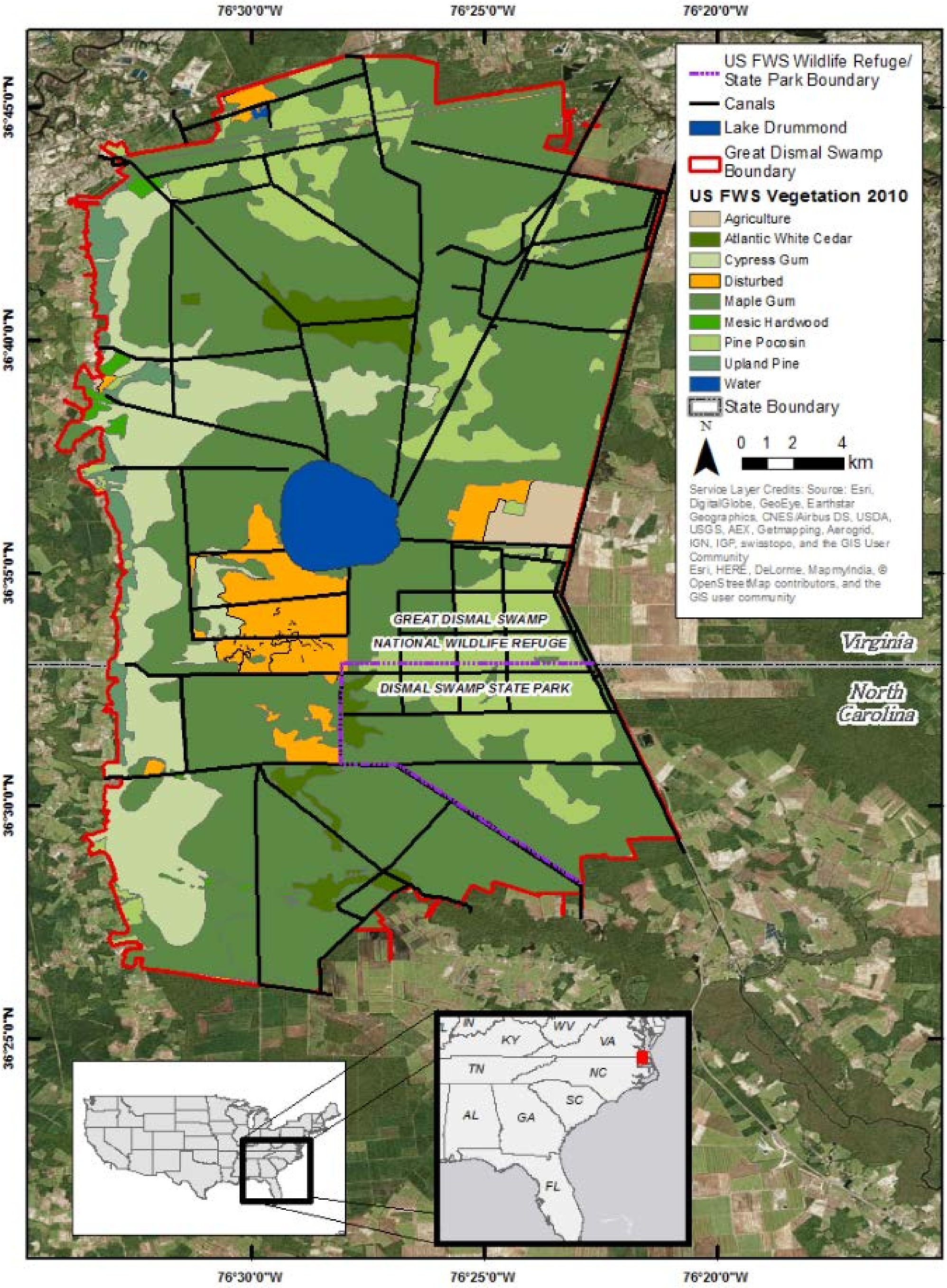

Figure 1: The GDSNWR showing location, vegetation cover, and the ditch system.

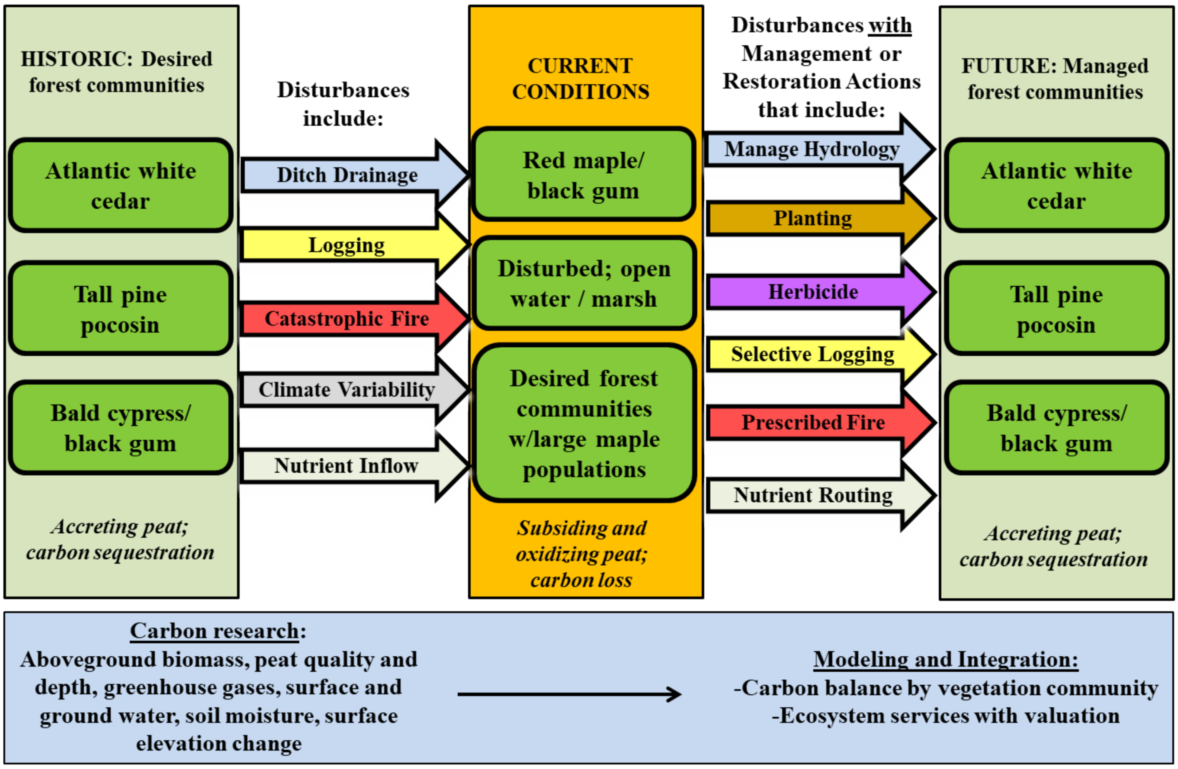

Figure 2: The GDSNWR conceptual model. The project focused on three dominant vegetation communities in the GDSNWR: Atlantic white cedar (*Chamaecyparis thyoides*), tall pond pine pocosin (*Pinus serotina*), and mixed red maple (*Acer rubrum*)/blackgum (*Nyssa sylvatica*). Atlantic white cedar and tall pine pocosin vegetation communities are desired and targeted for restoration of the swamp, while mixed red maple/blackgum represent the majority of the swamp vegetation cover due to the currently drier condition. Disturbances and management or restoration actions are indicated by arrows and reflect drivers for potential transitions between vegetation cover type and condition.

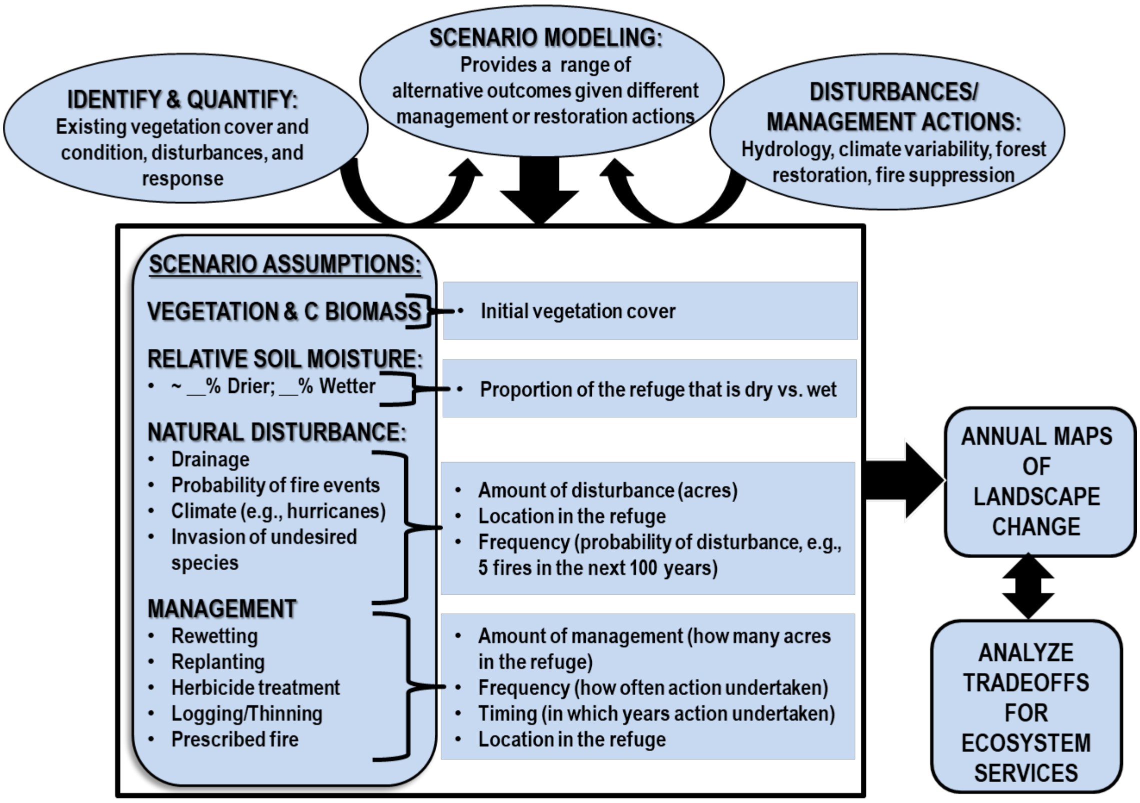

Figure 3: Management scenario modeling for decision support and temporal estimation of ecosystem services: The scenario modeling framework provides a tool that can represent the goals and objectives of all stakeholders with interests in the GDSNWR by allowing users to input different management scenarios. The tool is intended to bridge the gap between natural disturbances and processes, and management or restoration actions to provide ecosystem services information that may be used for decision support.

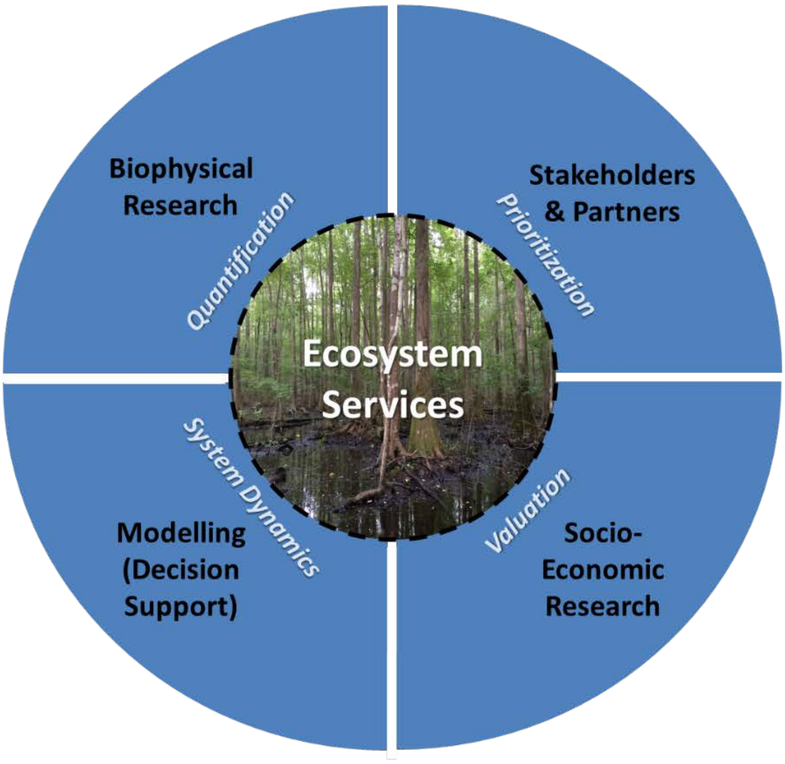

Figure 4: This iterative ecosystem services conceptual model is used as the basis for the ecosystem services assessment and land management decision support. The biophysical and socioeconomic research, and the partner input feed directly into model development with active feedback and communication among all four sections throughout the entire assessment period. For other applications or study areas, the details and methods feeding into the biophysical research, socioeconomic research, stakeholder and partner input, and model may be modified as appropriate.