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MODELING, ASSESSING AND VALUING PEATLAND ECOSYSTEM SERVICES

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SUMMARY

Accounting for the ecologic, economic, and social benefits provided by peatland ecosystems, and explicitly incorporating the goods and services they provide into land use and land management decision making, can be an effective approach for balancing diverse and often competing objectives at multiple scales. Highlighting a project in the Great Dismal Swamp in southeastern Virginia and northern North Carolina (USA), this paper discusses ecosystem service modeling, assessment, and valuation in support of peatland management decision making. A primary goal of this study is to increase understanding of how targeted peatland management can be used to maximize the regulating service of carbon (C) storage and sequestration, while assessing potential tradeoffs with other services. Local and regional stakeholders identified the following ecosystem services as the most important to consider in addition to C sequestration: wildlife viewing, hazard mitigation (e.g., peat fire), flood protection, and nutrient cycling. Working within an integrated fine-scale spatial modeling framework, service tradeoffs are identified and evaluated given alternative peatland management actions. These ecosystem service modeling, quantification, and valuation methods address the growing demand for more sophisticated analysis of the integrated environmental, economic, and social consequences of biophysical peatland management decisions.

Keywords: *Great Dismal Swamp, ecosystem services, carbon (C) sequestration, modeling, economic valuation*

INTRODUCTION

Ecosystem services are the benefits provided by the natural environment that are of value to humans such as provisioning services (e.g., production of food and clean water), regulating services (e.g., climate and flood protection), cultural services (e.g., cultural and recreational benefits), and supporting services (e.g., nutrient cycling) (MEA 2005). The ability of the natural environment to provide ecosystem services is compromised by factors including development, pollution, fragmentation, resource overuse, and climate change. By modeling, quantifying, assessing, and valuing ecosystem services, this work addresses how the services of C sequestration, recreation (e.g., wildlife viewing), hazard mitigation (e.g., peat fire), flood protection, and nutrient cycling may be impacted through peatland hydrologic and restoration management options. The focus of our study is on providing information that may be used to enhance the service of C sequestration while quantifying ecosystem service tradeoffs to inform land management decision making.

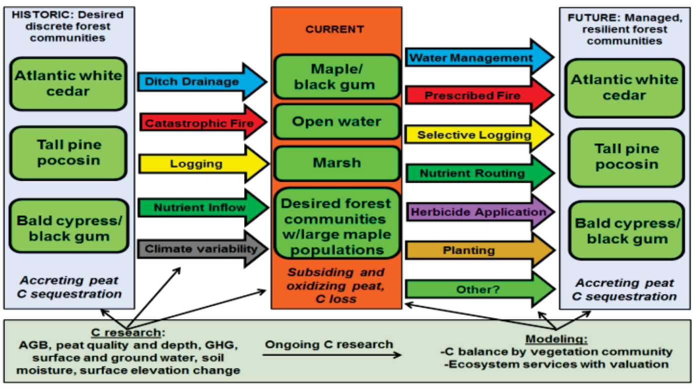

Figure 1: The Great Dismal Swamp Carbon Project Study Design. The C model, ecosystem services assessment, and C field research are organized around historic desired forest communities that, along with proper hydrology,

Study context and objectives

The work reported in this paper is part of a larger project being conducted in the Great Dismal Swamp National Wildlife Refuge (NWR) and the Dismal Swamp State Park (herein collectively referred to as GDS; Figures 1 and 2). That larger project, *The Great Dismal Swamp Carbon Project* (http://www.usgs.gov/climate_landuse/lcs/great_dismal_swamp/default.asp), is designed to (1) characterize potential C sequestration in representative vegetation communities via gaseous and water-based C fluxes and C storage in biomass and soil pools; (2) estimate the effects of refuge management and restoration on C sequestration, fire management, and establishing desirable types of vegetation communities; (3) develop a landscape vegetation-based C model to integrate the C research and support research analyses; and (4) provide an assessment and valuation of ecosystem services. This article describes the development of the vegetation-based C model and the ecosystem services assessment and valuation used to consider the tradeoffs for C sequestration and other ecosystem services associated with select management actions.

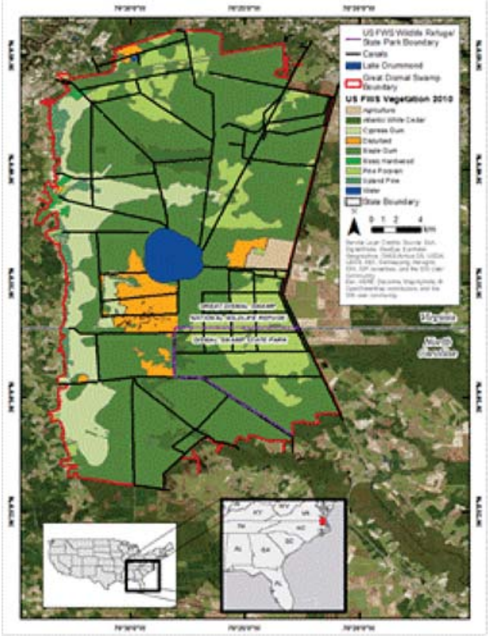

Figure 2: The Great Dismal Swamp National Wildlife Refuge and the Dismal Swamp State Park.

METHODS

The C modeling and ecosystem service assessment and valuation rely on values derived from *The Great Dismal Swamp Carbon Project* (Figure 1) and on published literature values. Because the C research is still ongoing (field research began in June 2014), the current C model and ecosystem service assessment are done primarily using literature values and will be updated as the results of the C research become available.

Study area

The GDS is composed of approximately 53,433 ha of forested peatlands located on the coastal plain in southeastern Virginia and northeastern North Carolina (USA) (Figure 2). The area was formerly privately-owned forest that was logged and ditched beginning in the 1700s. The extensive ditch networks have altered the natural water flow and led to drier, disturbed conditions (Lichtler and Walker, 1974; Ferrell *et al.*, 2007). These conditions have led to the replacement of desirable, peat-forming, historic vegetation communities, specifically Atlantic white cedar (*Chamaecyparis thyoides*), and tall pond pine pocosin (*Pinus serotina*), with a more drought tolerant, less desirable community of mixed red maple (*Acer rubrum*)/blackgum (*Nyssa sylvatica*) that currently covers more than 60% of the refuge. This project focuses on these three vegetation communities to represent a spectrum from natural to highly disturbed vegetation types within the refuge. The GDS NWR is undergoing management actions including hydrologic modifications, selective tree logging and planting, herbicide application, and prescribed fires with the goals of increasing soil saturation, reestablishing desired vegetation communities, and promoting ecological integrity to improve the provision of ecosystem services (USFWS, 2006).

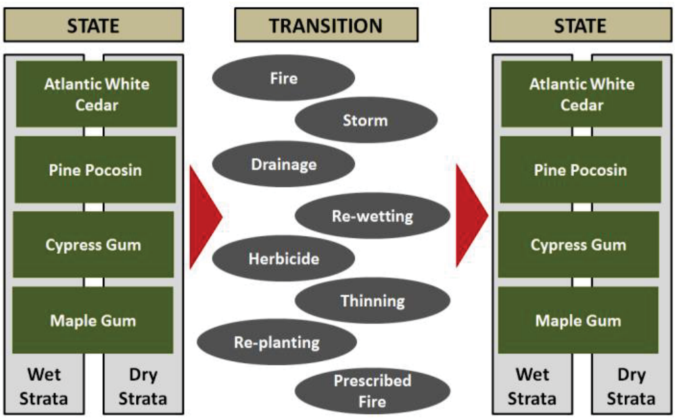

Figure 3: C model concept.

Ecosystem C Model Development

The Land Use and Carbon Scenario Simulator (LUCAS) uses the ST-Sim software package (www. apexrms.com) to integrate a state and transition simulation model with a stock flow model to characterize the effects of land use, land management, and disturbance on terrestrial C dynamics and other ecosystem services (Daniels and Frid, 2011; Sleeter *et al.*, 2015). The model framework spatially organizes the landscape into a grid of simulation cells that represent current conditions as a combination of dominant vegetation community, age, and moisture zone (Figure 3). Transitions between vegetation types reflect the complex spatial relationships between states associated with disturbances due to wildfire, hurricanes, drainage, and drought. Management or restoration actions include re-wetting, herbicide application, re-planting, and prescribed burn.

To evaluate C balance as a function of land management, biomass field measurements paired with existing literature values are used. Model parameterization includes C biomass and flux rates; fire history and probabilities; nominal ('wet' vs 'dry') soil moisture; vegetation response to disturbance, restoration, or management; probabilities of transitions between states; and the age and time since transition for every simulation cell as factors such as climate change can have different probabilities at different ages (Figure 3; Sleeter *et al.*, in prep). The landscape is then simulated through time using Monte Carlo methods.

Ecosystem Service Assessment

The ecosystem service assessment is an integrated ecologic-socioeconomic analysis of baseline (current) and potential future quantity, quality, and value of selected ecosystem services in the GDS (Figure 4). The assessment includes modeled biophysical endpoints, identification of beneficiaries, and valuation of the services. Alternative management scenarios are developed to estimate the impact of specific management actions or disturbance on priority ecosystem services incorporating decision maker input on scenario details (Figure 5). Substantial stakeholder input was obtained for the prioritization of selected services and on the development of alternative management scenarios through stakeholder meetings held in Chesapeake, VA in June 2014 and September 2015.

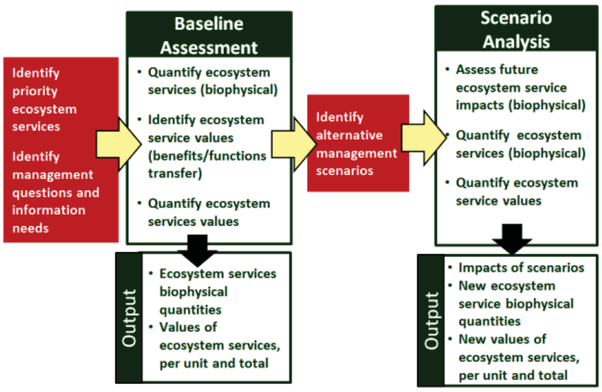

Figure 4: Ecosystem Service Assessment Approach. Red boxes signify key stakeholder participation activity.

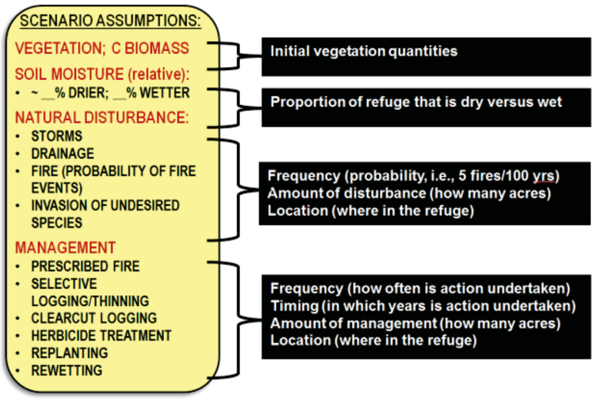

Figure 5: Stakeholder input to the model for development of alternative management scenarios for analysis.

The assessment of baseline ecosystem services incorporates in-situ ecologic (e.g., bird populations), social (e.g., visitor information), and economic (e.g., travel-costs) information. The relationships between the baseline services and parameters in the LUCAS model (e.g., wetness) are considered to assess the impacts on services under select management scenarios. Valuation relies on a hybrid methodology considering damages avoided (as in the case of fire mitigation or flood protection) assessed at the local scale, the application of standardized values (e.g., the Social Cost of Carbon), and benefits transfer from relevant and applicable research sites (e.g., the travel-costs associated with recreation) with the use of as much primary data as are available (e.g., refuge visitation numbers). The overall approach provides GDS specific quantities and values while also providing a framework with which to evaluate the services provided by similar peatland ecosystems.

RESULTS

The spatial, vegetation-based ecosystem model supports evaluation of management actions and disturbances in the GDS to identify ecosystem service tradeoffs and evaluate alternative peatland management actions. Priority ecosystem services as identified by local and regional GDS stakeholders are shown in Table 1.

Table 1: Priority GDS ecosystem services with a summary of the ecologic and economic assessment details.

Ecosystem Service	Ecologic	Economic
Carbon Sequestration	1. C storage and sequestration as a function of vegetation community using biomass, soil gas flux data, water flux data, and literature values	2. Climate change mitigation 3. Valuation via Social Cost of Carbon (SCC) (IWG SCC, 2013; US EPA 2015)
Wildlife Viewing	4. Provision of natural habitat for representative species as a function of management actions 5. Assuming all "non-consumptive" visitation	6. Non-consumptive visitation rates (GDS NWR, 2014; FWS, 2009) 7. Valuation via consumer surplus or "willingness to pay" above actual costs
Fire Mitigation	8. Annual probability, magnitude and/or effects of catastrophic fire 9. Mitigation via hydrologic balance and other management actions	10. Valuation via a. Air quality/human health impacts based on quantified cost of illness b. C emissions (SCC) c. Recreation; tourism lost due to closures
Nutrient Cycling	11. Water quality; impacts under consideration	12. May reduce need to decrease nutrients from urban or agricultural sources; methods under development
Flood Protection	13. Flow control / flood probability (magnitude and/or frequency) as a function of hydrologic management	14. Valuation via reduction in property flood damage

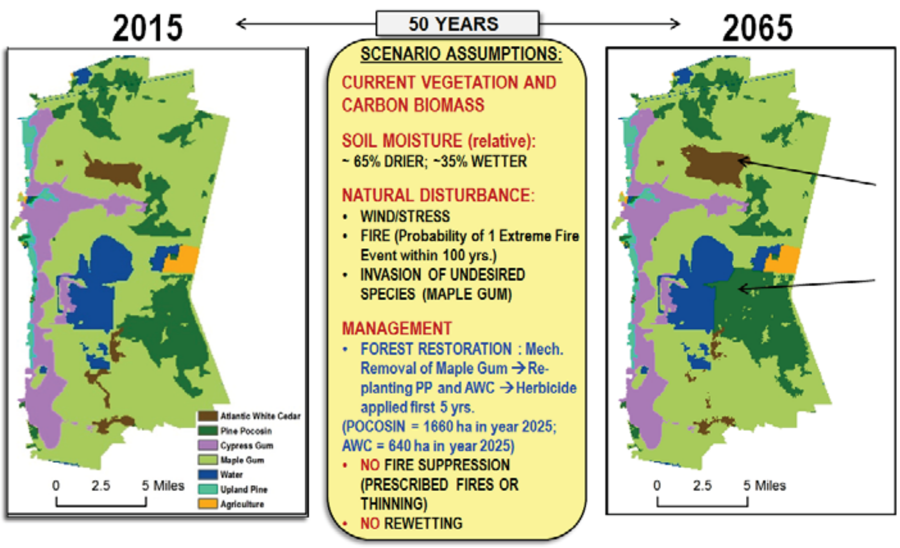

Figure 6: Forest restoration (Atlantic white cedar and pine pocosin) management scenario. Study area shown is the extent of the GDS.

Figure 6 outlines one management decision scenario, temporally modeled to estimate effects on vegetation, hydrology, and habitat, and examine potential future changes in ecosystem service provision given the specified management actions. This scenario simulates forested wetland restoration for Atlantic white cedar and pine pocosin imposed in specified locations, and assessed at baseline (current) and after 50 years. The management assumes the removal of undesirable maple/gum communities through management logging, and the subsequent planting of pine pocosin in one area, and Atlantic white cedar in another area. An assumption was made that herbicide was used within the first 5 years of new growth to prevent hardwood invasion. Using relationships among vegetation communities, condition, and other model parameters with the provision of ecosystem services, the output of the model estimates future (year 2065) ecosystem services that can be compared to initial (2015) services (Table 1). Scenario modeling such as this can provide a range of alternative outcomes given different assumptions, map products of landscape change, and the ability to analyze ecosystem service tradeoffs.

DISCUSSION AND CONCLUSION

The Great Dismal Swamp Carbon Project quantifies C sequestration in representative vegetation communities via gaseous and water-based C fluxes and C storage in biomass and soil pools. These data, along with literature values, are being used to develop a landscape vegetation-based C model and provide an ecosystem service assessment with valuation for the GDS to support land management decision making. This work will contribute to the understanding of current ecosystem services, the economic and qualitative values of those services, and the impacts of management decisions and disturbances on net benefits (or tradeoffs) for peatland ecosystems.

The ecosystem service assessment reported in this paper includes the direct use of the in-situ ecologic studies, and the LUCAS model to provide more accurate data for ecosystem service tradeoff analyses and decision support. The valuation work utilizes methods that incorporate both primary socio-economic information of beneficiaries and leverages previous work on valuation. The ecosystem service valuation is conducted at a fine scale, evaluating benefits at a detailed and site-specific level while also incorporating a suite of services. There are examples of national-level studies that evaluate ecosystem services using primarily meta-analysis and benefits transfer such as the noteworthy study conducted by Patton *et al.* (2012) that provided an ecosystem service valuation model applied to Fish and Wildlife Service (FWS) NWRs (Arrowwood, Blackwater, Okefenokee, and Sevilleta & Bosque del Apache). There are also detailed analyses related to peatlands that focus on single services and may or may not provide socio-economic values of outcomes (e.g., health impacts of catastrophic fires by Rappold *et al.,* 2011). The current work seeks to capture the benefits of both scales and add to the state of knowledge on the values of ecosystem services provided by peatlands.

Although the explicit use of ecosystem service concepts is relatively new, it is increasingly being used to guide land use and land management decision making. The ecosystem services approach focuses on the benefits provided by the natural environment that are of value to humans and provides a useful framework for directly integrating ecologic, economic, and social information. This supports the consideration of how ecological resources can be strategically and sustainably managed to meet the ecosystem service needs of the growing global human population.

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