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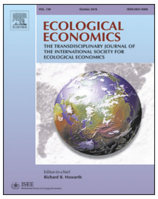

Analysis

Estimating the Societal Benefits of Carbon Dioxide Sequestration Through Peatland Restoration

Emily Pindilli[a,*], Rachel Sleeter[b], Dianna Hogan[b]

[a] U.S. Geological Survey, Science and Decisions Center, 12201 Sunrise Valley Dr. MSN 913, Reston, VA 20192, United States
[b] U.S. Geological Survey, Eastern Geographic Science Center, 12201 Sunrise Valley Drive, MSN 521, Reston, VA 20192, United States

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ABSTRACT

The Great Dismal Swamp National Wildlife Refuge (GDS) is a forested peatland that provides a number of ecosystem services including carbon (C) sequestration. We modeled and analyzed the potential capacity of the GDS to sequester C under four management scenarios: no management, no management with catastrophic fire, current management, and increased management. The analysis uses the Land Use and Carbon Scenario Simulator developed for the GDS to estimate net ecosystem C balance. The model simulates net C gains and losses on an annual time-step from 2013 through 2062 which is converted to carbon dioxide equivalent (CO_2-eq) and monetized using the Interagency Working Group's Social Cost of Carbon. Our analysis incorporates compounded uncertainty including variation in ecological processes, temporal and spatial heterogeneity, and uncertainty in the discount rate. The no management scenario results in 2.4 million tons of CO_2 emissions with a Net Present Value (NPV) under a 3% discount rate of −$67 million. No management with catastrophic fires emits 6.5 million tons of CO_2 with an NPV of −$232 million. Current management avoids 9.9 million tons of emissions (via sequestration) with an NPV of $326 million. Increased management avoids 16.5 million tons of emissions with an NPV of $524 million.

1. Introduction

Wetlands provide a number of ecosystem services including climate regulation via the terrestrial sequestration of carbon (C). In the United States, the ecological functions of wetlands have historically been undervalued (Barbier et al., 1997). The United States has experienced significant wetland losses on the order of 53% over the past two centuries (Dahl, 1990). Increased information on the benefits of functional wetlands, especially on public lands, supports land management decisions. As part of a multi-year study, which includes evaluation of hydrology, C budgets, and ecosystem services, the United States Geological Survey (USGS), in coordination with the U.S. Fish and Wildlife Service (FWS), considered the C sequestration potential of the Great Dismal Swamp National Wildlife Refuge (GDS), a forested peatland located in southeastern Virginia and northern North Carolina. Historically, the GDS has been highly altered from its natural state by means of logging, ditching and draining. The drained peat soils become oxidized and increase the risk of catastrophic wildfires; both of which lead to increased carbon dioxide (CO_2) emissions. While periodic surface wildfires are critical to native vegetation communities in the GDS (Sleeter et al., 2017; Reddy et al., 2015; Laderman et al., 1989), catastrophic wildfires are characterized by long-burning ground fires deep within the peat (> 0.5 m), which release large quantities of carbon (Reddy et al., 2015). These events are extremely damaging to the ecosystem and are frequently referred to as 'catastrophic.' Rewetting peat soils can increase C sequestration and also provides numerous cobenefits such as the provision of wildlife habitat, nitrogen and mercury sequestration, estuarine water quality protection, reduced frequency and severity of wildfires, and flood control (FWS, 2010). The FWS is interested in the trade-offs associated with different management actions in the GDS; this analysis along with the valuation of other ecosystem services provides information that can be used to by refuge managers in their decision making. We therefore model the GDS's capacity to sequester carbon under a set of potential conditions based on actual management practices and likely future conditions as informed by stakeholder input. We use an ecosystem services approach to assess the impacts of different levels of C sequestration on humans and the associated societal values.

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* Corresponding author.
E-mail addresses: epindilli@usgs.gov (E. Pindilli), rsleeter@usgs.gov (R. Sleeter), dhogan@usgs.gov (D. Hogan).

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Wetlands play an important role in global C dynamics with large stores of C in the soil and C uptake via peat formation, sediment deposition, and plant biomass (Bridgham et al., 2006).[1] It is estimated that peatlands in the Northern hemisphere store between 200 and 400 Pg of C (Gorham, 1991; Turunen et al., 2002), which is equivalent to 733 to 1650 billion metric tons of carbon dioxide equivalent (CO2eq).[2] In North America, peat C accumulation rates vary from 7 to 300 g of C per square meter (g C/m^2) per year (Kolka et al., 2011). C sequestration for a given wetland depends on a number of factors and can vary between being a source and a sink.

In the U.S., wetlands are threatened by vegetation removal, development, and drainage (EPA, 2016). The condition of wetlands largely influences the system's capacity to sequester C. Wetland drainage significantly alters the system's hydrology (Reddy et al., 2015) and is associated with lower water tables that reduces the ability of the peat to store C (Olson et al., 2013; Waddington et al., 2014). This also increases peatlands' vulnerability to fire (Benscoter et al., 2011; Turetsky et al., 2011a; Waddington et al., 2012). Peat fires are well known contributors to CO_2 emissions and climate change. Turetsky et al. (2011b) found that during a single northern peatland fire, 3300 to 3600 g C/m^2 were emitted. During the 2011 Lateral West Fire in the GDS, Reddy et al. (2015) estimated 44,000 g C/m^2 (1.1 Tg C) was emitted. Sleeter et al. (2017) had a similar finding for the GDS based on model simulations with 41,600 g C/m^2 (1.04 Tg C) released.

C stocks and sequestration rates have implications for climate change and ultimately human welfare. Fig. 1 provides an overview of the linkages between the physical processes of C sequestration and the benefits to humans. Wetlands store and sequester C in vegetation, the peat, and water. If the C balance is positive, i.e., more C is sequestered than emitted in the system, the ecosystem lowers atmospheric CO_2. The correlation between atmospheric CO_2 concentrations and temperature is well established (see Jouzel et al., 2007 and Lüthi et al., 2008). Reducing emissions (via sequestration) is therefore likely to reduce increased air temperatures which lead to increased ocean and freshwater temperatures, more frost-free days, more frequent heavy downpours, sea level rise, less snow-cover, shrinking glaciers, and reduced sea ice (Melillo et al., 2014). Fig. 1 shows the link from higher atmospheric concentration of CO_2 to higher future temperatures and to the final impacts on humans which include: human health, safety, water supply, agriculture, transportation systems, energy needs, infrastructure, property, and recreation, among others (Harris et al., 2017). The net value of these impacts is the cost associated with climate change and in this case the ecosystem service value is the costs avoided.

Climate change is unique in the realm of environmental economics due to the long time-scale, extent and nature of uncertainties, international scope of the issue, and the uneven distribution of policy benefits and costs across space and time (Goulder and Pizer, 2006). There are a number of estimates valuing the total cost of climate change (Cline, 1992; Fankhauser, 1995; Maddison, 2003; Mendelsohn et al., 2000; Nordhaus, 1991, 1994, 2006; Nordhaus and Boyer, 2000; Nordhaus and Yang, 1996; Rehdanz and Maddison, 2005; Tol, 1995, 2002). However, the total cost estimates available in the literature do not capture all of the impacts and are subject to many caveats including the simplification of physical models and human adaptation (Tol, 2008), but are derived using the best available information. The available estimates provide a proxy for damages and are used to derive marginal costs associated with additional CO_2 emissions.

To estimate the value of C sequestration in the GDS, we are specifically interested in the marginal value of CO_2 emissions avoided which can be defined as the social cost of C (SCC). The SCC is an estimate of the global economic damages associated with a one-ton increase (or decrease) in CO_2 emissions in a given year (EPA, 2016). There have been many attempts at monetizing the SCC. The National Research Council found that "[g]iven the uncertainties and the still preliminary nature of the climate damage literature… the range of estimates of marginal global damages [social cost of C] can vary by two orders of magnitude, from a negligible value of about \$1 per ton to \$100 per ton of CO2-eq" (NRC, 2009). Estimates of the SCC (per ton of CO_2) from the literature include \$7.70 (Nordhaus, 2008), \$5.20 (Anthoff and Tol, 2009), and \$5.10 (Hope, 2008) per metric ton of CO_2.[3] Tol (2008) conducted a meta-analysis of over 200 estimates of the SCC and found that for peer-reviewed literature with a discount rate of 3% the median value is \$32.57 per ton of C.[4] Weitzman (2009) argues that the fat tail associated with low-probability, high-impact events and uncertainty may render median and average estimates of the SCC meaningless. Nonetheless, policy decisions that impact emissions are frequently being made, therefore estimating the monetary value of the SCC may support more informed decision making.

Due to the diverse estimates of the SCC and the necessity to incorporate the value in policy decisions, an Interagency Working Group (IWG) was established to provide a standard value for federal agencies. Since 2010, U.S. government agencies have been using the IWG's SCC in regulatory impact analysis (NAS, 2017). State and local governments are also increasingly considering the SCC in decision-making (Rose et al., 2017). The IWG initially developed SCC estimates in 2010 and later revised these estimates in 2013 and 2015 (IWG, 2010, 2013, 2016). The current global value is \$47 per ton of CO_2.[5,6] It is important to note that all of the estimates cited including the one that we use in the analysis are valuations of the global impacts of climate change. For the purposes of rulemaking, the majority of U.S. policy decisions only consider the impacts on U.S. citizens. For example, in the recent regulatory impact statement reviewing the Clean Power Plan, a domestic SCC is estimated at \$5.50 per ton[7] (EPA, 2017a), which would result in values about 1/8 as large as those using a global estimate. While this value may be appropriate for evaluating policy, we suggest that the ecosystem services should be comprehensive and reflect the global SCC consistent with the avoided global damages associated with C sequestration. We therefore use the IWG's SCC to estimate the total potential benefits of C sequestration in the GDS.

There is a rich literature on C sequestration in peatlands, with many focused on the southeast United States (i.e., Bernal and Mitsch, 2012; Bridgham and Richardson, 1992; Bridgham et al., 2006; Clymo et al., 1998; Gorham, 1991; Richardson et al., 1981). However, there are a limited number of studies that extend C sequestration to the regulating ecosystem service of climate regulation. For example, Atkinson (2001) considered C sequestration as a service in the GDS but did not value this service. The majority of efforts to estimate the monetary value of C sequestration in peatland in the literature use average values for biological sequestration among various land types. For example, Richardson et al. (2014) used average C sequestration rates for major land types to estimate the value of C sequestered in the National Parks system. Similarly, Ingraham and Foster (2008) use average values to estimate C sequestration on lands in the National Wildlife Refuge system. We expand on the literature by using place specific data on C sequestration rates, utilizing a state and transition model to consider the full C cycle in various C pools, incorporating specific management

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[1] Methane emissions from wetlands can have potentially high impacts on net carbon balance of wetlands; however, we did not consider the contribution of methane in the current analysis.

[2] Conversion assumes there are 3.667 tons of CO_{2eq} per ton of carbon.

[3] Escalated to 2017 USD from 2005 USD using the CPI.

[4] Escalated to 2017 USD from 1995 USD using the CPI.

[5] Escalated to 2017 USD from 2007 USD using the CPI.

[6] Executive Order 13783 (March 28, 2017) disbanded the IWG and rescinded all memorandums, interim U.S. SCC values have been estimated by other U.S. federal agencies (i.e., EPA, 2017a); however, a global value has not been fully developed.

[7] Escalated to 2017 USD from 2011 USD using the CPI.