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Quantifying and modelling the carbon sequestration capacity of seagrass meadows – A critical assessment

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ABSTRACT

Seagrasses are among the planet's most effective natural ecosystems for sequestering (capturing and storing) carbon (C); but if degraded, they could leak stored C into the atmosphere and accelerate global warming. Quantifying and modelling the C sequestration capacity is therefore critical for successfully managing seagrass ecosystems to maintain their substantial abatement potential. At present, there is no mechanism to support carbon financing linked to seagrass. For seagrasses to be recognised by the IPCC and the voluntary C market, standard stock assessment methodologies and inventories of seagrass C stocks are required. Developing accurate C budgets for seagrass meadows is indeed complex; we discuss these complexities, and, in addition, we review techniques and methodologies that will aid development of C budgets. We also consider a simple process-based data assimilation model for predicting how seagrasses will respond to future change, accompanied by a practical list of research priorities.

1. Introduction

Reducing carbon (C) emissions is a necessary step in the fight against climate change. In addition, because greenhouse gases will linger in our atmosphere for another hundred years, there is also a need to find ways to remove C from the atmosphere. Biosequestration is one promising option that capitalises on natural CO_2 capture and storage by photosynthetic organisms and soil microbes. Ironically, it is the same process that created fossil fuels (i.e. the carboniferous forests, which produced the coal measures, and the rich deposits of microalgae which gave rise to oil-rich strata). Although much of the attention on biosequestration has centred on terrestrial forests, the world's greatest C storage potential may be in our coastal oceans.

Recent data estimates that seagrasses, together with saltmarshes and mangroves, are responsible for capturing up to 70% of the organic C in the marine realm (Nellemann et al., 2009), making them one of the most intense C sinks on the planet. Seagrass meadows bury C at a rate that is 35× faster than tropical rainforests, and their sediments never become saturated (McLeod et al., 2011). Furthermore, while terrestrial forests bind C for decades, seagrasses meadows can bind C for millennia (Macreadie et al., 2012; Mateo et al., 1997; Serrano et al., 2012). In a comprehensive survey of seagrass C stocks collected from almost 1000 meadows, Fourqurean et al. (2012) estimated that seagrasses can store 4.2–8.4 Pg C, 26 times higher than earlier estimates (Duarte and Chiscano, 1999). However, the significant capacity of coastal seagrasses to sequester C has gone unrecognised in models of global C transfer, and greenhouse gas abatement schemes. This is a major problem since the role of seagrasses as global C sinks continues to be threatened by coastal development and climate change.

Already 29% of the world's seagrasses have been destroyed (Waycott et al., 2009), heralding the loss of an important long-term C sink, and raising concern that degraded seagrass meadows could leak vast amounts of ancient C back out into the atmosphere, thus shifting seagrasses from C *sinks* to C *sources*, and potentially accelerating climate change. Recent estimates suggest that continued seagrass loss could release up to 299 Tg C into the atmosphere each year, which equates to 10% of all CO_2 emissions attributed to anthropogenic changes in land use (Fourqurean et al., 2012). The economic cost of this seagrass loss in terms of C emissions, at a C price of US$ 41 per ton of CO_2, is estimated to be between US$ 1.9 and 13.7 billion yr^{-1} (Pendleton et al., 2012). Thus, the potential emissions from continued loss of seagrass meadows is likely to have globally significant economic consequences, not to mention costs associated with loss of other ecosystem services provided by seagrasses, such as: shoreline stabilization (Bos et al., 2007); nutrient cycling (Costanza et al., 1997); and provision of habitat for fish, bird, and invertebrate species (Heck et al., 2003; Hughes et al., 2009).

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A current limitation to the inclusion of seagrasses in global greenhouse gas (GHG) abatement schemes (e.g. REDD+) is a paucity of data on C budgets from seagrass meadows covering a range of species and conditions. Those seagrass budgets that have attracted global interest are derived from a few pristine habitats and are not globally representative. Furthermore, the techniques used to generate these data are considered rudimentary and outdated by terrestrial standards. It is therefore necessary to conduct a comprehensive and rigorous assessment of seagrass C budgets using the latest technologies, and to use this information to model the sequestration capacity for different species and conditions.

The aim of this paper is to: (1) provide an update on policy development concerning inclusion of seagrasses (and other 'Blue Carbon' habitats; salt marshes and mangroves) within global C accounting frameworks; (2) highlight complexities and challenges in developing accurate C budgets; (3) review and critique key techniques and methodologies that can be used in research towards developing C budgets; (4) describe a process-based data assimilation model for studying C cycling within seagrass ecosystems; and (5) provide a practical list of research priorities that will lead to policy change concerning the development of effective measures to protect vulnerable seagrass C stocks, as well as restore and improve the C sequestration capacity of seagrass ecosystems.

2. Policy status: protecting C stocks and the sequestration capacity of seagrasses

In 1988, the Intergovernmental Panel on Climate Change (IPCC) was established as the world authority to assess the state of knowledge on climate change. The expert opinion of the IPCC influenced the Kyoto Protocol that was established by the United Nations Framework Convention on Climate Change (UNFCCC). Commissioned by the UNFCC, The International Blue Carbon Scientific Working Group has been tasked with determining the role of coastal wetlands (seagrasses, as well as saltmarshes and mangroves) in C sequestration, as well as establishing methodologies for C stock estimates in wetlands. The findings of this group have been used to outline activities for coastal wetlands to be included in the assessments used by the UNFCCC, as well as the voluntary C market as Voluntary Carbon Standards (VCS) (Herr et al., 2012).

Finally, the IPCC 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories will include a section on coastal wetlands. This document will provide guidelines for methodologies used to establish national-level C inventories, as well as default emission factors. Unfortunately, seagrasses are currently not included; however, much progress has been made towards the broad integration of coastal wetlands into IPCC procedures. Therefore, at present there is no mechanism to support C financing linked to seagrass. When seagrass are included in IPCC assessments, this will provide the incentive for management based system to enhance conservation and restoration of these valuable habitats (Herr et al., 2012).

For seagrasses and other coastal wetlands to be fully recognised by the IPCC and voluntary C market (mangroves already have established protocols), the UNFCCC will need to have approved methods of stock assessment. The IPCC uses three tiers of methodologies assessment: Tier 1 are national level estimates based on default values from global databases with a course spatial scale; Tier 2, is the same methodology as 1, but the data (activity, emission factors) are sourced from country/regional databases; and Tier 3, uses high-order methods (including simulation models and stock inventories) with field estimates of the particular site that are repeated over time (Penman et al., 2003). Statistical models are commonly used to estimate C stock for Tier 1 and 2 projects. Tier 3 has higher certainty and lower risk relative to Tier 1 and consequently attracts higher value C credits.

Before UNFCCC methodologies are approved, inventories of coastal wetland C inventories are being established and should follow standardised and robust methods, such as the IUCN Blue Carbon Working Group methods book to be released in middle of 2013. Most methods have been well documented in the literature over the past 10–20 years. However, the greatest knowledge gap for seagrasses is estimating the C flux from degraded or converted habitats and defining the origin of the C within a meadow. This will be discussed in Sections 3 and 4. However, in brief, movement of C between habitats is called leakage, and as C moves from the upland terrestrial forests into the river, estuaries, marsh, mangrove, seagrass and finally into the deep ocean; all this C is migrating from one habitat to the next. If the net import of C = net export of C, then the carbon accounting is straightforward, but if a habitat is a net sink for C, as seagrasses are thought to be, this becomes an issue for the providence of where the C has originated. Another important knowledge gap in all wetland C estimates is understanding just how much and how quickly C is released to the atmosphere when a healthy coastal wetland is "converted" to a less effective land use practice (Pendleton et al., 2012). Mapping the extent of the seagrasses is also a challenge, as traditional remote sensing techniques are less effective in shallow water than on land. These latter matters will be discussed further in Section 6.

Under the UNFCCC, there are a number of existing incentives apart from the direct C market to encourage emission reductions through nature-based activities. These include Nationally Appropriate Mitigation Actions (NAMA), Reducing Emissions from Deforestation and forest Degradation (REDD) and Land-Use and Land-Use Change and Forestry (LULUCF) linked to clean development mechanisms (CDM); the latter two being more likely to be used with mangroves than seagrasses at present (Herr et al., 2012). To attract C credits, a specific wetland project must demonstrate "additionality"; such that if this action did not occur, the C would not be captured. For example, the project needs to change a region from degraded mangrove into newly established mangrove forest, or to establish new habitats in regions where coastal wetlands are currently absent. Effectively, the goal is to create incentives for coastal conservation and restoration activities, while creating disincentives to damage coastal ecosystems.

The C market has biased the attention of policy makers on new sequestration rather than retaining existing C in wetland soils. In regions where coastal habitats have been mostly converted to aquaculture or urban settlements (SE Asia), there are some real opportunities for blue C offset schemes to encourage the restoration of these wetlands. However, opportunities for additionality should not detract from the importance of preventing the loss of already sequestered C, which vastly outweighs the potential gains of future C sequestration through additionality. Preservation of an existing seagrass meadow retains 50 times more C than new sequestration into barren soil from a restoration/rehabilitation project (Pendleton et al., 2012).

3. Developing a seagrass C budget: components, challenges, and complexities

The overall C budget of an ecosystem is defined by the amount of C stored (C stock), which is altered by the accumulation or release of C from this stock (=C flux). Simply measuring the C stock in isolation, without taking into consideration the rate of change or flux of a C stock, is not sufficient to assess whether the stock is accumulating, stable, or declining. Depending on their health, seagrasses can either behave as C sinks by sequestering C and burying it in the sediment, or as C sources, releasing C into the