Science of the Total Environment 605–606 (2017) 626–636

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Seagrass blue carbon dynamics in the Gulf of Mexico: Stocks, losses from anthropogenic disturbance, and gains through seagrass restoration

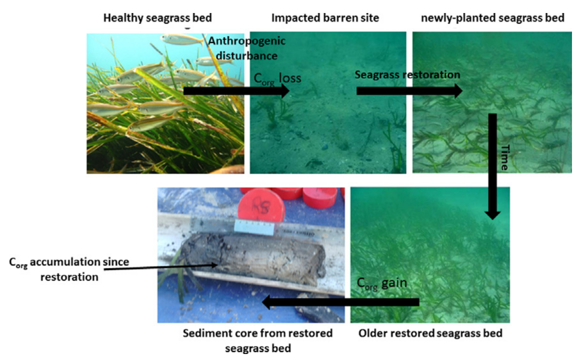
Anitra Thorhaug [a,*], Helen M. Poulos [a,b], Jorge López-Portillo [c], Timothy C.W. Ku [d], Graeme P. Berlyn [a]

[a] Yale School of Forestry and Environmental Studies, New Haven, CT 06511, United States
[b] Wesleyan University, College of the Environment, Middletown, CT 06457, United States
[c] Instituto de Ecología, A.C. (INECOL), Xalapa, Veracruz 91070, Mexico
[d] Wesleyan University, Department of Earth and Environmental Sciences, Middletown, CT 06459, United States

HIGHLIGHTS

- Anthropogenic disturbances have resulted in massive seagrass die-off.
- Loss of seagrasses has resulted in organic carbon flux.
- The magnitude of organic carbon loss depends on the type of seagrass disturbance.
- Seagrass restoration has the potential to reverse seagrass sedimentary C losses.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 17 April 2017
Received in revised form 21 June 2017
Accepted 22 June 2017
Available online xxxx

Editor: Jay Gan

Keywords:
Blue carbon
Seagrass carbon
Seagrass restoration
Gulf of Mexico
Seagrass impact carbon loss

ABSTRACT

Seagrasses comprise a substantive North American and Caribbean Sea blue carbon sink. Yet fine-scale estimates of seagrass carbon stocks, fluxes from anthropogenic disturbances, and potential gains in sedimentary carbon from seagrass restoration are lacking for most of the Western Hemisphere. To begin to fill this knowledge gap in the subtropics and tropics, we quantified organic carbon (C_{org}) stocks, losses, and gains from restorations at 8 previously-disturbed seagrass sites around the Gulf of Mexico (GoM) ($n = 128$ cores). Mean natural seagrass C_{org} stocks were 25.7 ± 6.7 Mg C_{org} ha^{-1} around the GoM, while mean C_{org} stocks at adjacent barren sites that had previously hosted seagrass were 17.8 Mg C_{org} ha^{-1}. Restored seagrass beds contained a mean of 38.7 ± 13.1 Mg C_{org} ha^{-1}. Mean C_{org} losses differed by anthropogenic impact type, but averaged 20.98 ± 7.14 Mg C_{org} ha^{-1}. C_{org} gains from seagrass restoration averaged 20.96 ± 8.59 Mg ha^{-1}. These results, when combined with the similarity between natural and restored C_{org} content, highlight the potential of seagrass restoration for mitigating seagrass C_{org} losses from prior impact events. Our GoM basin-wide estimates of natural C_{org} totaled ~36.4 Tg for the 947,327 ha for the USA-GoM. Including Mexico, the total basin contained an estimated 37.2–37.5 Tg C_{org}. Regional US-GoM losses totaled 21.69 Tg C_{org}. C_{org} losses differed significantly among anthropogenic impacts. Yet, seagrass restoration appears to be an important climate change mitigation strategy that could be implemented elsewhere throughout the tropics and subtropics.

* Corresponding author at: 1359 SW 22nd Ter., Miami, FL 33145, United States.
E-mail addresses: athorhaug@msn.com (A. Thorhaug), hpoulos@wesleyan.edu (H.M. Poulos), jorge.lopez.portillo@inecol.mx (J. López-Portillo), tcku@wesleyan.edu (T.C.W. Ku), Graeme.berlyn@yale.edu (G.P. Berlyn).

http://dx.doi.org/10.1016/j.scitotenv.2017.06.189
0048-9697/

1. Introduction

Seagrasses are a critical, but continually-diminishing blue carbon foundation habitat. The IPCC (Intergovernmental Panel on Climate Change) Wetlands Committee only recently recognized that wetlands and submerged aquatic vegetation including marshes, mangroves, and seagrasses contribute significantly to the global stored carbon sink, and Hiraishi et al. (2014) called upon governments to implement more sophisticated inventories of wetlands carbon emission factors to move beyond the use of basic default values for tidal wetlands (140 g^{-2} y^{-1}) and basic equations (i.e., Tier I standards). Current baseline estimates indicate that global seagrass carbon pool lies between 4.2 and 8.4 Pg of organic carbon (C_{org}) (Fourqurean et al., 2012a). Yet, these important seagrass blue carbon sinks continue to be lost at an alarming rate (Waycott et al., 2009). Given that blue carbon sequestration rates can be orders of magnitude higher than terrestrial carbon pools (Fourqurean et al., 2012a), information about seagrass blue carbon cycling is an important factor in IPCC decision-making and carbon accounting. Presently, regional subtropical and tropical seagrass blue carbon stock data remain sparse for seagrass and we lack a coherent fingerprint of the spatial variation in C_{org} stocks in relation to local environmental influences. Nor do we understand the potential of seagrass restoration for bolstering blue carbon stocks in these regions. Such information is critical for achieving long-term Tier II (regional/country-specific emission factor values) and Tier III (more complex, site-specific emission factor values) blue carbon accounting goals and REDD+ (reducing emissions from deforestation and forest degradation) carbon offset eligibility.

1.1. Seagrass blue carbon losses from anthropogenic disturbances

C_{org} fluxes from seagrass die-off after anthropogenic disturbance events can vary considerably depending on local environmental conditions, C_{org} inputs to the estuary, and the type and magnitude of the disturbance (Macreadie et al., 2013). Pendleton et al. (2012) generated a rough global estimate of blue carbon emissions from conversion and degradation of coastal marine vegetation. However, their estimates utilized default mean C_{org} stock values of 140 Mg ha^{-1} from Fourqurean et al. (2012a), and they did not incorporate spatial variation in sedimentary carbon stocks or the effects of different types of impacts on seagrass C_{org}-cycling. Several researchers have presented site-specific data on seagrass carbon flux from human impacts including Marbà et al. (2015) in Western Australia on the Indian Ocean at a location where the seagrass ecosystem sediment collapsed resulting in the disappearance of the seagrass carbon and its associated sediments in response to disturbance. Likewise, Macreadie et al. (2014) experimentally disturbed the sediment in small plots, and measured sediment carbon content over 24 months in central eastern Australia, but found no significant C_{org} loss. Such results highlight the need for more studies that address the mechanisms of seagrass carbon cycling following anthropogenic disturbances. The few existing empirical studies on seagrass blue carbon losses suggest that making common assumptions about coastal marine carbon cycling can be misleading (Macreadie et al., 2014).

1.2. Seagrass restoration as a climate change mitigation strategy

van Katwijk et al. (2016) demonstrated the importance of seagrass restoration on a global-scale for restoring coastal marine ecosystem services, yet the effects of restoration activities on blue carbon cycling have yet to be examined fully. Seagrass restoration theoretically provides one potential solution for mitigating the losses of blue carbon stocks from anthropogenic disturbances. Yet, few prior studies have examined the potential of seagrass restoration for bolstering blue carbon stocks. To date, data exist from only two sites (Chesapeake Bay, USA (Greiner et al., 2013) and Perth, Western Australia (Marbà et al., 2015)) that quantify the effects of seagrass restoration on seagrass sedimentary carbon stocks. The results of both studies indicate that C_{org} stocks in restored areas following seagrass die off from anthropogenic impacts can vary considerably. These studies represent two disparate data points from one temperate high energy site on Western Australia's Indian Ocean and one temperate Atlantic estuarine site in Chesapeake Bay, USA. Regional-scale studies of the effects of multiple seagrass restorations on blue carbon stocks under a variety of environmental and anthropogenic stressors are clearly needed for achieving detailed and regional-scale Tier II and III IPCC carbon accounting goals.

This study builds upon the limited body of literature on seagrass sedimentary carbon accounting via a regional-scale analysis of seagrass C_{org} stocks, losses from an array of anthropogenic disturbances, and C_{org} gains through multiple seagrass restorations across the USA GoM. Our overarching goal was to examine the dynamics of seagrass sedimentary carbon flux from disturbance and to evaluate the potential of subtropical/tropical seagrass restoration as a climate change mitigation strategy. We hypothesized that the effects of different types of seagrass disturbances on C_{org} losses would vary in accord with the disturbance type, and that different types of disturbances would also influence the subsequent carbon sequestration potential of seagrass beds that were then restored after such impacts. We also hypothesized that seagrass restoration would bolster blue carbon stocks in barren areas where seagrass die-off had previously occurred. We tested these hypotheses by systematically collecting C_{org} data from across 8 subtropical/tropical seagrass sites that had all been restored using a consistent restoration methodology across the USA GoM, which is considered a of North American carbon hotspot (Hofmann et al., 2008; Herrmann et al., 2015). Each sample site had experienced major seagrass die-off from an anthropogenic disturbance, and then Thorhaug subsequently restored portions of each site using standardized restoration methods over the last 4 decades in a series of restorations (see Table 1 for descriptions of individual restoration projects). The present study uses known seagrass kill dates (i.e. the dates of closing of thermal and sewage effluents, vessel groundings, and artificial-fill dates of US Army Corps of Engineers) and the exact restoration dates to estimate C_{org} losses and gains at 8 sites across the USA GoM (Table 1 contains descriptions of each study site and its anthropogenic impact). The dates of both the impact event and the restoration date, provided a fine-scale clock for quantifying both C_{org} losses since disturbance and gains since restoration.

2. Study region

2.1. Gulf of Mexico seagrasses

The GoM is an internal North American basin, that is dominated by sedimentary estuaries that contain seagrasses as a foundation habitat throughout the basin. Soft sandy and muddy bottoms are characteristic of estuaries across the region, and these wetlands support large expanses of seagrasses, marshes, and mangroves. Two benthic western Florida shelves also support seagrass. Seagrasses extents in the USA GoM have been estimated at near 1 million ha (chiefly found in Florida and in Texas's Laguna Madre (Appendix A) (Duke and Kruczynski, 1992; Pulich and Hardegree, 2006; Handley et al., 2007; Yarbro and Carlson, 2011) with rough estimates of 25,000 ha in the Mexican portion (Green and Short, 2003). Seagrass productivity is high in the GoM due to its year-long growing season and clear waters (Thorhaug et al., 1978; Dunton, 1994; Livingston et al., 1998). Extensive anthropogenic development has occurred chiefly during the last century, which has decimated intertidal wetlands and seagrasses throughout the region. Duke and Kruczynski (1992) estimated that 54% (19,250 km^2) of all wetlands and seagrasses in the GoM were lost by 1992. To date, this seagrass loss was considered to chiefly affect fisheries and habitat extent. However, such losses likely also have effects on GoM seagrass carbon capture and storage.