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# New insight into global blue carbon estimation under human activity in land-sea interaction area: A case study of China

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ABSTRACT

The C sequestration in coastal blue carbon ($C_b$) ecosystems, including mangroves, seagrasses and saltmarshes, was discovered to be useful in mitigating the increasing trend of carbon dioxide ($CO_2$) emission due to climate change. In this study, we systematically estimate traditional $C_b$ ecosystem distribution and the associated $C_b$ sequestration rate, and then further quantify the $C_b$ sinks fishery contribution to $C_b$ ecosystem due to human activity in coastal ecosystem. The results show that the global $C_b$ ecosystem is able to store 10.8 PgC, wherein biomass and soil are able to store 2.13 and 8.68 PgC, respectively. In China, the $C_b$ pools are 162 TgC in mangroves, 67 TgC in saltmarshes and 75 TgC in seagrass. The human activity induced global $C_b$ sink fishery on $C_b$ ecosystem is about 26.58–37.6 TgC $yr^{-1}$, accounting for 30.7%–43.4% of the world's traditional $C_b$ sequestration ecosystem.The global $C_b$ sequestration potential reaches up to 86.59 Tg $yr^{-1}$, while China can explain 1.70% of the world's total $C_b$ sequestration. However, in China, the $C_b$ sequestration due to human activity reaches up to 6.32–7.89 TgC $yr^{-1}$, accounting for 20.9%–23.7% of global $C_b$ sink fishery. Therefore, it is very important to build the $C_b$ sink fisheries measure and monitor system to scientifically valuate $C_b$ sink fisheries and associated development potential.


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## 1. Introduction

Traditionally, the blue carbon ($C_b$) is defined as the C captured by living organisms in oceans that stored in the form of sediments from mangroves, saltmarshes and seagrasses (Siikamäki et al., 2012), The costal vegetated habitats, in particular mangroves, saltmarshes and seagrasses only cover less than 2% of the area of the world's oceans, but sequester at least 50% of the C stored in ocean sediments (Nellemann et al., 2009; IWGCBC, 2011). Therefore, sustaining $C_b$ sinks in coastal ecosystems will be crucial for making climate change adaptation strategies and reducing vulnerability of human coastal communities in the future (Nellemann et al., 2009; Laffoley and Grimsditch, 2009). The land-sea interaction area in coastal ecosystem is commonly termed "gray zone" in the global C cycle. The available findings and reports on $C_b$ ecosystem are important for evaluating global earth surface C storage (Sifleet et al., 2011).

$C_b$ biosequestration in mangroves, saltmarshes and seagrasses can capture atmospheric $CO_2$ and store it in plant biomass and sediments as $C_b$. $C_b$ is considered as one of the most effective methods for long-term C storage (Duarte et al., 2013; Macreadie et al., 2014). $C_b$ sink is determined by the processes and mechanisms that marine organisms absorb and use atmospheric $CO_2$ (Arrigo, 2004; Gonzalez et al., 2010). Marine organisms are responsible for 55% of global photosynthetic C fixation each year (Bowler et al., 2009; Bauer et al., 2013), but compared to terrestrial plants, phytoplanktonic marine organism biomass is only 0.05% of terrestrial plant biomass. The coastal ecosystem transports the fixed $C_b$ to two adjacent ecosystems, including coastal ecosystems and the open oceans, as well as to the seabed buried in sediments in the form of humus. (Duarte and Cebrian, 1996; Duarte et al., 2005; Bouillon et al., 2008; Heck et al., 2008; Bauer et al., 2013). Once $C_b$ is transformed into humus, it is temporarily removed from the C cycle. Donato et al. (2011) recently estimated that coastal mangroves could store up to 20 PgC, which was equivalent to roughly 2.5 times current annual greenhouse gas emissions globally. This is a striking observation, especially given the fact that mangroves only cover about 0.7% of the tropical forest area worldwide.

Recently, it has been reported that human activities have greatly modified the exchange of C and nutrients between terrestrial and coastal zones (Regnier et al., 2013). Atwood et al. (2015) further revealed that predators were helpful for biosequestration and greatly changed the coastal ecosystem C cycling based on their indirect effects on plant or microbial community composition and structure (Wilmers et al., 2012; Atwood et al., 2014). Therefore, we believe that the human activities, such as $C_b$ fishery and aquaculture in coastal ecosystem, are able to alter food chain or increase the population of predators, and consequently enhance the $C_b$ biosequestration in coastal ecosystems. The aims of this study are to (1) summarize the current knowledge on $C_b$ ecosystem distribution and $C_b$ density; (2) comprehensively evaluate global $C_b$ sequestration potential and storage; (3) systematically estimate the contribution of $C_b$ sink fishery to coastal $C_b$ sequestration, and (4) provide recommendations for future $C_b$ management strategies.

## 2. Methods

In this study, in order to make sure the statistical data are uniform and unbiased, the basic statistical data on the distribution and $C_b$ sequestration of global mangroves, seagrasses and salt marshes were collected from the Food and Agriculture Organization (FAO) and International Working Group on Coastal "Blue Carbon" (IWGCBC) reports. The data on global fishery and aquaculture development were retrieved from the World Review of Fisheries and Aquaculture. The data related to $C_b$ ecosystem and fishery and aquaculture in China were extracted from China Marine Statistical Yearbook (CMSY) and China Fishery Statistical Yearbook (CFSY). All parameters used in the study are from published journal papers, conferences papers and government reports. The global $C_b$ storage and $C_b$ sequestration are estimated by the following equations and the detailed description of related parameter values is given in Table 1.

The coastal $C_b$ sequestrations are calculated using Eq. (1):

$$C_b = C_{rate} \times A_v \quad (1)$$

where $C_{rate}$ is the $C_b$ sequestration rate of a certain kind of vegetation; $A_v$ is the distributing area for the corresponding $C_b$ ecosystem.

The economic algae, shellfish and fishing C sequestration are calculated using Eq. (2):

$$C_{aquaculture} = C_a \times X_a \quad (2)$$

where $X$ is the annual mean production; $C_a$ is the C sequestration rate.

## 3. Global $C_b$ sink estimation in coastal ecosystem

### 3.1. Global $C_b$ ecosystem geographic distribution

Mangroves, seagrasses and salt marshes in coastal ecosystem are three major $C_b$ pools, which spread across the globe. At least one of the three can be found in almost every country with a coastline (Giri et al., 2010; Pendleton et al., 2012; Siikamäki et al., 2012) (Fig. 1). Seagrass meadows often lie adjacent to mangroves and saltmarshes, which are subject to similar land-use pressures as mangroves though their much broader and different geographic range (Duarte and Chiscano, 1999; Hemminga and Duarte, 2000). Therefore, the estimation of areal coverage of saltmarshes and seagrass exist considerable uncertainty (Siikamäki et al., 2012). Barbier et al. (2011) estimated that the $C_b$ ecosystem on mangroves, seagrasses and saltmarshes covered approximately $4.9 \times 10^5$ km$^2$ worldwide. Mangrove forests are coastal wetland forests that cover up to 75% of the tropical and subtropical shorelines of the world, so there are 111 countries with mangroves in the world (Siikamäki et al., 2012). Giri et al. (2010) reported that the total area of mangroves worldwide was $1.39 \times 10^5$ km$^2$, wherein Southeast Asia had obvious the largest mangrove area (66,687 km$^2$), which accounted for almost half of the total global mangroves area.

As Fig. 2 shows, we collect geographic data on the main mangroves and seagrass distribution in the top 20 countries in the world (Giri et al., 2011; Siikamäki et al., 2012). We find out that the main mangroves are concentrated on both sides of the equator and the total area for mangroves area in these 20 countries accounts for over 80% of the total area worldwide. The area of mangroves in Indonesia alone accounts for $2.7 \times 10^4$ km$^2$ or 19.5% of the world's total mangroves area. Followed by Indonesia, the next four countries with large mangroves area are Brazil, Australia, Mexico and Nigeria, which belong to other continents (Fig.2a). As Fig.2b shows, seagrass ecosystems are broadly distributed worldwide. The total area of seagrass is roughly estimated at $3.19 \times 10^5$ km$^2$. Meanwhile, there is an interesting phenomenon that mangroves mostly concentrate in developing countries around the equator, but seagrasses concentrate in both developing and developed countries (Giri et al., 2007). Southeast Asia has the largest area of seagrass. The total seagrass covered area in Southeast Asia is $8.13 \times 10^4$ km$^2$, which accounts for 25.4% of the world's seagrass (Fig.2b). The top four seagrass covered countries are Australia, Saudi Arabia, United States and Indonesia. The total area of seagrass in Australia is $4.11 \times 10^4$ km$^2$, which accounts for 12.9% of the world's total seagrass area. The salt marshes are mostly located in low temperate and high latitude area. In tropical areas, salt marshes would give way to mangroves (Allen and Pye, 1992). Chmura et al. (2003) roughly estimated that salt marshes covered $5.1 \times 10^4$ km$^2$ worldwide, which was in agreement with the estimation from Pendleton et al. (2012).

In China, most of mangroves distribute at Guangdong, Guangxi, Hainan and Fujian Province, and the mangroves covered areas are 323, 180, 135 and 134 km$^2$, respectively (CMSY, 2011). There are about 22 seagrass species distributed along China's coastal regions, which belong