Invited review

The role of root decomposition in global mangrove and saltmarsh carbon budgets

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ABSTRACT

This study aims to determine the drivers of root decomposition and its role in carbon (C) budgets in mangroves and saltmarsh. We review the patterns of root decomposition, and its contribution to C budgets, in mangroves and saltmarsh: the impact of climatic (temperature and precipitation), geographic (latitude), temporal (decay period) and biotic (ecosystem type) drivers using multiple regression models. Best-fit models explain 50% and 48% of the variance in mangrove and saltmarsh root decay rates, respectively. A combination of biotic, climatic, geographic and temporal drivers influences root decay rates. Rainfall and latitude have the strongest influence on root decomposition rates in saltmarsh. For mangroves, forest type is the most important; decomposition is faster in riverine mangroves than other types. Mangrove species *Avicennia marina* and saltmarsh species *Spartina maritima* and *Phragmites australis* have the highest root decomposition rates. Root decomposition rates of mangroves were slightly higher in the Indo-west Pacific region (average 0.16% day^{-1}) than in the Atlantic-east Pacific region (0.13% day^{-1}). Mangrove root decomposition rates also show a negative exponential relationship with porewater salinity. In mangroves, global root decomposition rates are 0.15% day^{-1} based on the median value of rates in individual studies (and 0.14% day^{-1} after adjusting for area of mangroves at different latitudes). In saltmarsh, global root decomposition rates average 0.12% day^{-1} (no adjustment for area with latitude necessary). Our global estimate of the amount of root decomposing is 10 Tg C yr^{-1} in mangroves (8 Tg C yr^{-1} adjusted for area by latitude) and 31 Tg C yr^{-1} in saltmarsh. Local root C burial rates reported herein are 51–54 g C m^{-2} yr^{-1} for mangroves (58–61 Tg C yr^{-1} adjusted for area by latitude) and 191 g C m^{-2} yr^{-1} for saltmarsh. These values account for 24.1–29.1% (mangroves) and 77.9% (saltmarsh) of the reported sediment C accumulation rates in these habitats. Globally, dead root C production is the significant source of stored sediment C in mangroves and saltmarsh.

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1. Introduction

Coastal wetlands, including mangroves and saltmarsh, are blue carbon (C) ecosystems that provide numerous benefits and services important in climate change adaptation Atwood et al. (2015). These habitats typically sequester C several times faster than terrestrial ecosystems, and are therefore important despite occupying a smaller area of the earth's surface (Breithaupt et al., 2012; Mcleod et al., 2011). Globally, these habitats, along with macroalgae, are estimated to contribute 50% of the C sequestration in marine sediments (Duarte et al., 2013). The role of mangroves in global C cycling and storage has been thoroughly reviewed, and led to the identification of significant unknown processes, e.g. the fate of dissolved inorganic C (DIC) from decomposition (Bouillon et al., 2008). For saltmarsh, although sequestration rates are known (Mcleod et al., 2011), their overall role in C cycling has not yet been fully described, despite a scale-up study of C cycling in saltmarshes on the U.S. East (Atlantic) Coast (Wang et al., 2016). For both habitats, syntheses of their roles have to date failed to incorporate the contribution of plant root decay to sediment C budgets. Assessing the contribution of mangrove and saltmarsh root production will be a significant step towards fully quantifying sediment C storage in these habitats.

Organic matter (OM) accumulation in mangroves and saltmarsh is dependent on the balance between the production and decomposition of below-ground biomass, in addition to above-ground production and import/export determined by the hydrological regime. Production and decomposition of below-ground roots and rhizomes in mangroves and saltmarsh are known to contribute to soil fertility through the formation of humic substances. However, it is their significant contribution to C storage and peat formation (Huxham et al., 2010; McKee et al., 2007; Ouyang and Lee, 2014) that we focus on here, because this drives sediment supply, sediment accretion, OM accumulation and influences responses to rising sea levels in coastal wetlands (Lovelock et al., 2015). Root and rhizome decomposition also produces significant greenhouse gases, predominantly from aerobic oxidation and sulphate reduction, which are the main pathways of OM degradation in coastal sediments (Alongi, 2009; Penha-Lopes et al., 2010). Even so, there exist other pathways of microbial OM decomposition, including manganese and iron reduction, which are among the sources of benthic DIC and alkalinity and thereby C sinks in the coastal zone (Krumins et al., 2013; Ovalle et al., 1990).

Little attention has been paid to the patterns of root decomposition in mangroves and saltmarsh, despite the expected significant role of root decomposition. Substrate quality and the presence and abundance of fauna are known to influence the decay rate of leaf litter in mangrove forests (e.g. Kristensen et al., 2008). A wide range of factors may influence the root decomposition processes. Different environmental, hydrological and climatic conditions can affect below-ground microbial activities and oxygen concentrations (Alongi, 2009; Gonzalez-Alcaraz et al., 2012; Sousa et al., 2010a), and thus the decomposition rate. Sediment porewater salinity might also modulate microbial decomposition of roots. Davidson and Janssens (2006) proposed that hydrological factors and substrate quality are the chief constraints on decomposition rates in wetlands. These factors potentially interact with an assumed response of decomposition rates to temperature. Although there is a growing literature on root decomposition in coastal wetlands, there has been no global synthesis of root decay rates in mangroves and saltmarsh. The integration of the influence of climatic, geographic, biotic and other drivers of root decay is a significant step in understanding the ecological function of these estuarine habitats and their capacity for blue C.

This study quantifies the contribution of root decay to global C budgets in mangroves and saltmarsh and assesses factors that may cause variation in reported rates. We analyse the nexus between root decay rates and climatic (temperature and precipitation), geographic (latitude), temporal (decay period), biogeochemical (sampling depth) as well as biotic (ecosystem type) factors. Then we investigate differences in root decay rates among ecosystem types, significant factors in the model, and with porewater salinity, as well as species. Global root decomposition rates are estimated by averaging individual rates in mangroves and saltmarsh, and also by integrating mangrove area with decay rates in latitudinal ranges. Then we examine how much C is mineralised in the root decay process and how much is buried in sediments. This is the first comprehensive global review synthesizing the fate of mangrove and saltmarsh root C production. The findings will contribute to an improved understanding of below-ground OM mineralisation and accumulation in mangrove and saltmarsh sediments, and its implications for C budgets in coastal wetlands.

2. Materials and methods

2.1. Data collection and collation

Decomposition rates of roots and/or rhizomes in mangroves and saltmarsh were compiled from the literature. We conducted a literature search in http://www.sciencedirect.com/ and http://pcs.webofknowledge.com/, using 'carbon OR decomposition' combined with either 'mangrove' or 'saltmarsh OR salt marsh' in 'Abstract, title and Keywords' or 'Topic, title'. These terms cover root and/or rhizome decomposition in mangroves and saltmarsh. In total, 2611 and 2427 results were found for mangrove and saltmarsh studies, respectively. Our careful sifting through these papers for studies containing primary data on root decomposition of mangroves and saltmarsh reduced the number to 36 for the two habitats.

Individual studies investigate root decomposition by quantifying the variation of root mass at intervals during the whole decay period. Specifically, in all studies replicates (the number depends on sampling intervals and duration of the whole decay period) of a known amount of roots were put in sediment in the field, retrieved at intervals and then re-weighed. The loss of root mass is calculated as the difference between the initial and remaining mass, and is a function of the decomposition rate.

When decomposition rates were not reported directly in individual studies, they were calculated from the decay period and the decay rate constant, as estimated by the linear or negative exponential model (remaining biomass ~ decay period). The selection of a linear or exponential model depended on which explained more variance in the dependent variable. For studies measuring remaining biomass over a series of decay periods, only root decay rates corresponding to the final decay period were used. Overall, the data from the 36 studies covered a latitudinal range from 38.3°S to 26.1°N for mangroves and 38.3°S to 51.4°N for saltmarsh (Fig. 1, and Table S1 in Appendix A). Root decomposition rates (% day^{-1}) are derived from Eqs. (1) and (3) for the linear model, to Eqs. (2) and (3) for the exponential model.

$$M_t = k_c t + b \tag{1}$$

$$M_t = \exp(k_c t + b) \tag{2}$$

$$\text{decomposition rate} = 100 \times \frac{M_0 - M_t}{M_0 T} \tag{3}$$

Where M_t is the remaining root mass (in g) at the specific decomposition period t (days), g; k_c is decay rate constant, g day^{-1}; b is the intercept in the regression models, g; M_0 is the initial root mass, g; T is the overall decomposition period in days.

Methods used by the studies to estimate the decomposition rate were categorised into four types: litter bags, litter tubes, unbagged litter and coring method. Litter bags are used to investigate root decomposition by enclosing a known amount of roots in permeable bags, and the mass loss from roots in the bags over time is an estimate of decomposition rate. Litter tubes are similar to litter bags but enclose roots in tubes, the end of which is closed with permeable mesh screens. In contrast to