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Salt marsh plants carbon storage in a temperate Atlantic estuary illustrated by a stable isotopic analysis based approach

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ABSTRACT

The biomasses, carbon standing stocks, and exportations of three saltmarsh species – *Scirpus maritimus*, *Spartina maritima* and *Zostera noltii* – were determined and their isotopic composition analyzed to illustrate their role in carbon storage in a temperate Atlantic estuary (Mondego, Portugal). Biomass values were higher in the warmer seasons than in the cold seasons, with carbon contents following the same trend. Carbon content ranged from 27–39% in *S. maritimus* and *S. maritima* to 30–39% for *Z. noltii*. *S. maritimus* had the highest carbon production in the aboveground organs and had similar results with *S. maritima* in the belowground carbon production. These three species together occupied about 50% of the salt marsh area and they stored in 21 months of study 24,000 kg of carbon in their aboveground and belowground organs. *Z. noltii* presented highest carbon concentration in the sediment and *S. maritimus* the lowest. Stable carbon isotopic analysis showed that apparently, the sedimentary organic matter is composed by a mix of terrestrial sources, macro and microalgae. Regard the high carbon exportation, *S. maritima* and *Z. noltii* are constantly accumulating carbon. The studied species have both a sink and source behaviour simultaneously.

1. Introduction

In the last 250 years, industrial activity has increased with a concomitant increase of the fossil fuel usage (Houghton, 1999) and consequent atmospheric CO_2 increase. This has recognized consequences on climate change, namely increasing the global surface temperature (Bluemle et al., 1999; IPCC, 2007). As a way to mitigate the high concentration of CO_2 in the atmosphere it is important to look to plant ecosystems (for e.g. salt marshes) that remain in a good ecological state and try to preserve or in many cases restore them. Coastal wetlands, such as salt marshes have high productivity, being one of the most productive ecosystems in the world (Mitsch and Gosselink, 2000), thus being excellent carbon sinks as they withdraw CO_2 from the atmosphere and store it in living plant tissue (Williams, 1999). Salt marshes are usually located in estuarine systems and their primary production allows for a greater reduction of CO_2 in the atmosphere and incorporation on organic tissues through photosynthesis (Sousa et al., 2010). Wetlands represent the largest carbon pool with a capacity of 770 Gt of carbon, overweighing the total carbon storage of farms and rain forests (Han et al., 2005). Plants can fix carbon through photosynthesis, displaying different mechanisms. The photosynthesis in C_3 plants occurs in the mesophyll cells, while in C_4 plants occurs in the mesophyll and bundle sheath cells (Taiz and Zeiger, 2009), allowing a high efficiency under stressful conditions. The carbon fixation occurs through Calvin cycle, where CO_2 and water are combined with ribulose-1,5-biphosphate into two molecules of 3-phosphoglycerate through ribulose-1,5-biphosphate carboxylase (rubisco), that is converted in carbohydrates. Rubisco can act as a oxygenase, producing 2-phosphoglycolate and 3-phosphoglycerate instead of two molecules of 3-phosphoglycerate, decreasing the photosynthetic efficiency; but some plants have mechanisms to exceed this decrease, like the C_4 photosynthetic pathway (Taiz and Zeiger, 2009).

In the present work the authors utilized a stable isotopic approach to study differences in the carbon concentration in the sediments, aboveground and belowground organs of three plant species in a temperate estuary salt marsh - Mondego estuary (Portugal) - considering their metabolic differences, and look to these three species (tissues and sediment) as different carbon compartments with different carbon storage abilities. Based in other similar works (Lillebø et al., 2003; Caçador et al., 2004) was expected that the belowground organs of the three species have higher carbon concentration than the aboveground organs; the high concentration occur in the warmer seasons and the species are carbon sinks.

Among the most abundant salt marsh plant species in the Mondego estuary are *Scirpus maritimus* with a C_3 photosythetic

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mechanism (Boschker et al., 1999), *Spartina maritima* with a C_4 type (Adam, 1990) as well as the seagrass *Zostera noltii* (Jimenez et al., 1987; Larkum et al., 2006). When compared with C_3 plants, the C_4 type have a photosynthetic pathway that has been shown to be to advantageous in areas with high irradiance, high temperatures and intermittent water stress (Ehleringer and Monson, 1993) and is associated with adaptations to avoid the stress, and an advantage in elevated-salinity salt marsh systems (Chmura and Aharon, 1995). The fixed carbon is used to plants needs, but the majority of biomass produced by plants is degraded or exported, only a small part is retained in the sediment (Howarth, 1993).

2. Methods

2.1. Study site

Mondego estuary (Fig. 1) is located in the Portuguese Atlantic coast (40°08N, 8°50W) (Marques and Nogueira, 1991) ending in the city of Figueira da Foz. The estuary has approximately 8.6 km^2 and its upstream limit, defined as a function of the tidal influence, was settled 21 km upstream from the mouth (Teixeira et al., 2008). The final part of the estuary, that has 7 km is divided in two arms (north and south) by the Murraceira Island (Marques et al., 2003). The north arm is deeper than the south arm and is the main navigation channel. The areas where the samples of *S. maritima* and *Z. noltii* were collected are relatively close, being the sample station hereafter denominated as Gala. The *S. maritimus* colonized area is more upstream the estuary in an area hereafter denominated as Montante.

2.2. Sampling and laboratory procedures

For each species were sampled seasonally three pure stands cores with 50 cm depth and 9 cm diameter, located at a minimum of 10 m distance from each other during almost 2 years (spring, summer and autumn of 2010 and winter, spring, summer and autumn of 2011). For the aboveground biomass three 0.3 m × 0.3 m squares of each species were randomly selected in each area and clipped out. To assess belowground biomass, inside each clipped square a core was taken, with 8 cm diameter and 30 cm long (Caçador et al., 2004). In the laboratory, the aboveground samples were washed and passed by ultrapure water (18.2 MΩ cm). The belowground organs were cleaned from the sediments by water flux inside a sieve with a mesh size of 212 μm and subsequently passed by ultrapure water. Both above and belowground tissues were dried at 60 °C until constant weight pulverized with the help of a grinding ball mill (Glen CrestomMM2000) (Gross et al., 1991). Sediment samples were oven dried at 60 °C until constant weight. After, the sediment was cleaned of roots, passed through a 0.25 mm mesh, homogenized and ground with an agate mortar. Pore water salinity was measured using a refractometer (Atago, S/Mill-E). The sediment organic matter content was determined in dried samples by loss of ignition (LOI) at 600 °C for 2 h (Caçador et al., 2000). Sediment grain size was determined by mechanical sequential sediment sieving, using analytical sieves housed in a shaker, to evaluate the relative abundance (Folk, 1954). The sedimentation rate were measured with woodpiles with millimetres marks that were buried in each species area until the zero mark and then were checked and noted in what millimetre mark the sediment were. Three woodpiles were buried in each species zone in February of 2011 and checked in February of 2012.

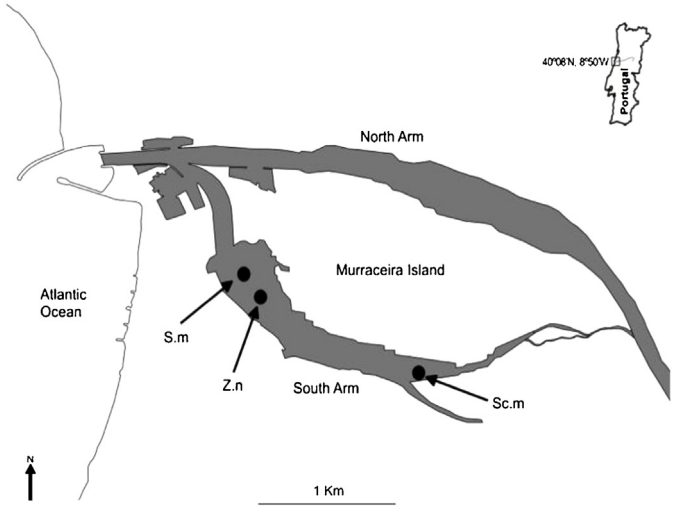

Fig. 1. Terminal part of the Mondego estuary and *Zostera noltii* (Z.n), *Spartina maritima* (S.m) and *Scirpus maritimus* (Sc.m) sampling location.

2.3. Carbon analysis

Total carbon content was determined for both aboveground and belowground species organs with a CHNS/O analyzer (Fisons Instruments Model EA 1108). The Net Primary Production (NPP, g) was determined using the Eq. (1), where the minimum biomass found in the study period is subtracted from the maximum biomass in the same period.

$$\text{NPP} = \text{Maximum bimass} - \text{Minimum biomass} \quad (1)$$

The root decomposition was calculated using Eq. (2), and the aboveground biomass losses (g) were assessed for the biomass lost during senescence.

$$\text{Root decomposition} = \left(1 - \frac{\text{Minimum root biomass}}{\text{Maximum root biomass}}\right) \times \text{Root NPP} \quad (2)$$

The carbon pool (g) for each species and for each season analyzed was calculated multiplying the results in percentage (%) from the CHNS/O analyzer by the biomass (Eq. (3)).

$$\text{Carbon pool} = [\text{Carbon}]_t \times \text{Biomass}_t \quad (3)$$

Carbon primary production was determined applying Eq. (4), using the same procedure as for the biomass NPP, but using the carbon pool values.

$$\text{CNPP} = \text{Maximum carbon pool} - \text{Minimum carbon pool} \quad (4)$$

For the carbon exports (g) calculations were applied Eqs. (5) and (6), where values were calculated as a percentage of CNPP (Eq. (4)) as described above, taking into account the percentage of mass losses due to decomposition of the belowground (carbon $\text{export}_{\text{dec}}$) or senescence of the aboveground organs (carbon $\text{export}_{\text{sen}}$).

$$\text{Carbon export}_{\text{dec}} = \text{root decomposition} \times \text{Root CNPP} \quad (5)$$

$$\text{Carbon export}_{\text{sen}} = \text{Aboveground senescence} \times \text{Aboveground CNPP} \quad (6)$$

The turnover rate was calculating using the CNPP divided by the carbon pool (Eq. (7)).

$$\text{Turnover rate} = \frac{\text{CNPP}}{\text{Carbon pool}} \quad (7)$$

The carbon in the sediment of each species was calculated with basis on the sedimentation rate of each species area and the carbon