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The effects of seasonal change of water level in an estuary on *Ludwigia octovalvis* (Jacq.) P. H. Raven (Onograceae) growth

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RESUMO

(Efeitos da variação sazonal do nível da água de um estuário sobre o crescimento de *Ludwigia octovalvis* (Jacq.) P. H. Raven (Onograceae)). O estuário do rio Massaguaçu é um estuário irregular, e seus ciclos da abertura de barra são irregulares e acontecem várias vezes por ano. A espécie *Ludwigia octovalvis* é perene em vários lugares do mundo, mas aparece de forma sazonal no estuário em questão. Nesse trabalho determinamos a relação entre o índice pluviométrico, o nível do estuário e a distribuição espacial e temporal dessa espécie. Em laboratório simulamos a variação do nível da água do estuário em aquários, de modo a entender como essa espécie responde ao alagamento. Em campo, determinamos a distribuição de *L. octovalvis* na estação mais chuvosa e menos chuvosa. A espécie é relativamente comum na estação mais chuvosa, mas ausente na menos chuvosa. Existem fortes evidencias de que isso acontece devido aos ciclos de abertura da barra do inverno, mas fundos e longos, que induz essa espécie ao estiolamento, e conseguintemente, a uma fragilidade mecânica. A sazonalidade de espécies em ambientes aquáticos sem uma estação biologicamente seca é incomum e pouco estudada.

Palavras-chave: ecologia de estuário, estiolamento, maré, estresse, submersão

ABSTRACT

(The effects of seasonal change of water level in an estuary on *Ludwigia octovalvis* (Jacq.) P. H. Raven (Onograceae) growth). The Massaguaçu River estuary is an irregular estuary with sandbar breaching cycles that are irregular and happen several times each year. The species *Ludwigia octovalvis* is a perennial weed in several places around the world, but it is seasonal in the Massaguaçu River. In this survey we determined the relationship between the rain, estuary water level variation, and the spatial and temporal distribution of this species. In a laboratory we simulated the water level variation in water tanks in order to understand how this species responds to flooding. In the field, we determined the distribution of *L. octovalvis* in the higher pluviose season and in the lower pluviose season. This species is relatively common in the higher pluviose season and completely absent in the lower one. There is strong evidence that this happens due to the longer and deeper sandbar breaching cycles during the dry season, which induce this species to etiolation, and, therefore, mechanical fragility. The seasonality of species in aquatic environments that do not have a dry biological season is unusual and little studied.

Key words: etiolation, estuary ecology, stress, submergence, tidal

Introduction

Plant distribution in flooded environments is mainly determined by flood frequency, intensity and duration (Kozlowski 1997; Sorell *et al.* 2002; Jackson & Colmer 2005). Soil waterlogging triggers a variety of physical, chemical and biological changes in the soil, which alter its capacity to support plant growth (Kozlowski 1997). Plant submergence causes a reduction of light, O_2 and CO_2 availability (Jackson & Ram 2003), resulting in a reduction of photosynthesis. Long-term flooding can have detrimental effects even on amphibious plants (Yánez-Espinosa *et al.* 2008), and re-exposure after prolonged submergence can produce toxic compounds through oxidation of the flooded soil (Biemelt *et al.* 1998). Submergence by moving water can also cause mechanical damage or remove the plant from the soil. To cope with water stress, many plants developed mechanisms of tolerance or avoidance to soil

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waterlogging and shoot submergence, such as aerenchyma formation in both the shoots and roots, lenticels, and timing of the life cycle according to flooding conditions (Blom & Voesenek 1996; Macek *et al.* 2006). Flooding also leads to changes in the growth process, and shoot etiolation is a common response of submerged plants (Blom & Voesenek 1996).

Estuarine environments, such as coastal lagoons and irregular estuaries, are generally characterized by abrupt variations in their environmental conditions (Suzuki *et al.* 1998; Miranda *et al.* 2002). The breaching of a sandbar that isolates these environments from the ocean causes a drastic reduction in water level, and exposes plants to two extreme water supply (Macek *et al.* 2006). This event plays a fundamental role in estuarine fauna and flora composition (Santos *et al.* 2006). However, sandbar breaching and its effects on the plant community are not completely understood, particularly when it comes to tropical estuaries.

The Massaguaçu River Estuary is a tropical irregular estuary where we noticed a seasonal occurrence of *Ludwigia octovalvis* (Jacq) (Onograceae). This species is found in the summer (higher pluviosity season - HPS) and absent in the winter (lower pluviosity season - LPS), but in our laboratory and in several other regions is perennial (Kissmann & Groth 1997; Pott & Pott 2000). The breaching cycles in the estuary appear to vary between seasons, being more frequent in the HPS. We expected that the seasonality of *L. octovalvis* arises from this difference. To test this hypothesis our objective in the work was fourfold: (1) better characterize the differences of the flooding conditions between HPS and LPS, (2) determine how *L. octovalvis* responds to the different flooding conditions, (3) understand what is the spatial and temporal distribution of this plant in the estuary, and (4) to answer how is the water level fluctuation related to the temporal and spatial distribution of *L. octovalvis*?

Materials and methods

Study species

Ludwigia ocotovalvis (Onagraceae) is a perennial shrubby plant that inhabits the borderline of water bodies, temporary lagoons, swamps and other flooded environments in the tropics (Kissmann & Groth 1997; Pott & Pott 2000). For over two years we cultivated this species at the Federal University of São Carlos garden, both in flooded and dry soils, were the species lived and flourished regardless of the conditions.

Study site

The Massaguaçu River Estuary (23º37'20"S, 45º21'25"W) is an irregular estuary. Its breaching cycles are unpredictable, and range from few days to over a month. The period that the sandbar remains open is also irregular, and the connection with the ocean can last from one tidal cycle to more than two weeks. Breaching happens several times per year, and to the best of our knowledge there are no studies on its periodicity. According to the Köeppen classification system, the clime is tropical rain forest (*af*), with no pronounced winter, rain in every month, and no biological dry season.

Estuary water level variation

Inside the estuary, we installed a fixed graduated scale, where zero represented the lowest level that the estuary water could reach (which occurs at low tide when the sandbar is open). From July 2007 to July 2008 we performed daily reading of the water level. We collected pluviometric data at the Ilhabela meteorological station (2 km from the study site), and classified the year into two main seasons according to the amount of rain.

Ludwigia octovalvis distribution in the estuary

In February 2008 we made a careful search in the Estuary macrophyte banks (Ribeiro *et al.* 2011), plotted with a GPS the location of all points were *L. octovalvis* occurred, and measured the relative height (to the graduated scale) of each point. In July 2008 we performed another search, and also checked the spots previously georeferenced.

Responses to water level variation in the laboratory

In a glass tank (80 cm deep, 80 cm long, 35 cm wide) we assembled four shelves, which along with the tank bottom, provided five levels 15 cm apart (respectively A, B, C, D and E from top to bottom). In each of these levels we randomly distributed five plastic pots with soil and humus (2/1) and one individual of *L. octovalvis* 7±0.86 cm high. We started the experiment (day 0) with a 15 cm water column, and we gradually filled the tank so that the water level would be 30 cm on day 5, 45 cm on day 10, 60 cm on day 15, 75 cm on day 20. Between day 20 and day 25 we kept the level at 75cm, and then reduced the level back to 15 cm, keeping the plants in the tank until day 30. Every five days we measured the size of each plant, and visually classified the relative size of the leaf (as small, medium and big). The goal of the experiment was to simulate the estuarine flooding conditions during one breach cycle.

Results

Estuary water level variation

There is no biological dry season at the study site (Walter 1986), but there is a period when pluviosity is higher (HPS - November to April) and a period when it is lower (LPS - from May to October). In the LPS, the water level rises slower, while the larger amount of rain in the HPS makes the estuary fill quicker. Rapid increases in the water level leads to a greater number of sandbar breachings, which is about four times more frequent in the HPS. As the time gaps between each breach are smaller, the ocean does not have enough time to make a higher sandbar, and the average water level at the breaching during the HPS is 28 cm lower when compared to the LPS.

Ludwigia octovalvis distribution in the estuary area

In the HPS we found 19 spots where *L. octovalvis* occurs. The average height of these spots is 88 cm (minimum 64 cm, maximum 105 cm) above the lowest level. In the LPS scan, we were unable to find *L. octovalvis* individuals in the 19 spots or anywhere else.

Response to the water level variation

There were three growing patterns in the *L. octovalvis* individuals: I) plants with both soil and shoots flooded during all of the experiment showed slow growth and relatively smaller leaves (plants from E shelf); II) plants flooded through most of the experiment, but with at least part of the shoots out of the water, grew quicker, and had small flooded leaves and big non-flooded leaves (plants from D and C shelves); and III) plants that underwent a brief flooding, grew slowly and had big leaves (plants from A and B shelves). When we removed the water, the quick-growing plants from shelves C and D were unable to support their own weight, and about 80% died. Plants from shelves A and B did not undergo an etiolation process, and still grew normally after removal of the water. Plants from shelf E etiolated in the beginning of the experiment, but soon became submerged, and their growth slowed down (Figure 1).

Discussion

In the study region, the estuary flooding cycles behave seasonally because there is a seasonal distribution of rain. This imposes on the organisms of the estuary a seasonality that is unusual, which is poorly studied, especially in aquatic environments in regions without a dry season. We suggest that the seasonality of *L. octovalvis* arises from this process.

Comparing the average height of the spots where *L. octovalvis* occurs and the daily levels of the estuary makes it possible to quantify the flooding differences between the two seasons (Table 1). In the HPS, the spots with *L. octovalvis* remained unflooded 43% of the time. This means that, when compared to the LPS, the plants have about four times more time to grow in normoxia. The HPS also presents a shorter continued submergence period, and the submerged periods are, on average, shorter. This reduces the etiolation, and allows the development of a mechanical-resistant tissue.

Shoot etiolation to reestablish contact with the air is a well-known response in aquatic plants (Blom & Voesenek 1996). While etiolating plants underinvest in sustentation tissues, and become susceptible to mechanical failures (Sorell *et al.* 2002). The resulting botanical dry matter weights from our experiment were far below the minimum amount required by any protocol of lignin and cellulose quantification. Therefore, although highly supported in the literature, the hypothesis that the lignin production and consequent mechanical resistance are inversely proportional to *L. octovalvis* etiolation still needs to be tested. In the laboratory experiment, when the sustentation provided by the water column was removed, most of etiolated individuals either died or suffered severe injuries. In the field, it is likely that longer periods of flooding in the dry season induced etiolation, and therefore mechanically fragile plants. This seems to be fatal to this species when a sandbar breaches and the water sustentation disappears. Thus, the flooding condition of the C and D shelves seems to be analogous to the flooding condition in the estuary during the LPS; both lead the plants to death.

On the other hand, plants from shelves A and B did not undergo shoot submersion, and the soil was only briefly flooded. This situation seems to be analogous to what was found for *L. octovalvis* individuals during the HPS; both allow for mechanical-resistant growth.

Except for the first three days of experiments, plants from shelf E were completely submerged. The submersion of the leaves reduces the light intensity and limits the access to CO^2, which drastically reduces photosynthesis (Jackson & Colmer 2005), leading to a very slow growth rate. The small size at the moment the water was removed allowed the individuals from the shelf E to support their own weight, though it is very unlikely that these plants would be competitive in the wild (Jackson & Colmer 2005). Therefore, it is probable that the flooding is responsible for the absence of this species in deeper spots (spots lower than 64 cm) anytime of the year. As this species is able to live in non-flooded conditions, the flooding cycles cannot explain its absence in the higher spots (spots higher than 105 cm). This seems to happen due to inter-specific competition (Sorell *et al.* 2002), particularly competition for light, because higher spots have taller macrophytes and some trees, which may block the light needed by this shade-intolerant species.

The effects of occasional variation in water level are relatively well documented (Fernández-Aláez *et al.* 1999; Riis & Hawes 2002; Peintinger *et al.* 2007), and as found in this work, there is an inverse relation between water level variation and diversity and biomass.

The artificial breaching of coastal lagoons and irregular estuary bars is common in Brazil (Suzuki *et al.* 2002; Santos *et al.* 2006; Branco *et al.* 2007). There is a relatively small number of studies regarding the impact of the breaching on estuarine communities, and they do not seem to be taken into account by the management organs. Moreover, the breaching is often performed by anonymous without any knowledge of the management organs (Santos & Esteves 2004). In the Massaguaçu River estuary, sandbar breaching used to be made by fishermen or surfers but is now mainly conducted by the Caraguatatuba City Hall. The aim is to

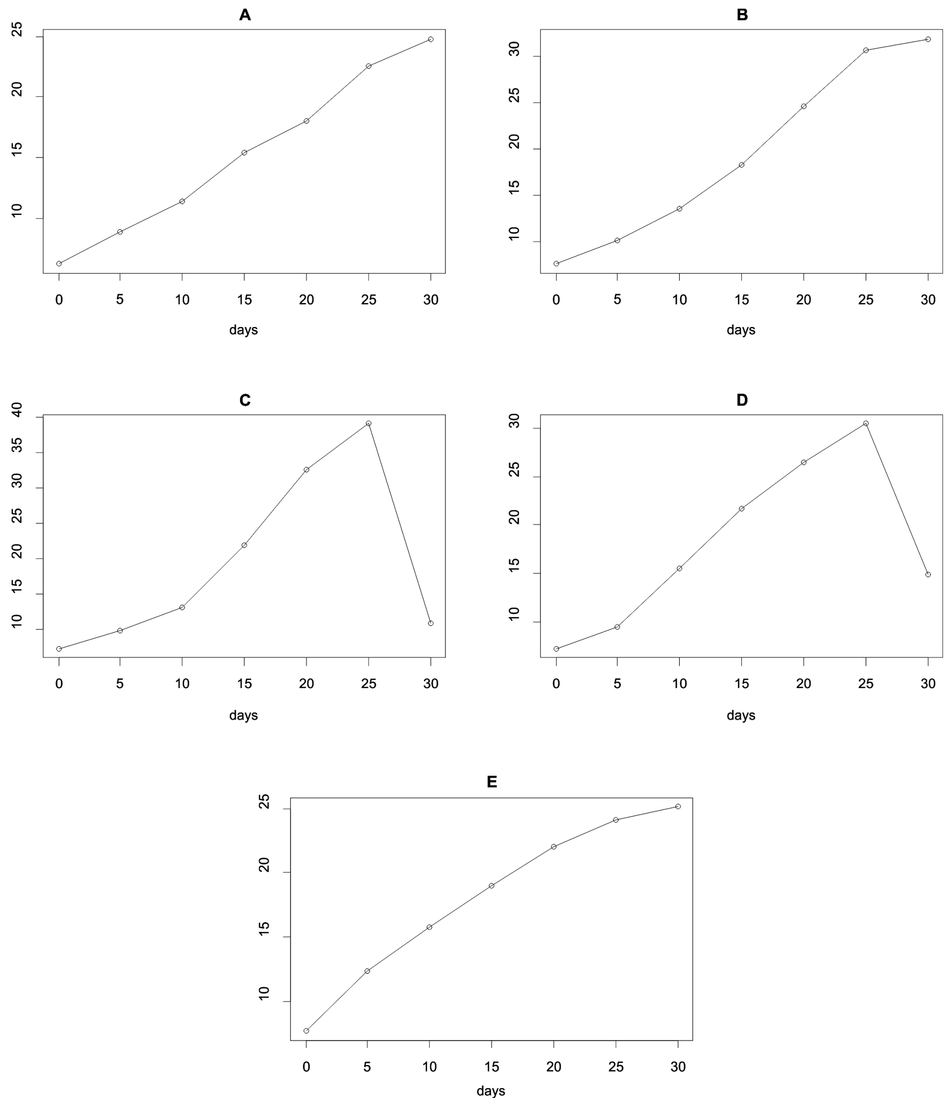

Figure 1. *Ludwigia octovalvis* (Onagraceae), average size of individuals in the different flooding conditions. Dead individuals were given the value 0 cm, and negative growth values arise from that. A, B, C, D and E are the shelves.

prevent flooding in adjacent neighborhoods. Unfortunately this is conducted without any impact studies, and the effects from this water level management, as described for *L. octovalvis*, will certainly impact other flora and fauna species.

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