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Temporal variations and spatial patterns in saline and waterlogged peat fields: II. Ion accumulation in transplanted salt marsh graminoids

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ABSTRACT

Our earlier study in New Brunswick, Canada showed that *Spartina pectinata* Link survived very well after transplantation in a barren cutover bog that was contaminated by seawater, in all combinations of salinity and moisture content tested. However, the survival of *Juncus balticus* Willd. was adversely affected in areas with very high moisture contents. The main aim of this current study was to understand the salinity tolerance of both species grown in salinized peat fields by determining how much salt ions, especially Na^+ and Cl^- were accumulated in the above-ground and below-ground parts of these plants. A second aim of this paper was to determine the accumulation of potentially toxic metals Fe and Mn. *S. pectinata* had significantly greater concentrations of Na^+ and Cl^- in the above- than in the below-ground parts. In contrast, *J. balticus* had Na^+ concentration significantly greater in the below- than in the above-ground parts while for Cl^-, there was no significant difference. These contrasting patterns of Na^+ accumulation demonstrated typical characteristics of a halophyte (*S. pectinata*) and a glycophyte tolerant to salinity (*J. balticus*) described in literature. Fe and Mn concentrations in both species were low but only Fe approached deficiency levels in plants.

1. Introduction

Establishing a vegetation cover within a short period, on an abandoned cutover bog contaminated with seawater, requires transplantation of suitable wetland plants. Montemayor et al. (2008) found *Spartina pectinata* Link and to some extent *Juncus balticus* Willd. to have good survival rate under high salinity, low pH, and slightly anaerobic conditions of the cutover bog. The accumulation of salt ions in different parts of salt-tolerant wetland plants under these conditions is not known. How salt ions are partitioned between the above-ground and below-ground parts can provide indications on the tolerance of plant species to salinity. This information gives some understanding of plant species survival and growth under saline conditions. Consequently, such knowledge provides guidance in the selection of appropriate species to revegetate a site characterized with definite or predictable spatial patterns and temporal variations in salinity.

Vegetation that can complete their life cycles at salinities $\geq$300 mmol L^{-1} NaCl are called halophytes (Flowers et al., 1977). Some glycophytes (plants that establish in non-saline environments) can tolerate salinities lower than those tolerated by halophytes (Moghaieb et al., 2004; Poljakoff-Mayber and Lerner, 1999; Flowers et al., 1977). Flowers et al. (1977) further distinguished halophytes from glycophytes by their ability to accumulate ions to high concentrations, particularly in the leaf cells. Halophytes growing under saline conditions accumulate high concentrations of inorganic ions in their tissues. These inorganic ions play a major role in osmotic adjustment or osmotic regulation that maintains the plant's ability to uptake water and to sustain turgor (Moghaieb et al., 2004; Bradley and Morris, 1991; Flowers, 1985; Greenway and Munns, 1980).

Excessive accumulation of Na^+ and Cl^- inhibits plant growth and can cause damage to many plants (Tester and Davenport, 2003; White and Broadley, 2001) but halophytes and salt-tolerant glycophytes manage salt ions by various means to avoid injury, especially to the shoots. Halophytes respond positively to NaCl and accumulate salt concentrations equaling or exceeding those of sea water in their leaves without detriment (Flowers et al., 1977). Since the shoots are susceptible to salt damage Na^+ can be accumulated in, or be excluded from, the roots; a typical response of salt-tolerant glycophytes (Tester and Davenport, 2003; Poljakoff-Mayber and Lerner, 1999). Typical of halophytes is the regulation of Na^+ accumulation in the shoots by excretion from the leaves through salt-secreting glands (Marcum, 1999; Marcum and Murdoch, 1992; Bradley and Morris, 1991; Rozema et al., 1981; Atkinson et al., 1967), compartmentalization in the vacuole (Yeo, 1981), and succulence (Tester and Davenport, 2003; Albert, 1975). Salt glands

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remove both salt and water from the leaves and the loss of water restricts these plants to habitats with abundant water such as salt marshes (Tester and Davenport, 2003). In saline environments, plants may take up Na^+ at the cost of K^+ and Ca^{2+}, both essential nutrients (Alam, 1999; Cramer et al., 1987); K^+ activates about 50 enzymes (Bhandal and Malik, 1988) and Ca^{2+} is responsible for cell membrane integrity that prevents passive accumulation of Na^+ and Cl^- (Alam, 1999; Lauchli, 1990; Cramer et al., 1987; Lynch et al., 1987). Thus, the maintenance of the uptake of both K^+ and Ca^{2+} is key to plant survival in saline environments.

In saturated and reduced conditions common to wetlands, essential micro-nutrients like Fe and Mn can be readily bioavailable. Excessive accumulation of Fe or Mn can result in toxicity especially in plants lacking an avoidance mechanism. Iron plaque formation consequent to radial oxygen loss (ROL) from the roots is an avoidance mechanism (Pezeshki, 2001; Neue et al., 1998; Ernst, 1990; Lanbroek, 1990; Jones, 1971).

Therefore, the objectives of this paper were to determine the accumulation of salt ions as well as of potentially toxic metals Fe and Mn in transplanted *S. pectinata* and *J. balticus*. These plant species grew well in certain locations on the cambered peat fields characterized by certain ranges in salinity, pH, and moisture contents found in our earlier study, *i.e.*, Montemayor et al. (2008). Specifically, the objectives were to determine (1) the concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, $SO_4{}^{2-}$, Fe and Mn in the above-ground and below-ground tissues and, (2) the concentrations of these ions in the seawater-contaminated peat fields, early in the season when the underlying frozen ground layer is still present, and later when it is completely thawed.

2. Study area and methods

This current study is a continuation of our previous study (Montemayor et al., 2008). The study site is a cutover bog located on Pokesudie Island, in the Acadian Peninsula of New Brunswick, Canada (47°48′N, 64°46′W). It was contaminated by seawater during a storm surge in January 2000 and thereafter peat extraction operations were closed down. Mechanized peat extraction operations created long rectangular fields (300–400 m long, 30 m wide) with cambered surfaces along the longitudinal centre line, bordered by drainage ditches. Five years after the closing of operations, the fields were mostly barren and the ditches were partially filled with eroded peat. The cambered surfaces in the middle of fields had a slope of about 2% towards the side ditches. This slope created a moisture gradient that was divided into three zones and named as Up-areas, Mid-areas, and Low-areas. These zones correspond to relative dry, moist and wet areas, respectively.

The previous study had a factorial design experiment and was consequently maintained in this current study. The first factor in this experimental design was Location (Up-areas, Mid-areas, and Low-areas). The second factor was Depth of the peat from the surface (0–5, 5–10, 10–15, and 15–20 cm). In order to have 10 replicates, 10 fields were randomly selected from a total of 17 separate and independent fields at the site. Thus, each replicate was located on an independent long rectangular field. Details of the study site and climatic data can be found in Montemayor et al. (2008).

Collection of plants and transplanting were carried out on 25 July–8 August 2004. However, *S. pectinata* was re-planted on 4–9 June 2005 in the Up-areas and Mid-areas, and 19–21 June 2005 in the Low-areas. It was not suitable to transplant *S. pectinata* at the end of the growing season. *S. pectinata* plants were obtained from the uppermost edge of its zone in a salt marsh and *J. balticus* plants from a non-saline marsh. Both marshes were within 2 km distance of the study site. *S. pectinata* was planted as bare rhizome J-section (NRCS, 2000) individual plants at three individuals per planting spot. *J. balticus* was planted as sods of volume 2145 cm^3 at one sod per planting spot. For each plant species, there was a pair of parallel planted rows per Location spaced 30 cm apart and each row had 10 planted spots spaced 30 cm apart. Hence, there were 20 planted spots per Location for each species. Each planted row in each Location was 2 m away from the corresponding row in the adjacent Location. In each Location, a pair of parallel planted rows was separated from the adjacent pair of parallel planted rows by a 1 m undisturbed area reserved for peat sampling. More details on the planting layout can be found in Montemayor et al. (2008).

Our earlier study (Montemayor et al., 2008) found two distinct periods that differentiated peat characteristics. These were the pre-thaw and post-thaw period of the underlying frozen peat layer. Changes in peat characteristics upon the thaw of the frozen peat layer were: lowered water table depths that significantly increased redox potentials ($P = 0.05$), decreased moisture content that increased dry bulk density ($R^2 = 0.9$), and increased electrical conductivity that decreased pH ($R^2 = 0.7$). Moisture content increased from Up-areas to Down-areas. A notable effect of Depth was found in electrical conductivity which increased with Depth at pre-thaw period but the trend reversed at post-thaw period. A highly significant increase in electrical conductivity was found at the 0–5 cm Depth. Plant survival at the start of the following growing season (June 2006) of *S. pectinata* was high 89, 91.6, and 84.2% for Up-areas, Mid-areas, and Low-areas, respectively. *J. balticus* survived relatively well at the Up-areas (68.5%) and Mid-areas (58.5%) but survival was poor at Low-areas (27.5%).

2.1. Experimental design

Our previous study (Montemayor et al., 2008) reported the physical conditions of the peat and the survival of the two transplanted plant species. This current study reports the chemical characteristics of the peat and the ion accumulation in the two transplanted plant species in the same experiment. Thus, this current study, being a continuation of the previous study (Montemayor et al., 2008) maintained the original factorial design experiment consisting of two factors. This current study tested the effect of Location (Up-areas, Mid-areas, and Low-areas) as the first factor and Depth (0–5, 5–10, 10–15, and 15–20 cm) as the second factor, on ion concentration in peat water during two periods (pre-thaw and post-thaw of the underlying frozen peat layer).

In order to determine the effect of Location and Depth of peat on ion concentration in peat water, at pre-thaw and post-thaw periods, peat core samples were collected from each Location at Depths 0–5, 5–10, 10–15, and 15–20 cm from five (out of a total of 10 from the previous study) randomly selected replicates on 26 June, 2005 (pre-thaw period) and 29 July, 2005 (post-thaw period). The total number of core samples was 3 Locations × 4 Depths × 5 replicates × 2 periods = 120. Peat core samples were taken from the 1-m wide undisturbed spaces between pairs of parallel planted rows within each Location as described in Montemayor et al. (2008).

In order to determine the effect of Locations (Up-areas, Mid-areas, and Low-areas) on ion concentrations in plant tissues, plants from one planted spot (3 individual plants for *S. pectinata* and a whole sod for *J. balticus*) were collected from each of the three Locations within each of the 10 replicates. A planted spot was selected at random. Hence, for *S. pectinata*, there were 3 Locations × 10 replicates = 30 planted spots, each spot consisting of three individual plants. However, for *J. balticus*, the Low-areas, and two replicates each for Up- and Mid-areas were not sampled because of their very low survival rate. Thus for *J. balticus*, there were 2 Location × 8 replicates = 16 planted spots or sods. Plant samples were collected on 11 August 2005, which was one full growing season for *J. balticus* and 2 months of incubation for *S. pectinata*.