Aquatic Botany 121 (2015) 52–56

Contents lists available at ScienceDirect

Aquatic Botany

journal homepage: www.elsevier.com/locate/aquabot

Short communication

Inundation and precipitation effects on growth and flowering of the high marsh species *Juncus gerardii*

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ARTICLE INFO

Article history:
Received 18 April 2014
Received in revised form 22 October 2014
Accepted 27 October 2014
Available online 11 November 2014

Keywords:
Vegetation change
Dieback
Storms
Sea level rise

ABSTRACT

Accelerated sea level rise threatens coastal wetland plant communities where coastal development restricts transgression, and inundation increases and declining sediment supplies limit the capacity of coastal wetlands to build in elevation. *Juncus gerardii* Loisel., black needle rush, is a high latitude cosmopolitan plant species and, within salt marshes of the U.S. mid-Atlantic and New England coasts, it occupies a narrow belt along the marsh-upland border. Examination of historic aerial photography, vegetation resurveys, and peat composition analysis for U.S. Northeastern marshes have shown vegetation change patterns indicative of increased inundation, including decline of *J. gerardii*. To interpret loss patterns for *J. gerardii* in southern New England, we conducted a factorial experiment to establish its sensitivity to inundation and drought. A strong relationship was found between inundation and growth for *J. gerardii*, which together with marsh elevation and water level data, suggests that growth is reduced by current flooding patterns. Examination of *J. gerardii* flowering also indicates that floret and inflorescence density vary with inundation, suggesting that negative impacts of sea level rise on *Juncus* may extend to seed production. Late spring and summer drought impacted neither *J. gerardii* growth nor its flowering, implying that *J. gerardii* is insensitive to below-average precipitation or drought during this time of year. We conclude that current inundation patterns are incompatible with robust growth for *J. gerardii*, and recommend conservation actions be focused on the marsh-upland border to facilitate the upslope migration of *J. gerardii* and other transitional high marsh plant species.

1. Introduction

Coastal wetland plant communities are vulnerable to accelerated sea level rise where coastal development limits transgression, and increases in flooding and the duration of inundation exceed the capacity of salt marshes to build in elevation. In southern New England (USA), salt marshes are exceptionally vulnerable due a developed coastline, low sediment supply (Roman et al., 2000; Weston, 2014), and high rates of sea level rise (3-4 times the global average; Sallenger et al., 2012), which collectively limit adaptive responses (Watson et al., 2014). Sediment accumulation simulation models predict a state change from salt marsh to tidal flat for current sea level rise rates for the region, primarily due to low suspended sediment concentrations (e.g., 2 mg L^{-1}; Morton, 1972), which are at the extreme lower boundary for stable salt marsh (Kirwan et al., 2010). Studies of salt marsh vegetation change have revealed species composition shifts consistent with a response to increased inundation for the U.S. northeastern states of Connecticut, Rhode Island, New York, and Massachusetts over the twentieth century as historic rates of sea level rise (1 mm y^{-1}; Donnelly et al., 2004) have increased, and accretion deficits have developed (Warren and Niering, 1993).

Historic southern New England salt marsh landscape patterns were comprised of a mosaic of vegetation communities (Miller & Egler, 1950; Redfield, 1972; Nixon, 1982) where environmental stresses (i.e., soil anoxia and flooding) were thought to control the lower elevation boundaries of individual species, with competitive interactions a more common control at higher elevations (Bertness, 1991). The marsh-upland border was composed of *Phragmites australis* (Cav.) Trin. Ex Steud at the irregularly flooded upland edge, while *Iva fructescens* L. was associated with more regular flooding. A belt of *Juncus gerardii* Loisel., most noticeable during spring, was

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http://dx.doi.org/10.1016/j.aquabot.2014.10.012
0304-3770/Published by Elsevier B.V.

typically seaward of *Iva.* On the high marsh, *Spartina patens* (Aiton) Muhl. was typically the most expansive species, and was found in mixed stands with *Distichlis spicata* (L.) Greene. *Salicornia depressa* Standley, an annual succulent and short-term colonizer, occupied disturbed locations. The tall ecotype of *Spartina alterniflora* (Loisel) was found adjacent to the shoreline and tidal channels. Botanical nomenclature follows Haines (2001).

A combination of vegetation resurveys and peat analyses for U.S. Northeastern marshes have shown patterns suggestive of increased inundation. A decline in the upper marsh *J. gerardii* belt and replacement of the high marsh species *S. patens* by *S. alterniflora* has been noted in the Wequetequock-Pawcatuck marshes of Connecticut (Niering and Warren, 1980; Warren and Niering, 1993), and landward movement of *S. alterniflora* through the twentieth century is concurrent with declines in high marsh vegetation in Rhode Island (Donnelly and Bertness, 2001). Likewise, historic reports of vegetation composition for sites on Long Island suggest a shift in dominance from the high marsh species *S. patens* and *J. gerardii* to *S. alterniflora* between 1938 and 1972 (Nixon, 1982). Analysis of historic air photos from Cape Cod also reveals loss of high marsh vegetation since the 1980s (Smith, 2009).

In addition to increased inundation associated with accelerated sea level rise, climate model simulations corresponding to Intergovernmental Panel on Climate Change emissions scenarios suggest that by the end of this century, one to three month droughts could occur as frequently as once per summer in the U.S. Northeast (Wehner, 2004; Frumhoff et al., 2007). As drought conditions have been associated with coastal marsh die-off events (McKee et al., 2004; Silliman et al., 2005), a process that has affected *Juncus gerardii* (Alber et al., 2008), this shift in precipitation patterns may accelerate loss of high marsh vegetation. In particular, *Juncus gerardii* is thought be sensitive to drought, as previous studies have shown growth reductions in *Juncus gerardii* in response to increased salinity or low precipitation conditions (Rozema and Blom, 1977; de Leeuw et al., 1990).

This study documents the interactive effects of inundation and precipitation on growth and flowering of the high marsh species *J. gerardii*, or black needle rush. Plants were field collected in early spring and propagated through the growing season in a greenhouse factorial experiment, using flow through seawater to simulate tidal inundation. Based on field studies that have suggested a loss of *J. gerardii* as a consequence of increased inundation in combination with accretion deficits (e.g. Warren and Niering, 1993), we hypothesized that growth would be most vigorous under treatments where tidal inundation occurred less frequently than under typical field conditions. Because previous studies have also identified *J. gerardii* growth reductions with increased salinity or reduced precipitation (Rozema and Blom, 1977; de Leeuw et al., 1990), we further hypothesized that reductions in precipitation would similarly result in reduced growth. This study aimed to determine the sensitivity of *Juncus gerardii* to current and future climate change impacts, and whether specific environmental sensitivities can explain the ongoing loss of *Juncus gerardii* from New England coastal wetlands.

2. Materials and methods

A factorial greenhouse experiment was conducted to test our hypotheses that flooding and drought impact *J. gerardii* growth. Sods were propagated for 125 days (7 May to 9 September 2013) during the summer growing season in three 700 L tanks with simulated semi-diurnal tides (Fig. 1). The greenhouse experiment used a 5 × 3 factorial design, replicated three times, for a total of 45 experimental units. Five inundation regimes were created by housing pots on shelves within tanks (Fig. 1). Seawater used for the experiment was drawn from lower Narragansett Bay (Rhode Island, USA), was low in nutrient concentration (∼6 μM dissolved inorganic nitrogen; <2 μM phosphate), and of moderate salinity (23–30 psu). Tides simulated were semi-diurnal: tanks remained at tide levels (high/low) for two hours, with four hour fill and drain cycles. No supplemental lighting was used; day length at 41°N ranged from about 13 h at the beginning and end of the experiment period to 16 h on the summer solstice. Temperature was not controlled but automated greenhouse window vents allowed equilibration with outside temperatures. Local air temperature during the coolest and warmest months was 10–20 °C in May 2013; and 20–30 °C in July 2013; local water temperature was 10–15 °C in May 2013; and 21–24 °C in July 2013.

Sods containing a *Juncus gerardii* monoculture were collected 7 May 2013 from Colt State Park, Bristol, RI (41.68°N, 71.30°W). Sods were separated using an electric knife into 5 × 5 × 10 cm plugs for planting; shoot density ranged from 17 to 59, with a mean of 35, and standard deviation of 10. Plugs were planted in circular pots 10 cm in width, and 40 cm in length, to hold constant volume available for root growth, and fitted with a basal collar and nylon screen to allow water exchange through the soil column. To reduce environmental impacts, and to provide a more homogenous soil matrix, sods were planted in a mixture of native marsh soils collected in small batches from four salt marsh ponds (Mary Donovan Marsh, Little Compton, RI; 41.55°N, 71.21°W; Galilee Bird Sanctuary, Narragansett, RI; 41.38°N, 71.50°W; Old Mill Cove, Warwick, RI; 41.71°N, 71.37°W; Round Marsh, Jamestown, RI; 41.51°N, 71.38°W) mixed using a cement mixer. Soils had a mean organic content of 12.2%, and were 15.7% sand, 75.4% silt, and 8.9% clay. Pots were assigned randomly to one of 15 inundation and precipitation treatment combinations, and position was distributed between tanks so that each tank contained a mixture of treatments (Fig. 1).

For each set of nine pots grown at each elevation, three each received the following precipitation treatments: no precipitation ('drought'), ambient precipitation (50 cc rainwater, 3 times weekly), or an intermediate precipitation treatment (25 cc rainwater, 3 times weekly). The volume of rainwater used for the ambient treatment was calculated from mean rainfall figures for Narragansett, RI multiplied by pot area. Pots were watered with rainwater from roof collectors.

To relate laboratory treatments to field conditions, water levels were monitored for a five month period at five Narragansett Bay salt marshes using pressure transducers (one Aquatroll 200 and four Solinst Leveloggers, compensated for atmospheric pressure using a Solinst Barologger). Site-specific values of mean high water (MHW) during the time of deployment were calculated and marsh elevation profiles were expressed relative to MHW using a combination of static GPS surveys (differentially corrected using the public Continuously Operating Reference Station network) and differential surveys using a rotary laser and stadia rod.

Variables associated with growth and flowering for *J. gerardii* were monitored. Growth response was measured as shoot height and density monthly (7 May, 11 June, 11 July, and 14 Aug) and as dry aboveground biomass at the conclusion of the experiment (9 Sept 2013). The number of shoots supporting inflorescence, and the number of florets per inflorescence were recorded once, on 11 June 2013, just after a synchronous pulsed flowering event occurred. Aboveground biomass was harvested, rinsed of salts and adherent materials, dried, weighed, and converted to biomass per square meter through multiplication by a constant.

Variables from the factorial experiment (dry aboveground end of season biomass, shoot density at peak biomass [mid August], mean shoot height at peak biomass, percent flowering, floret density) were analyzed using multivariate analysis of covariance (MANCOVA) using SPSS Statistics (version 22, IBM, Armonk, NY, USA).