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The role of groundwater flow in controlling the spatial distribution of soil salinity and rooted macrophytes in a southeastern salt marsh, USA

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Abstract

Groundwater flow is an important factor in governing botanical zonation in the salt marsh at North Inlet, SC. Areas of the marsh adjacent to upland forest are characterized by upward flow of fresh groundwater. This inhibits the infiltration and evapoconcentration of saline tidal water and the development of a habitat for hypersaline-tolerant fugitive species such as *Salicornia europaea*. Areas of high marsh that are not adjacent to extensive upland forest are characterized by downward gradients in hydraulic head. This allows the infiltration and evapoconcentration of tidal water and the development of hypersaline conditions that are suitable for salt-tolerant fugitives.

1. Introduction

Salt marshes are among the most dynamic ecosystems on Earth, partly as a result of their interaction with adjacent uplands and the coastal ocean. These interactions often play key roles in controlling some of the ecological phenomena observed in marshes. Several investigations have examined the relationship between botanical distribution and hypersalinization in marshes (Bertness and Shumway, 1993; Bertness et al., 1992a; Pennings and Callaway, 1992; Pethick, 1974). Recent related studies have also examined the effects of plant shading on salt accumulation in salt marshes (Bertness and Callaway, 1994; Shumway and Bertness, 1994). Little attention, however, has been given to the impact of groundwater flow on salt marsh processes, particularly with regard to plant distribution and soil salinity patterns. Bertness et al. (1992b) suggested that surface water runoff from adjacent uplands is an important control on hypersaline soil formation.

We demonstrate that groundwater flow is an important factor in determining and maintaining plant distribution, particularly as regards *Salicornia europaea* in the high marsh. We use groundwater flow observations in conjunction with published concepts for plant distribution and the dynamics of bare patches to establish linkages among botanical zonation, salt distribution, and groundwater flow patterns in a salt marsh. The intent of this discussion is to present an underlying mechanism that enables salt-tolerant fugitives such as *Salicornia europaea* and *Salicornia virginica* to persist in a disturbed environment. Local groundwater flow patterns through these areas influence the interspecific interactions with competing adjacent dominant turf species, thereby affecting the continuance of the fugitive species in disturbed patches.

Recent studies recognize the role of plant shading in lowering salinities, and that vegetative cover and shading have a substantial impact on evaporation rates (Bertness, 1988). Passive shading by indigenous flora is thought to be the main control on substrate salinity. The absence of plant shading, and not the absence of active plant growth or transpiration that could reduce substrate salinity, is the mechanism responsible for elevated salinities. This creates a less tolerable physical setting for some marsh flora, thereby affecting plant distribution. The most distinct examples of the effects of limited plant shading occur in bare patches that are observed mostly in high marsh sediments.

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Bare patches are most often created in salt marshes through disturbance events, such as the delivery of large amounts of plant debris, or tidal wrack, by a storm event (Bertness, 1992; Hartman et al., 1983; Reidenbaugh and Banta, 1980). In general, the underlying vegetation is destroyed by long periods of cover by tidal wrack. The wrack is eventually displaced by a later storm event or decays naturally, leaving a bare patch in its place. Following the removal of wrack, the bare patch is exposed to increased solar radiation and evaporation. Tidal flooding leaves behind pooled and infiltrated salt water in the surface sediments. As this tidal water evaporates, chloride concentrations and salinities rise (Bertness et al., 1992a). Experiments have been conducted to mimic the effects of plant shading (Bertness and Hacker, 1994) which confirm that shading is a key factor in inhibiting hypersalinization. The development of hypersaline porewater in the patches prevents most species of marsh flora from living there as few species are able to withstand the harsh conditions. However, some fugitive species of marsh plants are salt tolerant, and readily invade and exploit bare patches. The two dominant fugitive species in this category are *Distichlis spicata* and *Salicornia europaea*. Both of these species are competitively inferior to indigenous perennial marsh turf dominants (typically: *Spartina alterniflora*, *Spartina patens*, and*Juncus roemerianus*). Thus, fugitive plants are unable to successfully create a stable niche under normal environmental conditions. However, as the only hypersaline-tolerant species of the indigenous marsh flora, they readily colonize hypersaline patches of surface soils in the marsh (Bertness, 1992).

2. Methods

2.1. The study area

This investigation was conducted in the forest and marshes of the Hobcaw Barony, near North Inlet, South Carolina (Figure 1). The Barony encompasses an area of roughly 60 square kilometers of undeveloped land, maintained as a wildlife refuge and scientific research resource. The North Inlet tidal basin is one of 21 sites in the National Estuarine Research Reserve System (NERRS). The tidal basin is composed of approximately 32 square kilometers of meandering tidal creeks and salt marshes, and is subject to semidiurnal tides with an average range of 1.5 meters and a spring tide range of 2.0 meters (Kjerfve et al., 1978).

The western half of the Barony consists of Pleistocene beach ridge terrain while the eastern half is comprised of Holocene salt marshes and barrier islands. The relict beach ridge terrain is a regressive sequence that records an episode of falling sea level during the last glacial epoch (D. Colquhoun, University of South Carolina, personal communication). Narrow beach ridge peninsulas, such as Goat Island, are separated by finger marshes such as in the Bly Creek and Crabhaul Creek basins (Figure 1). The substrate of these finger basins is generally sandy forest spodosols, not marsh mud as is found east of Goat Island. The characteristic spodic horizon of the former forest soils usually may be found at depths less than one meter below the surface of these finger marshes (Gardner et al. , 1992). Thus, the finger marshes are young (or immature) marshes that have formed as the result of the intrusion of sea water along swales during recent sea level rise. As sea level rises, the finger marshes penetrate further up the swales, whereas forested peninsulas shrink and disappear. A series of transects were installed normal to the axis of the Crabhaul Creek finger marsh. The sequence of transects represent stages in the evolution of the forest-marsh landscape with the younger stages near the tip of the finger (Transect B, Figure 1) and more advanced stages further seaward (Transects C and D). A detailed discussion of the basin's stratigraphy is geomorphology is provided in Thibodeau (1997).

2.2. Transect installation

On the basis of the scenario for landscape evolution described above, three transects were created in the Crabhaul Creek Basin along the lines shown in Figure 1. The three transects extend from the mainland forest on the west, across the marsh and into the peninsula forest on the opposite side of the basin. All of these transects run from ridge to ridge across the intervening swale over a total distance of 200 to 250 meters. Piezometer bundles were installed through a combination of jetting and auguring at sites along each transect. Sites within 30 meters of the forest-marsh boundary were located at 6 meter intervals, while those further out in the marsh or into the forest were spaced at wider intervals from 15 to 30 meters (Figure 2). Denser spacing near the forest-marsh boundary is warranted by the steep salinity gradients, dramatic botanical changes, and complex hydrologic dynamics of this zone. At each site, 32 mm inner diameter PVC pipe was used for the piezometers and installed at depths of 0.6, 1.2, 2.4, 3.6, and 4.8 meters below ground level (Keenan,