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Salinity limits of vegetation in Cienega de Santa Clara, an oligotrophic marsh in the delta of the Colorado River, Mexico: Implications for an increase in salinity

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ABSTRACT

Greenhouse and field trials were conducted to determine the salinity limits for main vegetation types in Cienega de Santa Clara, an oligohaline marsh in the delta of the Colorado River in Mexico. The Cienega is the largest brackish marsh in the Sonoran Desert and supports numerous bird, mammal and invertebrate species, including threatened or endangered marsh birds. It is supported by brackish agricultural return flows from the USA and Mexico, and operation of the Yuma Desalting Plant (YDP) could reduce the volume and increase the salinity of inflows. Current inflows average 4 $m^3 s^{-1}$ at 2.8 $g L^{-1}$ Total Dissolved Solids (TDS), and the dominant vegetation type is *Typha domingensis*, with subdominant stands of *Schoenoplectus americanus* and other emergent species distributed amidst the *Typha* stands. A greenhouse experiment showed that under flooded-soil conditions, *T. domingensis* had a linear reduction in relative growth rate based on biomass production ($RGR_{Biomass}$) with salinity, with zero $RGR_{Biomass}$ at 8.3 $g L^{-1}$ TDS and a 50% reduction at 4.0 $g L^{-1}$ TDS. *S. americanus* was about twice as salt-tolerant, with zero $RGR_{Biomass}$ at 12.5 $g L^{-1}$ TDS and 50% $RGR_{Biomass}$ at 9 $g L^{-1}$ TDS. The results are consistent with other studies that show a mean reduction in $RGR_{Biomass}$ of 13.3% per g L^{-1} TDS for *Typha* spp. and 4.3% per g L^{-1} TDS for *Schoenoplectus* spp. Field surveys showed that *T. domingensis* stands were restricted to salinities of 6.5 $g L^{-1}$ TDS or less, and that annual biomass production was reduced by 85% in a stand at 5.9 $g L^{-1}$ TDS compared to a stand at 3.0 $g L^{-1}$ TDS. Normalized Difference Vegetation Index (NDVI) values of *T. domingensis* stands from satellite imagery showed a linear decline with increasing salinity in the marsh. It was concluded that 6 $g L^{-1}$ TDS is the approximate upper limit for vigorous stands of *T. domingensis*, and that replacement by *S. americanus* is a possibility if salinities increase. Implications for marsh vegetation structure and habitat value are discussed under different possible operating scenarios for the YDP.

1. Introduction

1.1. Wetland plants in oligohaline marshes

Plant communities in brackish wetlands are often structured at least in part in response to salinity, due to wide differences in salinity tolerance among wetland species and the existence of salinity gradients within the marshes (Odum, 1988). Oligohaline wetlands with salinity levels of 0.5–5 $g L^{-1}$ Total Dissolved Solids (TDS) (Cowardin et al., 1979) are colonized by a mosaic of species, including fresh-water species that are growing under some degree of salinity stress (e.g. *Typha* spp, *Sagittaria* spp., *Eleocharis* spp., *Cladium jamaicense*), miohalophytes with intermediate levels of salt tolerance (e.g. *Juncus* spp., *Scirpus* spp., *Schoenoplectus americanus*, *Phragmites australis*) and euhalophytic species adapted to seawater salinities (e.g., *Spartina patens*, *Spartina alterniflora*, *Distichlis spicata*) (Brewer and Grace, 1990; Zengel et al., 1995; Gourh and Grace, 1998; Howard and Mendelssohn, 1999a,b; Caitlin et al., 2004; Crain et al., 2008; Sharpe and Baldwin, 2009). Changes in salinity regimes can alter marsh productivity and structure, and is a focus of interest due to local impacts of land use on salinity as well as potential effects on salinity increases in coastal marshes due to sea-level rise from climate change (Howard and Mendelssohn, 1999a,b; Spalding and Hester, 2007).

As a generality, Crain et al. (2008) concluded that plant distributions in brackish wetlands are set at the high end of the salinity spectrum by salt tolerance and at the low end by competitive

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ability. This was also noted by Engels and Jensen (2010) in a reciprocal transplant experiment in which brackish species were transplanted to a salt marsh with or without competition, and salt marsh species were similarly transplanted into a brackish marsh. Brackish species grew poorly with or without competition in the salt marsh, while salt marsh species grew well in the brackish marsh in the absence of competition but were out-competed when brackish species were present. However, other factors such as water depth also determine the zonation of vegetation within a marsh (Grace, 1989; Odum, 1988; Spalding and Hester, 2007; Bonin and Zedler, 2008; Crain et al., 2008). As evapotranspiration (ET) proceeds, salinity in the water body can increase, creating a negative feedback on growth and presenting an opportunity for species competition based on salt tolerance (Jiang et al., 2012). However, the salt tolerance of many wetland species has not been fully determined (Crain et al., 2004). Furthermore, intra-specific variation in stress tolerance can influence plant population structure in coastal wetlands, complicating attempts to predict species-level responses to changes in salinity (Howard and Rafferty, 2006).

1.2. Goals and objectives of the study

The goal of this study was to understand the salinity constraints on vegetation in Cienega de Santa Clara, an anthropogenic marsh in the delta of the Colorado River in Mexico (Glenn et al., 1992; Zengel et al., 1995). The Cienega provides important regional wildlife habitat, especially for water birds (Hinojosa-Huerta et al., 2001a,b); it is in the core zone of the Biosphere Reserve of the Upper Gulf of California and the Delta of the Colorado River and is a Ramsar site. It could undergo a decrease in inflow volumes and increased salinity due to operation of the Yuma Desalting Plant (YDP) in the USA (Gabriel and Kelli, 2010). We sought to understand the possible consequences of a salinity increase on the species composition of the marsh.

The Cienega is supported by agricultural return flows from the USA, sent for disposal in Mexico via the Main Outlet Drain Extension (MODE) canal. Since 1977 the MODE canal has delivered a mean flow of 4.0 $m^3 s^{-1}$ with a salinity of 2.8 g L^{-1} TDS, creating a 5600 ha emergent marsh (Fig. 1) (Mexicano et al., 2012). *Typha domingensis* is the dominant macrophyte in the Ciénega de Santa Clara, making up over 90% of the vegetation cover. However, *Schoeneoplectus americanus* (formerly *Scirpus americanus*) and *S. maritimus* are also widespread throughout the marsh. *P. australis* occurs in patches in shallow areas of the marsh and 20 other wetland species growing on the periphery of the marsh (Zengel et al., 1995).

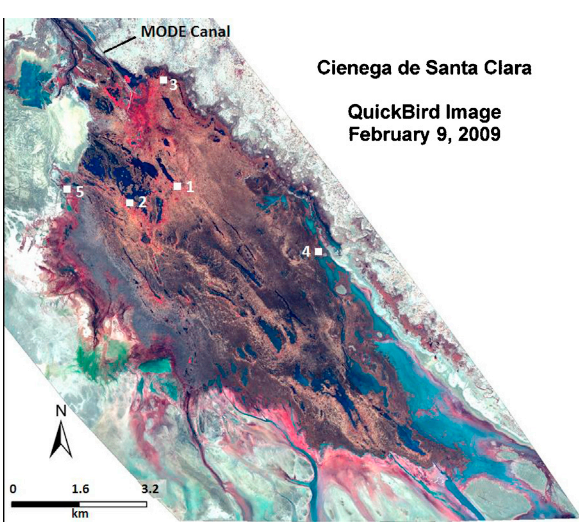

Fig. 1. Quickbird satellite image of the Cienega de Santa Clara, showing the locations of 5 salinity monitoring stations selected for field and remote sensing study sites. In this winter scene, *T. domingensis* plants are dormant, and bright false color red plant near the inlet of the MODE canal are *P. australis*.

This study attempted to determine the salinity tolerance limits of the dominant vegetation through greenhouse and field studies. The objectives were to determine the salinity range for *T. domingensis* and *S. americanus* in the marsh. The mean salinity in the Cienega is currently 3.73 g L^{-1} TDS, but could increase to >6 g L^{-1} TDS if the YDP is operated at full capacity (Gabriel and Kelli, 2010). The growth response of *T. domingensis* and *S. americanus* were determined in greenhouse trials under emergent conditions typical of the marsh environment. Relative growth rates ($RGR_{Biomass}$), rates of leaf elongation and shoot production, root:shoot ratios, and cation and anion contents were measured across a salinity gradient of 0–12 g L^{-1} TDS. Then the effect of salinity on *T. domingensis* was determined by supplementary field and remote sensing surveys in the Cienega. Based on the results, an attempt is made to project possible vegetation changes in the Cienega under different operating scenarios of the YDP.

Numerous studies have been conducted on the salinity limits of plants in oligohaline marshes. However, comparison among studies is complicated by the different growth parameters measured, different experimental conditions, and potentially differences in response among ecotypes. In Section 4 the present results are compared in detail to other studies in an attempt to develop a synthesis across species, ecotypes and growth parameters.

2. Materials and methods

2.1. Greenhouse experiment

The greenhouse experiment was conducted in the Environmental Research Laboratory located in Tucson, Arizona with methods modified from Glenn et al. (1995), in which the growth response of *T. domingensis* to salinity was quantified in preliminary trials. Rhizomes of *T. domingensis* and *S. americanus* were collected from the Sweetwater Wetland in Tucson, AZ. Rhizomes were collected in Tucson rather than from the Cienega in Mexico due to restrictions on importing plant material into the USA from the Biosphere Reserve in Mexico. By contrast, the earlier trial (Glenn et al., 1995) was conducted with rhizome material from the Cienega, allowing us to compare the growth response of two different populations of *T. domingensis* to salinity. Other studies have found clonal variations in salt tolerance of marsh macrophytes (e.g. Howard and Rafferty, 2006), including *T. domingensis* (Beare and Zedler, 1987; von Oertzen and Finlayson, 1984; Mufarrege et al., 2011).

Rhizome sections were planted in trays in a soil mix that was one part peat-based commercial potting mix and two parts washed river sand (proportions by volume) and were irrigated daily with fresh water from the municipal supply until they produced new roots and shoots in the trays. They were then transplanted into individual 9.5 L pots filled with the same soil mixture. Pots were fitted with a 1.27 cm diameter bulkhead fitting and plug to allow them to be periodically drained and refilled with new test solution to prevent salinity increases over the experiment. Before transplanting, plants were trimmed to a uniform height (8 cm) and each pot received 38.1 g ± 14.9 (SD) of plant material. Leaves were trimmed to a uniform initial height of 8 cm. Prior to the imposition of experimental salinity treatments, the plants were irrigated with untreated tap water for 10 days to ensure firm establishment in the pots.

Each pot was randomly assigned to one of five salinity treatments (0, 3, 6, 9 and 12 g L^{-1}) with four replicate pots of each species