Journal of Arid Environments 85 (2012) 114–121

Contents lists available at SciVerse ScienceDirect

Journal of Arid Environments

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

Quantifying soil salinity in areas invaded by *Tamarix* spp.

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ARTICLE INFO

Article history:
Received 12 June 2011
Received in revised form
10 March 2012
Accepted 17 April 2012
Available online

Keywords:
Age
Arid climate
Flooding
Middle Rio Grande
Stem diameter
Texture

ABSTRACT

Elevated soil salinity is often associated with *Tamarix* invasion; however, it's unclear whether soils are more saline because of *Tamarix* or other environmental factors. Surface soil salinity was investigated along a flow-regulated, arid river with dense *Tamarix* of varying age to determine which factors best explain soil salinity. Flooding was the most important predictor, reducing salinity by nearly 70%. Soils under *Tamarix* had lower salinity than adjacent areas without woody cover in non-flooded areas suggesting that evaporation in arid environments may contribute more surface salts than *Tamarix* or may exacerbate plant inputs. Under most conditions, higher salinities were found under *Tamarix* than natives. An exception to this pattern was that soils under the smallest trees were more saline for natives. Relationships between soil salinity and stem size suggest that salts increase over time under *Tamarix* unless they are removed by flooding. However, the most mature stands had lower salinity than expected, reflecting some additional mechanism. Soil texture and distance from the river were important, but interacted strongly with other factors. The observed relationships between surface soil salinity and *Tamarix* stem size, a predictor of aboveground age, suggest *Tamarix* plays an active role in floodplain salinization within the sampled area.

1. Introduction

Tamarix spp. (*Tamarix ramosissima*, *Tamarix chinensis* and hybrids) invasion is considered a major threat to ecological health at both national and global levels, with potential impacts on soil chemistry. As the common name "saltcedar" implies, one of the most often cited mechanisms of ecosystem change by *Tamarix* lies in its ability to sequester salts in its tissues. This deciduous tree can extract salts from the groundwater, secrete these compounds from leaf tissue, and deposit them onto the soil surface through mature leaf senescence and exudation (Arndt et al., 2004; Berry, 1970; Thomson et al., 1969). Despite this ability to redistribute salts to the soil surface, some suggest that any positive relationships that have been observed between *Tamarix* and elevated soil salinity may result from *Tamarix*'s known higher tolerance to salinity; that its presence may be the consequence rather than the cause of this condition (Stromberg et al., 2009).

Elevated floodplain salinity has undoubtedly contributed to the large-scale replacement of native riparian vegetation with *Tamarix* (Busch and Smith, 1995; Glenn et al., 1998; Ohmart et al., 1988; Stromberg, 2001). The most often cited cause of elevated soil salinity along streams and rivers is river regulation. Flow-regulated and channelized river stretches can develop saline streambanks and adjacent riparian zones because they are no longer subjected to periodic overbank flooding that dilutes and flushes salts from the soil (Busch and Smith, 1995; Stromberg, 2001). Soil salinity is typically exacerbated in flood-deprived arid regions due to a lack of sufficient rainfall that would leach and transport salt deposits, and high evaporation rates (Goodall et al., 1981). These factors tend to further concentrate salts in the surface soil horizons.

Tamarix salt secretion has led many authors to speculate that soil salinity may increase significantly below *Tamarix* canopies (Brotherson and Field, 1987; Busch and Smith, 1993; Sala et al., 1996; Shafroth et al., 1995). Studies are often cited for showing that *Tamarix* elevates soil salinity, but generally these studies simply correlate high salinity with the presence of *Tamarix* (Carman and Brotherson, 1982; Ladenburger et al., 2006). Others indicate that environmental variables such as distance from the river,

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doi:10.1016/j.jaridenv.2012.04.011

flooding, capillary rise from the aquifer, and eolian deposition may be more influential on salt levels (Glenn et al. 2012; Stromberg, 1998; Taylor et al., 1999; Yin et al., 2010) or that *Tamarix* salt contributions do not elevate soil salinity above the tolerance range of native riparian vegetation (i.e. <4 mmhos cm^{-1}; Lesica and DeLuca, 2004). Much of the published research on the subject was designed to address questions unrelated to evaluating *Tamarix* contributions to soil salinity, and thus sampling may not have been sufficient to support or refute a causal relationship (Bagstad et al., 2006; Brotherson and Winkle, 1986; Campbell and Dick-Peddie, 1964; Nagler et al., 2008; Sexton et al., 2006). To assess whether *Tamarix* is responsible for significant salt-loading in surface soils, other potential sources of environmental salts must be examined with sufficient replication.

Many researchers have observed similar salt constituents in *Tamarix* leaves and the root environment (Berry, 1970; Sookbirsingh et al., 2010), but only recently has elemental composition of leaves and groundwater been compared with surface soils under *Tamarix*. Glenn et al. (2012) observed similar ratios of cations and anions in subtending groundwater, *Tamarix* leaves, and surface soils underneath trees, but these salt signatures were different than deeper soils and concentrations were higher than soils outside the plant canopy. These findings provide the most convincing evidence to date that *Tamarix* is redistributing salts to surface soils but it is still unclear which environmental factors are most important for understanding floodplain salinity.

If *Tamarix* does directly contribute to soil salinity, then we might expect that the magnitude of its impact would be related to stand features such as age, density, and cover. Stromberg (1998) found older *Tamarix* individuals to be associated with the highest levels of soil salinity along the San Pedro, a free-flowing river in Arizona. On the other hand, the oldest *Tamarix* stands along a regulated river reach of the Middle Rio Grande in central New Mexico have been observed to have surprisingly low surface soil salinity (<4 mmhos cm^{-1}; K. Lair, unpublished data). Sexton et al. (2006) reported that soil salinity did not change with age of *Tamarix* along three rivers in southern Montana. This discrepancy suggests that soil salinity underneath *Tamarix* may depend on interactions between age and other environmental factors.

The objective of this research was to fill the critical gaps in understanding salt-loading by *Tamarix* with a quantitative study of soil salinity in *Tamarix*-infested locations in the field. Specifically this research sought to determine which environmental factors or combinations of factors, including hydrologic and climatic factors, are critical for explaining soil salinity in *Tamarix*-invaded areas along an arid river. Results were examined in the context of *Tamarix* aboveground age (as reflected by basal stem size), cover, and density to determine how these stand features affect soil salt loads.

2. Materials and methods

2.1. Study sites

The study area focused on an approximate 100-km reach of the Middle Rio Grande from State Highway 60 near Bernardo, south to the Fort Craig Bridge (Fig. 1a and b). The study area along the Middle Rio Grande is associated with an arid climate with a mean maximum daily temperature of nearly 40 °C during summer months and an average of 217 mm of precipitation annually (WRCC, 2011, Bosque del Apache weather station 291138). Summer monsoon thunderstorms deliver about half of the annual precipitation in brief high-intensity events. The sampling reach of the Middle Rio Grande contains a system of levees or barriers to flood flow. *Tamarix* has a strong presence in both the distal historic floodplain (i.e. outside the levees and deprived of flooding) as well as the proximal active

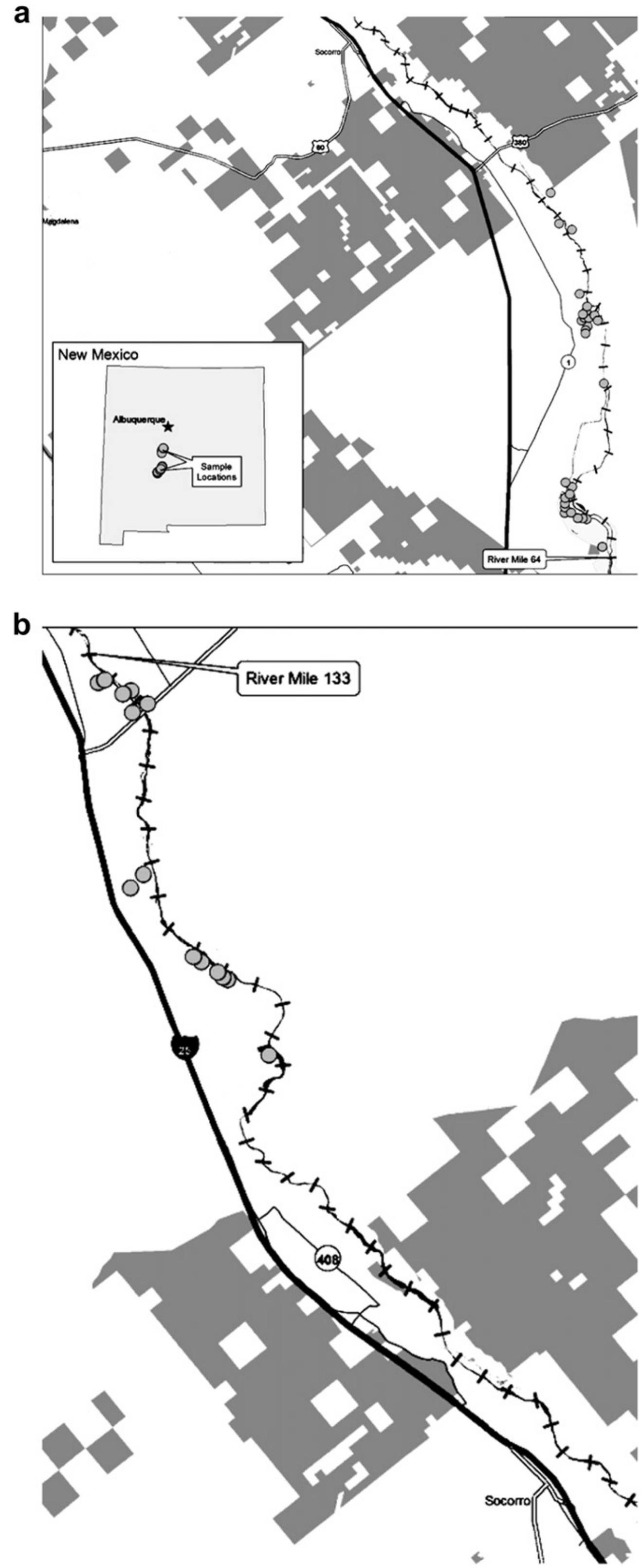

Fig. 1. Location map for research sites (gray circles) along the Middle Rio Grande, NM. a) Sites south of Socorro managed by Bureau of Reclamation and United States Fish and Wildlife Service used for models relating environmental variables to surface soil salinity and for comparison of open and closed-canopy surface soil salinity. b) Sites north of Socorro managed by Department of Game and Fish and Middle Rio Grande Conservancy District used for comparison of open and closed-canopy surface soil salinity only.