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HABITAT RELATIONSHIPS OF SALTCEDAR (*TAMARIX RAMOSISSIMA*) IN CENTRAL UTAH

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ABSTRACT.—Nineteen study sites were established in areas infested with saltcedar bordering Utah Lake in central Utah. Saltcedar cover on the sites averaged 57% but varied widely from community to community. Seventeen soil factors were measured relative to the stands studied. Cover of saltcedar was regressed against the different soil factors, but no patterns were detected. Saltcedar functioned equally well at all levels of each gradient studied and appeared able to accommodate wide variations in all factors studied. It is suggested that saltcedar has evolved a general-purpose genotype that contributes to its being a vigorous and troublesome weed. Criteria as to why it is such an aggressive weed are listed.

Saltcedar (*Tamarix ramosissima*) is an important introduced shrub and phreatophyte in western North America, where it occupies vast acreages. Saltcedar is a vigorous woody invader of moist pastures, rangelands, and riparian habitats. It is poor in forage value, and as a weed it continually causes management problems.

The genus *Tamarix* is native to the Mediterranean area. It is one of four genera of the Tamaricaceae common in Africa, Europe, and Asia. For a time it was thought that species of Tamarix were brought to the Americas by Spanish explorers. However, since the only early sightings of saltcedar were along the U.S.-Mexican border, it appears that such may not be the case (Robinson 1965). It is now believed that the first introduction of saltcedar to North America was made by nurserymen on the east coast of the United States in 1823. According to Horton (1964), saltcedar was offered for sale that year by the Old American Nursery operated by Lawrence and Mills. Later, in 1828, Bartram's nursery of Philadelphia was selling saltcedar. When in 1868 the U.S. Department of Agriculture began raising saltcedar, it reported six different species growing in the Department Arboretum (Horton 1964).

Saltcedar made its appearance on the West Coast of the United States in the 1850s. Several California nurseries offered two or three species for sale as early as 1854 (Robinson 1965). It is believed that these western nurseries were supplied by those in the East.

Although saltcedar was planted as an ornamental in the western United States during the latter half of the 1800s, it apparently did not escape cultivation until the 1870s. The only accurate information concerning sightings is found in herbarium collections. The earliest collection of saltcedar (*T. gallica*) was in 1877 near Galveston, Texas. Thereafter, sightings were reported in Arizona, California, New Mexico, and Utah (Robinson 1965).

For the next several decades, little attention was paid to the increasing spread of saltcedar, and there is no record that anyone was aware that a problem was in the making. For example, in the early 1900s farmers were using this plant for erosion control (Everitt 1980). However, it became clear by the 1920s that saltcedar was becoming a serious problem. By then saltcedar was spreading rapidly from one watershed to another. It spread up and down nearly every stream in the Southwest, and then northward into the Great Basin and the Rocky Mountains.

Fathers Dominguez and Velez de Escalante, on their expedition to Utah Valley in 1776, described lush pastures, willows, alders and poplar trees, but they made no mention of saltcedar (Auerbach 1943). The first report of saltcedar in Utah was from St. George in the 1880s, where it was grown as a cultivated species (Robinson 1965). M. E. Jones collected specimens at Harrisburg and Silver Reef, Utah, in 1894 (Robinson 1965). The next reported sightings were by Walter Cottam

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(1926), when he identified saltcedar in his study of the flora of Utah Lake (Cottam 1926). Soon after Cottam's study, Wakefield (1937) stated that *Tamarix* was one of the primary invaders of Utah Lake plant communities between 1930 and 1936. By 1942 Saltcedar had spread to Bird Island in the middle of Utah Lake (Beck 1942). It must have just recently arrived there, however, because it was not mentioned in a study of Bird Island by Hayward in 1935.

Murphy (1951) recorded that saltcedar could be found in all the shore communities surrounding the lake. By the early 1960s concern was being expressed over the saltcedar invasion, particularly by Christensen (1962). He wrote that "Tamarix occurred as a major species along much of the lake shore, and that [sic] dense stands of Tamarix plants one, two or three years old, [sic] were a conspicuous feature of the vegetation on the recently exposed beaches." By 1962 saltcedar was actively invading not only the lower valley streams and lakes, but those in the mountains as well. Christensen (1962) mentioned sightings of saltcedar in Spanish Fork Canyon along the Spanish Fork River at elevations between 4,900 and 5,000 feet and in Provo Canyon on the shores of Deer Creek Reservoir at elevations of 5,400 feet. More recent descriptions of the saltcedar communities surrounding Utah Lake are by Coombs (1970) and Brotherson and Evenson (1982).

Brotherson and Evenson (1982) described the aerial extent and densities of saltcedar communities surrounding Utah Lake. They concluded that saltcedar now occupies about 2,000 acres, or 3.7% of the total land area close to the lake. Furthermore, they suggested that additional invasion is likely.

Although research studies concerning saltcedar invasion and its eradication are numerous, few studies have dealt with its physiology and ecology. Everitt (1980) indicated a need for more ecological studies to help determine the relationships of saltcedar to its environment. In this paper we describe the biotic and abiotic factors influencing the saltcedar communities in central Utah.

STUDY AREA

Nineteen study sites were established in June and July of 1980 in saltcedar communities bordering Utah Lake, Utah County, Utah, at approximately 40 degrees 10′N, 11 degrees 50′W (Fig. 1). Elevations at the sites ranged from 1,370 m to 1,402 m.

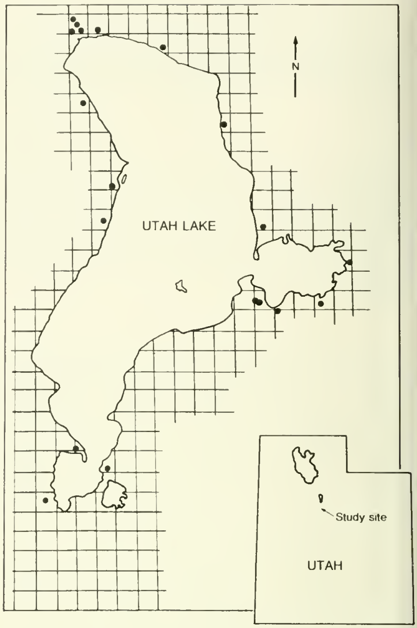

Fig. 1. Map of study site locations in the saltcedar community in central Utah.

Annual precipitation in the area averages 340 mm (14 inches), 60% falling during the winter and spring months. Temperatures range from −13 C to 36 C, July being the hottest month and January the coldest. The majority of water entering Utah Lake comes from streams heading in the Wasatch and Uinta mountains east of the lake. Precipitation in these mountains ranges from 760 to 1,270 mm (30 to 50 inches) annually (Swenson et al. 1972).

MATERIALS AND METHODS

The study sites were selected to represent typical saltcedar communities in the Utah Lake area. A 10 x 10 m study plot was established at each site. Study plot boundaries were marked by a cord 40 m long with loops very 10 m for corners. Each plot was subsampled, with twenty 0.25 m quadrats distributed uniformly across the plot on a 2 x 2 m grid in ive rows of four quadrats each.

Total cover of living plants, plant cover by ife form (i.e., trees, shrubs, perennial forbs, perennial grasses, sedges, rushes, annual grasses, annual forbs), litter, and bare soil vere estimated from each quadrat following a procedure suggested by Ostler (1980). Cover of individual plant species was estimated, using the cover-class categories suggested by Daubenmire (1959). Species were also classified according to whether they were perennial, biennial, or annual, and whether they vere native or introduced.

Three soil samples from the top 20 cm of the oil profile were taken in each plot (from opposite corners and the center) and were later combined for laboratory analysis. The soil samples were analyzed for texture (Bouyoucos 1951), pH, soluble salts, mineral composition, and organic matter. Soil reaction was taken vith a glass electrode pH meter. Total soluble salts were determined with a Beckman electrical conductivity bridge. A 1:1 q/v soil-water paste (Russell 1948) was used to determine pH and total soluble salts. Soils were extracted with 1.0 neutral normal ammonium acetate for the analysis of exchangeable calcium, magnesium, potassium, and sodium Jackson 1958, Hesse 1971, Jones 1973). Zinc, manganese, iron, and copper were extracted from the soils by use of DTPA (diethylenetriaminepenta-acetic acid) extracting agent Lindsay and Norvell 1969). Individual ion concentrations were determined using a Perkin-Elmer Model 403 atomic absorption spectrophotometer (Isaac and Kerber 1971). Soil phosphorus was extracted with sodium bicarbonate (Olsen et al. 1954). Total nitrogen was determined using macro-Kjeldahl procedures (Jackson 1958). Organic matter was determined by methods described by Allison et al. (1965) through weight loss following ignition of a 10 gram soil sample at 950 C in a LECO medium temperature resistance furnace.

The following characteristics were recorded for each plot: elevation (taken from published U.S. Department of Interior Geological Survey 7.5-minute series topographic maps), percent slope, slope position (1 = ridge top, 2 = midslope, 3 = drainage accumulation area), erosion (0 = none, 1 = light, 2 = moderate, 3 = heavy), moisture (1 = dry, 2 = moist, 3 = wet, 4 = seasonally inundated, 5 = submerged), and grazing impact (0 = none, 1 = light, 2 = moderate, 3 = heavy).

Plant nomenclature follows Welsh and Moore (1973) for the dicotyledons (trees, shrubs, forbs, etc.) and Cronquist et al. (1977) for the monocotyledons (grasses, sedges, rushes, etc.). Prevalent species (those most frequently encountered during sampling) of the various plant communities are reported as equal to the average number of species per 0.01 ha sampling area examined (Warner and Harper 1972). Diversity values were computed following Pielou (1977).

Data analysis consisted of computing means, standard deviations, and coefficients of variation for all measured biotic and abiotic variables (Ott 1977). Linear regression analysis (Cochran and Snedecar 1976) was applied to the cover values of saltcedar in relationship to associated soil factors to determine the degree to which they were associated.

RESULTS AND DISCUSSION

Saltcedar (*Tamarix ramosissima*) has invaded a wide variety of community types in central Utah since its introduction near the turn of the century. It now occupies a number of disjunct sites totaling nearly 2,000 acres, or about 3.2% of the land area, around Utah Lake and its bays. It forms part of many different communities in the area but is found more often in seasonally submerged sites or saline meadows. In much of the area it forms almost pure stands, and it is the most widespread introduced species around the lake. Its presence represents the invasion of an exotic species into the natural communities, and thus the establishment of a new vegetation type in the area.

There are two vegetation layers in the saltcedar community, the tree-shrub overstory and an herbaceous understory. The herbaceous understory is important in all areas, where it varies greatly from site to site. The variation is in species and in the internal heterogeneity of the vegetation.

Saltcedar is the dominant overstory species, whereas saltgrass (*Distichlis spicata*) is

TABLE 1. Means and standard deviations of prevalent species associated with saltcedar communities around Utah Lake.

Species	Percent presence	Mean frequency	Mean cover	Stand deviation	Coefficient of variation
Tamarix ramosissima	100.0	82.1	56.7	24.1	43.0
Distichlis spicata	79.3	70.5	48.5	35.1	73.0
Kochia scoparia	63.2	31.6	13.5	26.9	198.0
Cardaria draba	15.8	10.8	7.7	22.9	299.0
Iva axillaris	42.1	26.8	6.6	11.0	166.0
Polypogon monspeliensis	68.4	25.3	5.4	9.2	170.0
Cynodon dactylon	5.2	5.2	4.9	21.5	436.0
Atriplex patula	47.4	16.8	4.6	8.9	191.0
Bromus tectorum	26.3	10.5	4.4	15.4	350.0
Hordeum jubatum	36.8	15.5	3.0	7.5	252.0
Poa pratensis	5.2	5.2	2.9	12.7	435.0
Juncus arcticus	26.3	15.0	2.6	5.0	189.0
Lepidium montanum	26.3	12.4	2.3	5.6	244.0

the dominant understory species (Table 1). The compositional patterns of the community seem related to the tendency of saltcedar to invade predominantly saline meadow areas around the lake. The saltcedar community shows some modification by human activities. Coombs (1970) considered the type to be expanding and suggested that much of the saltcedar community was in various stages of recovery from disturbance. If his evaluation is accurate, it appears that this woodland community will undergo a great deal of change in the future.

The saltcedar community around the lake is dominated by trees and perennial grasses; annuals and perennial forbs make smaller but significant contributions. Shrubs, sedges, and rushes contribute only 1%–2% of the total cover (Table 2). Total cover varied little across the study sites, averaging nearly 98%.

Diversity values and species-richness figures varied widely (Table 2). A total of 85 species were encountered on the study sites, but only 13 species were abundant enough to be considered prevalents (Table 1). The 13 prevalent species contributed 85% of the total cover on the study sites, whereas the other 72 species contributed the remaining 15%. Also, the average coefficient of variation (CV = 236%) for the cover values of the individual prevalent species was significantly lower ($p < 0.05$) than the same value (CV = 370%) for the nonprevalents. This indicates that the understory composition of the saltcedar community is highly varied and heterogeneous. The coefficients of variation were high for both prevalent and nonprevalent species, indicating uneven or patchy distribution for all species. In contrast to most species, saltcedar and saltgrass were more abundant and uniformly distributed. This is further evidenced by the percent presence and mean frequency values (Table 1), which are low for all species except saltcedar and saltgrass.

Eight of the 13 prevalent species were introduced. Together they made up 61% of the cover of the prevalent species. The remaining portion of the prevalent species cover was contributed by saltgrass. Thirty-seven species in the community (45%) were introduced. Together these species contributed 56% of the total cover on the study sites (Table 2). Since introduced species generally invade sites of moderate to high disturbance, these data support the contention of Coombs (1970) that the saltcedar community occupies areas of high disturbance.

The saltcedar communities in the Utah Lake area occupy sites with intermediate moisture, high water tables, little erosion, and uniform elevations of about 1,386 m (Table 2). Soils were silt loams and silt clay loams high in organic matter with little or no rock in the profile. Soluble salt concentrations in the soils ranged from 650 to 16,000 ppm and averaged 5,994 ppm. In an earlier study Carmen and Brotherson (1980) showed that differences in soil salt concentrations distinguished sites infested by saltcedar from adjacent uninfested sites and from sites infested by Russian Olive (*Elaeagnus angustifolia*). The high level of salts, along with basic

TABLE 2. Highs, lows, range, means, and standard deviations and coefficients of variation for environmental factors (biotic and abiotic) for saltcedar community around Utah Lake. (a) The slope position is defined as 1 = top of ridge, 2 = midslope, 3 = bottom of slope. (b) The moisture index runs from 1 to 5, with 1 indicating xeric conditions and 5 indicating standing water. (c) Grazing impact is defined as 1 = light, 2 = moderate, 3 = heavy grazing.

Environmental factor	High	Low	Range	Mean	Standard deviation	Coefficient of variation
GENERAL SITE FACTORS						
Elevation	1399.9	1368.6	31.4	1386.1	9.5	1.0
Slope position	3.0	1.0	2.0	2.0	1.0	50.0
Moisture	3.0	1.0	2.0	2.3	0.7	29.0
Percent litter cover	5.8	0.0	5.8	0.5	1.3	290.0
Percent exposed bareground	5.6	0.0	5.6	1.7	3.2	189.0
GENERAL SOIL FACTORS						
Percent sand	73.0	14.0	59.0	32.8	14.9	45.0
Percent silt	70.0	17.0	53.0	44.8	16.1	36.0
Percent clay	54.0	2.5	51.5	22.4	13.8	62.0
Percent fines	86.0	27.0	59.0	67.2	14.9	22.0
Percent organic matter	20.0	4.2	15.8	10.7	4.6	43.0
pH	9.0	7.0	2.0	8.0	0.5	6.0
Soluble salts (ppm)	16058.0	652.0	15406.0	5994.6	4164.8	69.0
SOIL MINERAL NUTRIENTS						
Nitrogen (percent)	0.7	0.1	0.5	0.3	0.1	42.0
Phosphorus (ppm)	89.6	10.9	78.7	24.9	17.3	70.0
Calcium (ppm)	51120.0	6096.0	45024.0	11736.5	9954.4	85.0
Magnesium (ppm)	2325.0	376.0	1949.0	1325.0	544.4	41.0
Sodium (ppm)	5976.0	235.0	5741.0	2042.7	1526.9	75.0
Potassium (ppm)	1824.0	78.0	1746.0	761.5	429.0	56.0
Iron (ppm)	188.2	3.8	184.4	40.4	45.8	114.0
Manganese (ppm)	41.9	1.6	40.3	13.8	11.3	82.0
Zinc (ppm)	18.6	0.6	18.0	3.8	4.4	114.0
Copper (ppm)	7.6	0.5	7.1	3.1	2.0	66.0
BIOTIC FACTORS						
Total living cover	100.0	94.4	5.4	98.8	1.9	2.0
Percent tree cover	45.0	8.8	36.3	29.5	10.0	34.0
Percent shrub cover	8.0	0.4	7.6	1.2	2.5	208.0
Percent perennial shrub cover	55.0	0.0	55.0	14.1	13.9	99.0
Percent perennial grass cover	61.4	0.0	61.4	32.4	17.7	55.0
Percent sedge cover	8.0	0.0	8.0	1.7	2.7	157.0
Percent rush cover	11.0	0.0	11.0	0.6	2.5	435.0
Percent total annual cover	64.0	0.0	64.0	20.5	19.5	95.0
Percent annual grass cover	58.0	0.0	58.0	7.5	13.8	183.0
Percent annual forb cover	56.0	0.0	56.0	13.0	15.7	121.0
Diversity	3.2	1.0	2.2	2.2	0.5	23.0
Mean no. of species/stand	25.0	5.0	20.0	11.7	5.2	44.0
Mean no. of native species/stand	15.0	2.0	13.0	6.5	3.6	55.0
Mean no. of introduced species/stand	14.0	2.0	12.0	5.3	3.1	59.0
Native species (percent of total)	75.0	26.0	49.0	54.8	14.6	27.0
Introduced species (percent of total)	75.0	25.0	50.0	45.2	14.6	32.0
Total cover of native species	88.0	1.0	87.0	44.1	23.6	54.0
Total cover of introduced species	99.0	12.0	87.0	55.9	23.6	42.0
Grazing impact	3.0	1.0	2.0	2.1	0.7	35.0

pH levels (mean pH = 7.5), indicate a preference by saltcedar for somewhat alkaline substrates.

Soil mineral ion concentrations are shown in Table 2. The soils are characterized by high levels of phosphorus and calcium. All minerals studied appear abundant and are probably not limiting for plant growth. Concentrations for all elements varied widely among sites, with coefficients of variation ranging from 41% to 140%.

When cover of saltcedar was regressed against 17 different soil factors, no patterns were detected. Saltcedar did equally well at all levels of each mineral gradient studied and appeared able to accommodate wide varia-

TABLE 3. Characteristics of saltcedar that contribute to its success as a weed. (*) corresponds to Baker's (1974) criteria of the ideal weed.

*1. Continuous seed production for as long as growing season permits.
*2. Cross-pollination by the wind.
*3. Self-compatible when cross-pollination unavailable.
*4. Very high seed output in favorable environmental circumstances.
*5. Ability to produce some seed under a wide range of environmental conditions.
*6. Adaptations for long or short range dispersal.
*7. A vigorous vegetative reproduction capability.
*8. Brittleness in its stems, and not easily drawn from the ground.
*9. Salt-glands that allow its individuals to compete interspecifically by allelochemics.
10. Tolerance for an extreme range of environmental conditions.
11. Vigorous root sprouter following fire.
12. A "facultative phreatophyte," as distinguished by its ability to live totally inundated or in total absence of saturated soils.
13. Resistance to control with foliar chemicals.

tions in these abiotic factors. It appears, therefore, that the major conditions necessary for saltcedar's success in the Utah Lake environment are alkaline soil conditions, available soil water, and sufficient disturbance of natural vegetative cover to permit the species to become established.

Observations in the field indicated that seedling establishment occurred most often when soils were seasonally saturated at the surface. These findings agree with those of Tomanek and Ziegler (1960), who indicated that the establishment of saltcedar seedlings in the greenhouse depended on high moisture levels at or near the soil surface.

Once established, the primary root of saltcedar grows steadily downward with little branching until it reaches the water table. Secondary branching of the root becomes profuse on contact with the water table (Tomanek and Ziegler 1960). The primary root of a tree in one study (Merkel and Hopkins 1957) was followed to a depth of 16 feet, where it was still 3/16 inch in diameter. At that point the root was still descending. The water table was located at a depth of 26 feet.

Saltcedar has been labeled an "extreme phreatophyte" because of its ability to exploit deep water tables. However, once established, it can survive almost indefinitely in the absence of surface saturation of the soil (Everitt 1980). Because of saltcedar's ability to accommodate such wide variation in its environment, it is often a troublesome weed. Baker (1974) developed a list of characteristics expected in "the ideal weed." At that time he indicated that there were no species that filled all categories; however, the greater the number of weedy characteristics combined in a single species, the more serious a weed the plant should be. Saltcedar as a species combines 9 of his 12 characteristics (Table 3). To Baker's 9 we have added 4 more characteristics (Table 3) that also appear equally important for saltcedar to become a successful and troublesome weed. An important outcome of the incorporation of the listed characteristics, through an "evolutionary synthesis" in saltcedar, has been the development of a general purpose genotype, and thus a vigorous weed capable of exploiting a wide spectrum of habitats.

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