FACTORS THAT INFLUENCE THE DISTRIBUTION AND COVER OF *HELIANTHUS PARADOXUS* IN A WEST TEXAS SALT MARSH

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ABSTRACT

The Diamond Y Spring is one of the last major flowing springs in west Texas. It is habitat for six federally endangered or threatened species including *Helianthus paradoxus*, the Pecos (= puzzle) sunflower. While the plant communities in the Diamond Y Spring Preserve seem to be fairly well delineated, the *H. paradoxus* population and distribution varies considerably on an annual basis. Some relationships between *H. paradoxus* growth and some abiotic factors including soil moisture, soil salinity, and soil oxygen have been examined in other studies. This study uses GIS mapping techniques to investigate relationships between *H. paradoxus* cover and the abiotic soil characteristics. Locations in the marsh with *H. paradoxus* at greater than 5 % cover were found to coincide with locations with depth to water greater than 25 cm, soil salinity between 7 and 12 g/kg, and soil pH between 8.3 and 8.5. This study suggests that annual fluctuations of the cover and distribution of the *H. paradoxus* populations is influenced by the level of water coupled with soil pH and soil salinity found in the salt marsh.

KEY WORDS: *Helianthus paradoxus*, sunflowers, soil salinity, arid environments, inland salt marshes, spatial changes, distribution

The genus *Helianthus* is composed of approximately 67 annual and perennial species divided into four sections (Correll and Johnston 1979; Heiser 1965). *Helianthus paradoxus* is an annual hybrid species belonging to the Asteraceae family and was proposed for listing as a federally threatened species in 1998 and listed in 1999 (McDonald 1999). *Helianthus paradoxus* and its parental species *H. annuus* and *H. petiolaris,* all belong to the same section with the same chromosome number (n = 17) (Rieseberg 1991; Rieseberg et al. 1990). The species are easily delineated based on distinct morphological, phenological and habitat characteristics (Correll and Johnston 1979; Heiser 1958; McDonald 1999).

Helianthus paradoxus differs from *H. annuus* in having narrower leaves, fewer hairs on the stems and leaves, smaller flower heads, narrower less abruptly acuminate phyllaries, and later flowering (Heiser 1958). It differs from *H. petiolaris* in having shorter petioles and no hairs at the tips of the pales of the flower head (Heiser 1958). *Helianthus paradoxus* is intermediate between its parents in morphology, but not in habitat preference likely indicating a long period of independent evolution after its origin (Rieseberg et al. 1990; Schilling and Heiser 1981). Molecular studies have indicated *H. paradoxus* is a true species and estimated the hybridization from *H. annuus* and *H. petiolaris* occurred approx. 75,000 to 208,000 years ago (Rieseberg et al. 1990; Rieseberg 1991; Welch and Rieseberg 2002).

Helianthus paradoxus is able to establish and persist in an extreme habitat, an inland sulfate dominated salt marsh. Neither parental species grow in the marsh nor are they competitive under similar salinities (Bush and Van Auken 2004; McDonald 1999; Welch and Rieseberg 2002; Van Auken and Bush 2006). *Helianthus paradoxus* germinates in January when soil water content is highest and surface salinity is lowest (Van Auken 2001). *Helianthus paradoxus* seems to be a true wetland species that is usually found in saturated saline soils and will continue to grow even when inundated although at reduced levels (Bush 2006a).

Saline habitats are quite often thought of as existing near large bodies of saltwater. While those environs account for most of the worlds salt marsh habitat, inland salt marshes occur in many different geographical areas worldwide (Odum 1988). Inland salt marshes can develop within high-evaporation basins, next to small inland saline lakes, and lowlands associated with desert springs (Odum 1988). Often small inland salt marshes are found in desert areas without a large body of water nearby. Inland salt marshes occur throughout the southwestern desert areas of North America due to the high rate of evaporation and low and highly variable level of precipitation in the desert ecosystems (Shaw and Fredine 1956). The level of salts and the kind of salts found across an inland salt marsh vary in both time and location (Borchert 1971; Ungar 1974). This phenomenon is due to the variable amount of precipitation in the system and the underlying substrate (Brune 1981).

Limited tolerance of most plant species to salt damage typically accounts for saline habitats having low species diversity (Chapman 1974). Sodium (Na^+) and chloride (Cl^-) can be extremely toxic to most plants at moderate to high concentrations (Lavelle and Spain 2001). Relatively few plant species have evolved structural, physiological, and/or biochemical mechanisms of salt resistance (Salisbury and Ross 1991; Troughton and Donaldson 1972).

The locations of the specific plant communities in salt marshes have been suggested to depend mainly on the differing species tolerances to the varying abiotic factors (Bush 2002; Chapman 1974; Cooper 1982; DeJong 1978; Ewing 2000; Grunstra and Van Auken 2006; Naidoo et al. 1992; Rand 2000; Snow and Vince 1984; Van Auken and Bush 2006). Four major plant species including *Helianthus paradoxus*, *Sporobolus airoides* (alkali sacaton), *Schoenoplectus americanus* (formerly *Scirpus americanus*, bulrush), and *Distichlis spicata* (saltgrass) as well as several other minor species inhabit the salt marsh of the Diamond Y Spring Preserve (Grunstra and Van Auken 2006; Van Auken and Bush, 1998; Van Auken 1998; Van Auken and Bush 2006; Van Auken et al. 2006) (Figure 1). The locations of the salt marsh species are most likely due to their water requirements, salt tolerance, or ability to out-compete rivals in the differing salinity levels of the soil (Bertness 1991; Bush 2006b; Chapman 1974; Niering and Warren 1980; Van Auken and Bush 1998).

Some studies have used statistical techniques to identify the role of the abiotic factors present on the distributions of the species in a salt marsh area. Bush (2006a,b) used regression techniques to show that salinity and the soil moisture content played an important role in the growth of *H. paradoxus*. Dependence on soil salinity and soil moisture was also shown in an analysis of the plant communities of an Egyptian inland salt marsh (El-Ghani 2000).

Figure 1. Example of the delineation of the plant species into distinct areas across the marsh landscape in the Diamond Y Spring Preserve located in Pecos County, Texas. The species present in the photograph are mainly: *Sporobolus airoides* in the foreground, *Distichlis spicata* is at midfield, and *Schoenoplectus americanus* is the dark vegetation across the middle-top of the picture.

The purpose of this study was to determine and map the abiotic factors of water table depth, soil pH and soil salinity in the salt marsh of the Diamond Y Spring Preserve through one growing season, as well as estimating the plant cover of *D. spicata*, *H. paradoxus*, *S. americanus*, and *S. airoides*. Geographical Information System (GIS) software was used to show the relationship between locations in the salt marsh maintaining specific levels of water table depth, soil pH, and soil salinity with the locations identified as high in *H. paradoxus* cover. These abiotic levels most likely play an important role in determining the growth and distribution of *H. paradoxus* in the salt marsh of the Diamond Y Spring Preserve.

METHODS

The Diamond Y Spring Preserve is located in Pecos County Texas and occupies a total area of approximately 6.1 km^2. The study site encompasses the 37 ha salt marsh formed near the junction of the Diamond Y Spring and Leon Creek drainages. Historically, this is one of the main areas in which the federally threatened *H. paradoxus* grows (Bush 2002; Van Auken and Bush 1998). The borders of the study area are limited on the western and eastern edges by fencing (Figure 2). The northern and southern limits of the study area are delimited by limestone outcroppings producing a sharp change in elevation out of the lowland salt marsh and into slightly higher *Prosopis glandulosa* (honey mesquite) and *Larrea tridentata* (creosote bush) woodlands.

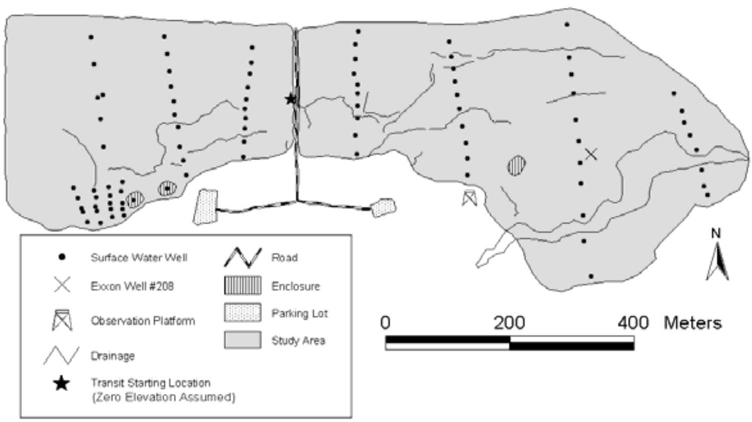

Figure 2. Overview of the 37 ha study area and the observation site grid pattern. The locations of the 87 observation sites and surface features in the study area are labeled. The dirt roadway crossing the marsh and connecting the two observation parking lots is shown. The observation platform can be seen on the southern edge of the eastern side of the study area.

The water table for the salt marsh was studied using shallow piezometers or observation wells based on a design used in previous studies in the marsh area as well as standard monitoring well construction techniques (Bush 2002; EPA 1975; WRP 1993). The piezometers consisted of 5 cm in diameter PVC pipe buried vertically to a depth of approximately 60 cm in the ground. A grid pattern was planned based on the existing pattern of wells located in the southwestern corner of the marsh (Figure 2). The grid pattern was expanded to a larger scale to increase the size of the study area and encompass more of the lowland region of the salt marsh, especially areas where *H. paradoxus* populations were previously found (Van Auken and Bush 1998). The well site locations, as well as, many surface features of the study area were mapped using Trimble's GeoExplorer III GPS and Beacon-on-a Belt units (Figure 2).

Water table depths were monitored at the 87 piezometers in the study area and recorded on a monthly basis beginning in January 2002 and continuing until October 2002 for 870 total observations. This time period included observations in both the wet and dry seasons of the marsh area as well as covering the growing season of the marsh plants including *H. paradoxus* (Bush 2002; McDonald 1999).

In addition to water depth, soil samples were collected at each well site. A total of 870 samples were collected, eighty-seven during each monthly collection. Approximately 300 g of surface soil was gathered at a 2 m distance in a cross pattern around each well pipe. Surface litter was removed and the sample was collected from the top 1 cm of soil (TAES 1983). After the soil was air-dried, the sample was crushed and sieved with a USDA size 4 mesh to remove debris and rock fragments. Salinity and pH of the soil were measured by making a 1:1 paste (soil:de-ionized water) then measuring with a pH meter and salinity probe. (Rowell 1994; TAES 1983; Westerman 1990). This data was then entered into the ArcView 3.3 GIS software.

During the month of October 2002, estimations of the percent plant cover for the major herbaceous species were made across the study area. October was chosen in order to observe *H. paradoxus* in bloom (McDonald 1999). A 1.0 m^2 (1 m x 1 m) quadrat was located 1.5 m to the west of each well location. Locating the quadrat 1.5 m to the west, removed any possible effect from the disturbance caused by digging the well or any subsequent foot travel in the area of the well.

The point data sets of the depth to water, pH, and soil salinity were converted to a raster grid to produce a continuous surface or contour plot across the study area.

This analysis was done by calculating the mean values for each of the well site locations from the ten-month data sets for each of the factors (depth to water, soil pH, and soil salinity). Surface contour plots were then created for the mean values of the factors using the IDW interpolation method available in the Spatial Analyst extension of the ArcView 3.3 GIS software. These surface contour plots were then examined using the map calculator function in the Spatial Analyst extension (ESRI 1999; Ormsby and Alvi 1999).

The map calculator was used to identify the locations of greater than 5 percent *H. paradoxus* cover in the study area. The surface contour maps were then systematically evaluated for values corresponding to the locations of the high *H. paradoxus* cover by beginning with large intervals of acceptance for the three different factors and slowly reducing the intervals until an area was left matching the high *H. paradoxus* cover locations.

RESULTS

Helianthus paradoxus cover was low during this study (Figure 3, top). There were few *H. paradoxus* plants found in the study area. A small concentration of *H. paradoxus* with a high total coverage was found in the southwestern portion of the study area (Figure 3, top). The eastern half of the study area had a couple of small communities of *H. paradoxus* but all had a low percentage of coverage with only one location over 5 % total coverage (Figure 3, top). Across the marsh single *H. paradoxus* plants could be seen but were not usually located and represented in the sampling. Using the map calculator feature of ArcView 3.3 the study area was searched for high densities (greater than 5 %) of *H. paradoxus*. The light gray areas indicate such areas (Figure 3, bottom).

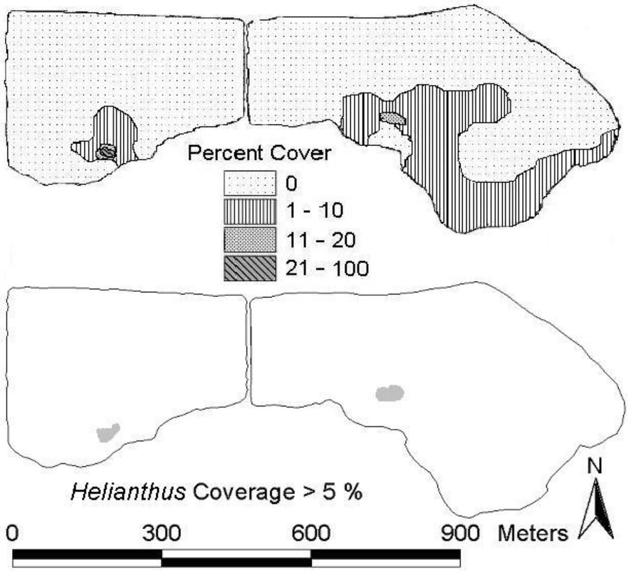

Figure 3. Top - Surface contour plots of the ten-month *Helianthus paradoxus* mean cover created using the IDW interpolation method in the ArcView 3.3 GIS software. Bottom - Surface plot created using the map calculator feature of ArcView 3.3. The calculator was set to search for areas with *H. paradoxus* cover greater than 5%. The light gray colored areas are where the search returned a positive result.

The ten-month averages of the abiotic soil factors were created to show the trends of the three abiotic factors (Figure 4). The mean depth to water was found to be relatively shallow (0 - 10 cm) across 68 % of the study area (Figure 4, top). There were several locations with standing water. The average depth to water increased from the center of the marsh and/or locations of the drainage areas towards the northern and southern borders of the study area (Figure 4, top). This coincided with the elevation and slope increasing towards the hills and limestone outcroppings in the northern and southern directions.

Most of the study area was found to have low levels of salinity between 3 - 10 g/kg (Figure 4, middle). High levels were found along the northern and southern boundaries with the highest levels concentrated on the western side of the marsh. These areas tended to be of higher elevation and away from the lower areas and drainages. The highest average values were in the range of 26 - 43 g/kg for salinity (Figure 4, middle).

The averages of the soil pH levels across the marsh revealed the largest portion of the study area was in the pH range of 8.2 - 8.4 (Figure 4, middle). Soils with an average in the 7.5 - 8.1 pH range occupied the center or lower elevation of the marsh. These lower pH areas tended

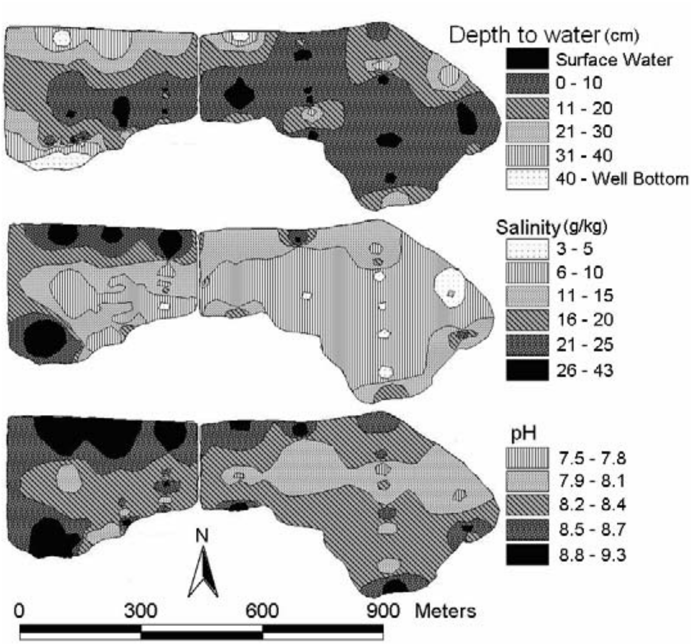

Figure 4. Surface contour plots of the ten-month abiotic factor means created using the IDW interpolation method in the ArcView 3.3 GIS software. Top plot shows the ten-month average depth to water (cm). The middle plot shows the ten-month average soil salinity across the marsh (g/kg). The bottom plot shows the salt marsh's ten-month average soil pH.

to correspond to the areas of the marsh with an average higher water table (Figure 4, top and bottom). High average pH values were found along the northern and southern border specifically on the western half of the study area (Figure 4, bottom). These high soil pH areas had average values between 8.8 and 9.3 and corresponded to areas with a deeper water table (Figures 4, top and bottom).

The ten-month averages of the abiotic soil factors (depth to water, salinity, pH) were examined at locations of the *H. paradoxus* cover (Figure 5). Individually the three characteristics did not seem to influence where high *H. paradoxus* cover areas were located. The three factors by themselves (alone) did not directly correspond to the high *H.*

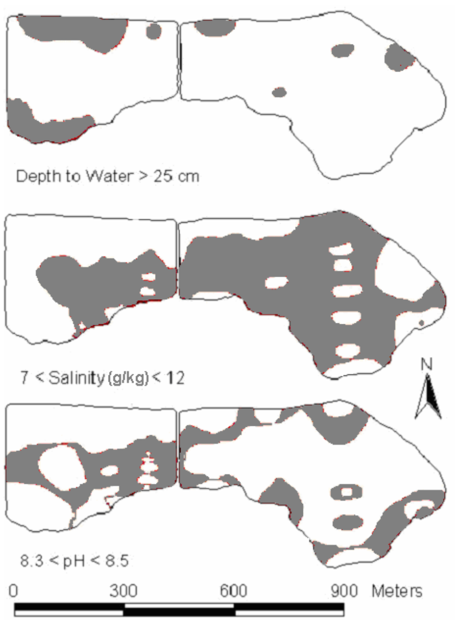

Figure 5. Analysis plots showing search conditions and locations (shaded areas) lying within those conditions. Top plot indicates where the average depth to water is greater than 25 cm. The middle plot specifies locations with an average of salinity levels between 7 and 12 g/kg. The bottom plot identifies areas with an average pH level between 8.3 and 8.5.

paradoxus cover areas (Figure 5). The factors were then combined to determine possible combinations that would correspond to the high *H. paradoxus* cover locations. Combinations of depth to water and soil salinity, depth to water and soil pH, and soil salinity and soil pH did not correspond to the high *H. paradoxus* cover locations. However, when the three factors were combined and the following search criteria were used: depth to water greater than 25 cm, soil salinity between 7 and 12 g/kg, and pH between 8.3 and 8.5, an interesting relationship emerged (Figure 6). The only areas in the salt marsh that met these three conditions were the same locations as the 5 % *H. paradoxus* cover (Figure 6). No other combinations of the factors examined matched the 5 % *H. paradoxus* cover distribution.

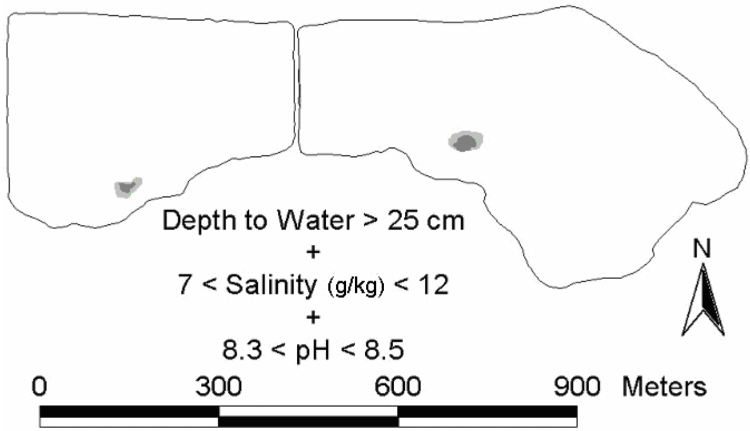

Figure 6. Surface plot created from aligning the *H. paradoxus* search criteria with the combined search criteria (depth to water greater than 25 cm, salinity between 7 and 12 g/kg, and pH between 8.3 and 8.5). Positive results for the combined search are shown in the dark color. The lighter gray color areas are the locations with greater than 5 % *H. paradoxus* cover. The *H. paradoxus* location and search criteria locations are overlapping.

DISCUSSION

Historically, high numbers of *H. paradoxus* plants have been found in the salt marsh of the Diamond Y Spring Preserve. Usually with so many plants present in October the sunflowers cover the study area in a sea of yellow flowers (Van Auken 2002). During the 2002 study period, the *H. paradoxus* plants were only found sporadically across the study area (Figure 3). The low density of this species was most likely due to the atypical rainfall and soil water pattern of that year.

The rainfall pattern for 2001-2002 was not anything like the long term monthly mean for the area (Figure 7) (NCDC 2002). January of the study year received no precipitation when it usually receives approximately 2 cm while June and July received greater amounts of precipitation than expected (Figure 7). The month of August shows very little precipitation (0.4 cm) compared to the mean precipitation

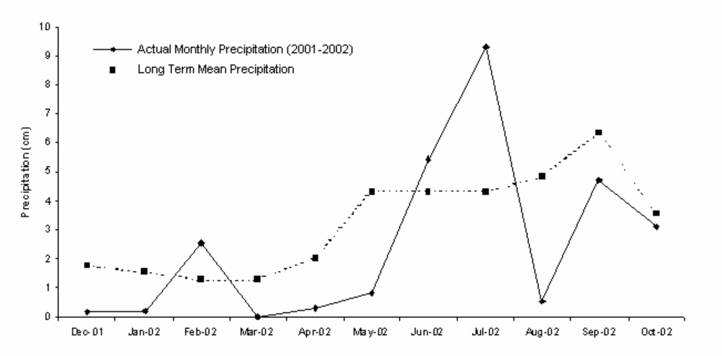

Figure 7. Total monthly precipitation data from December 2001 to October 2002. The values are plotted for the center of the months. The solid line is the actual monthly precipitation reported from Fort Stockton, Texas. The mean precipitation data is based on 1231 months from years 1859-1987 (NCDC, 2002).

normally expected during that month (5 cm) (Figure 7). The variation from the annual mean precipitation had a pronounced effect on the level of moisture in the marsh. In July of 2001 when precipitation followed a mean trend, only 0.5% of the study site had surface or subsurface water between 0 and 10 cm below the surface while for July 2002 almost 60% of the study area had water between 0 and 10 cm below the surface (Grunstra 2002).

The locations of the mean water table depths can be readily seen in the surface contour plots created in this study (Figure 4, top). The shallow surface water areas corresponded to the central lower elevation areas of the salt marsh while the upper elevations had little to no surface water and a much deeper water table on average. This central low area of the marsh also maintained the lowest levels of soil pH and soil salinity throughout the growing season (Figure 4). The higher elevations in the study area consistently showed the highest levels of soil pH and soil salinity (Figure 4, middle and bottom).

In the Diamond Y salt marsh, the higher salinity and pH values at the northern and southern borders are attributed to a deeper water table that allows the surface soil to dry and deposit higher levels of soil surface salt. The areas with high soil salinity have been shown to grow larger seasonally as the water table got deeper the surface and marsh dried out (Grunstra 2002; Grunstra and Van Auken 2006). The same high surface soil salinity areas then receded when the water table rose and the salts were most likely flushed from the surface soil by the surface water.

The spatial patterns and trends of different abiotic factors as well as their interactions may play an important and significant role in the distribution of the salt marsh vegetation. It has been suggested that the *H. paradoxus* communities tend to move around the study area from year to year possibly caused by soil water content, salinity, temperature and the interaction of these factors (Grunstra and Van Auken 2006; Van Auken and Bush 1993; Van Auken and Bush 1995). Spatial distributions of soil moisture, pH, and ionic composition were found to be significant in determining plant community locations in a Mediterranean salt marsh (Rogel et al. 2001). In an inland salt marsh within the Great Basin Desert of Utah, spatial succession has been shown to be related to the plant species salinity tolerance (Bolen 1964). Bush (2002) found that surface salinity had a negative effect on all growth parameters and aboveground dry mass of *H. paradoxus* at the

Diamond Y Spring Preserve depending on the time of year. Several studies based on vegetation communities of coastal marshes have indicated the importance of soil salinity and community distribution (Bertness 1991; Naidoo et al. 1992; Ewing 2000; Rand 2000).

Based on the results from this study and disregarding possible biotic relationships, *H. paradoxus* appears to have a niche in areas where the average depth to water is greater than 25 cm, the average soil salinity level is between 7 and 12 g/kg, and the average soil pH is between 8.3 and 8.5. These findings are in agreement with other studies which found *Helianthus paradoxus* to be restricted to areas with surface salinity levels of approximately 10 g/kg (Bush 2006b; Poole 1992; Poole and Diamond 1993; Siviniski 1996). Bush (2006b) further showed that the abiotic factor which best determined dry mass of *H. paradoxus* was determined by the time of year. In that study, regression analysis indicated that soil salinity was the most important determinant of *H. paradoxus* above ground dry mass, except later in the growing season when surface moisture was the most important factor.

In a growth box experiment, soil moisture was found to be the most important factor regarding *H. paradoxus* growth (Bush 2006a). In the same experiment, the higher soil salinities were also shown to inhibit *H. paradoxus* growth. The salinity levels showing reduced growth by Bush were much lower than some of the salinity levels found to occur in the salt marsh. This may indicate that in the areas of higher salinity levels found in the salt marsh *H. paradoxus* may experience reduced growth or be prevented from establishment in those locations entirely.

Although abiotic factors have been determined to be important, biotic factors such as competition may also play a role in *H. paradoxus* distribution (Bertness 1991). Previous competition experiments have given varied results. Field experiments with *Sporobolus airoides* and *Distichlis spicata* have been shown not to inhibit *H. paradoxus* establishment (Jackson 2001; Van Auken and Bush 2006). However, competition from *D. spicata* may reduce *H. paradoxus* growth later in the growing season (Bush and Van Auken 1997). The different results suggest that biotic factors may also vary in their influence temporally.

Because both abiotic and biotic factors vary from year to year in both location and amount, their effects are quite often difficult to study and interpret. Specific factors may play a temporal and spatial role in *H. paradoxus* growth and distribution. Nevertheless, data from this study seem to indicate an underlying niche of abiotic constraints that need to be fulfilled and maintained at different growth stages of *H. paradoxus*.

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