WATER, SALT, AND PEPPER: *LEPIDIUM LATIFOLIUM* INVASION POTENTIAL ALONG A SALINITY AND MOISTURE GRADIENT

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ABSTRACT

Lepidium latifolium is an exotic species that invades upland and wetland sites in both salt and freshwater. This study examined how *L. latifolium* characteristics such as inflorescence number, seed production, seed viability, seed longevity, and dispersal influence the susceptibility of these landscapes to invasion. Three sites in the San Francisco Bay Delta were chosen with varying salinity and moisture levels. Results demonstrated that inflorescence number was unaffected by salinity or soil moisture. Seed production was significantly affected by salinity ($P < 0.0001$) and moisture levels ($P < 0.0001$). Salt water seed production was reduced by 29% from freshwater sites. Seed production at the wet site had an 87% reduction from the dry site. Seed viability was reduced by both salinity ($P<0.0001$) and soil moisture ($P=0.0005$). Viability at the highest salinity site was reduced by 49% from freshwater sites. Viability was reduced by 8% from the wettest to driest sites. Seed longevity showed no decline in viability 7 months after dispersal at all sites. Seed dispersal was compared only to salinity and showed a 0.22 meter increase at freshwater sites, but was not statistically significant ($P=0.1815$). With the increased seed production and viability, drier freshwater sites experience much greater propagule pressure. Although dispersal distances were not significantly different between sites, the increased propagule pressure, may result in increased invasion potential. Therefore, land managers must be extra vigilant in drier freshwater sites to prevent the accelerated spread of *L. latifolium*.


Figure 1. *Lepidium latifolium* adult

INTRODUCTION

Lepidium latifolium, commonly known as perennial pepperweed, is invading wetland and riparian zones throughout the western United States. It has been known to grow from a single plant into a dense patch several meters in diameter in two years.[1,2]

Lepidium latifolium is difficult to control and once established it can persist in an area and continue to spread. Therefore *L. latifolium* is best controlled by preventing the invasion from occurring.[3] To prevent or slow invasion it is important to understand how *L. latifolium* responds to environmental stresses, in term of its reproductive potential and dispersal ability.

Lepidium latifolium has exhibited plasticity related to varying environmental conditions. Stresses due to flooding have been shown to adversely affect growth and survival.[4,5,6] The deleterious effects of salinity have also been well-documented.[4,7,8,9] If these two stresses have variable effects on *L. latifolium* along each gradient, they may be used to determine the relative susceptibility of a site to invasion. Therefore understanding the response of *L. latifolium* to these gradients may be a critical step for developing effective management practices.


Figure 2. Typical *Lepidium latifolium* dispersal plot scaled with distance from plant

PROJECT GOALS

To gain insight into *L. latifolium* invasion dynamics and its invasion potential this study had three major objectives.

- To evaluate the effects of salinity and soil moisture on adult physiological characteristics of *Lepidium latifolium*.
- To determine the reproductive potential of *Lepidium latifolium* in response to changes in salinity and soil moisture.
- To determine the distance and rate of seed dispersal of *Lepidium latifolium*.

METHODS

To examine the effects of salinity and soil moisture on adult *L. latifolium*, three study sites were established within the San Francisco Bay Estuary at Cosumnes River Preserve, San Pablo Bay NWR, and Don Edwards NWR. The sites correspond to three different salinity and soil moisture levels, with Cosumnes being a drier freshwater site, San Pablo Bay having near saturated soils with intermediate salinity, and Don Edwards NWR having wet soils and high salinity.

At each location, 16 study plots were established to examine the effects of salinity and soil moisture on *L. latifolium* characteristics. In each study plot, the inflorescence number and inflorescence height was recorded for each plot. In addition, soil samples were collected to examine salinity and soil moisture conditions at each location. To assess the reproductive potential of *L. latifolium* along salinity and soil moisture gradients seed production was assessed by bagging one inflorescence per plot.

Field effects on seed quality were then assessed at each study site by placing seeds in nylon biopsy bags that were then buried in the soil at each study plots. The bags were then recollected from the field after 1, 3, 5, and 7 months. Seed viability was then compared to seed kept in dry storage at room temperature.

Viability was assessed before seeds were placed in the field and immediately following each collection time. Upon collection from the field, seeds were germinated in a greenhouse for one week. After seven days, all of the seeds that germinated in a greenhouse for one week. After seven days, all of the seeds that germinated were removed and the remaining seed were scarified to help break any dormancy. The scarified seed was then placed back out in the greenhouse for three more days. Seed that didn't germinate in the greenhouse were then treated with tetrazolium red to determine viability.

To determine the distance and rate of seed dispersal, five additional dispersal plots were established at each site. To ensure isolation, all other *L. latifolium* inflorescences within 10 meters of a target plant were removed. Three transects were established radiating out from each target plant. Each transect consisted of 11 plywood trap platforms spaced from 0 to 5 meters from the target plant in half meter intervals (Figure 2). The trap size was scaled to the dispersal distance, such that the percent area being sampled remained consistent with distance. This provided even sampling intensity with distance from the target plant. After two weeks in the field the dispersal traps were examined for *L. latifolium* seed. Trap collections were carried out 8 times during the season.

RESULTS

Inflorescence number tended to decline in drier soils, but this trend was not statistically significant ($P= 0.4992$). Inflorescence number was lowest at Cosumnes River Preserve with 33.9. Don Edwards NWR had 35.1, and San Pablo Bay NWR had 45.1 (Table 1).

Inflorescence height at Cosumnes River Preserve averaged 115.8 cm, Don Edwards NWR averaged 115.2 cm, and San Pablo Bay NWR was 104.5 cm (Table 1). Site averages were not significantly different ($P= 0.2708$).

Seed production differed from one site to another. Cosumnes River Preserve averaged 3231 seeds per inflorescence, Don Edwards NWR had 2297, and San Pablo Bay NWR averaged 424 (Table 1). The difference in seed production between the sites was statistically significant ($P< 0.0001$). Across the salinity gradient there was a 29% reduction in seed production from the fresh water to the highest salinity site. Across the soil moisture gradient there was an 87% reduction from the driest to the wettest site. Peak seed production occurred at 5% soil moisture and dropped to zero with soil moistures greater than 50%. (Figure 3)

Soil samples taken from the three study sites quantified differences in salinity and soil moisture. Specifically, Cosumnes River Preserve had an average salinity of 2.7‰, and soil moisture of 17.8% by weight, San Pablo Bay NWR had 21.2‰ and 40.5%, and Don Edwards NWR had 30.3‰ and 27.6%. (Table 1)

TABLE 1. Plant Characteristics and seed viability at three sites in the San Francisco Bay Estuary

Study Site	Inflorescence Number†	Maximum Inflorescence Height (cm)	Seed Produced*	Seed Viability (%)	Soil Moisture (%)	Salinity (‰)
Cosumnes River Preserve	33.88	115.84	3231.50	96.40	17.83	2.67
San Pablo Bay NWR	45.09	104.45	424.46	89.00	40.51	21.20
Don Edwards NWR	35.09	115.16	227.25	49.80	27.59	30.28

† Inflorescence per square meter
* Seed produced per inflorescence

Seed viability varied between seed sources. Cosumnes River Preserve had an average viability rate of 96%, Don Edwards NWR averaged 50%, and San Pablo Bay NWR averaged 89% (Table 1). Tetrazolium tests following germination demonstrated little to no observed seed dormancy. Less than 1% of nongerminating seed were shown to be viable. Seed source significantly influenced seed viability ($P< 0.0001$). Soil moisture effects on viability were muted with an 8% decrease from the driest to the wettest sites. Seed viability decreased by 49% from the freshwater to the most saline site. Seed mortality remained below 10% for salinities less than 15‰ but mortality approached 100% at salinities above 45‰ (Figure 4).

Field exposure had little impact on seed viability over the 7 months of field study. Only Cosumnes River Preserve showed a decrease in viability, after 7 months in the field with a 17% decrease in viability.

Seed dispersal profiles were obtained for Cosumnes River Preserve and Don Edwards NWR. Seed dispersal profiles were very similar at both Cosumnes River Preserve and Don Edwards NWR (Figure 6). Mean dispersal distance showed that Cosumnes River Preserve averaged 116 cm and Don Edwards NWR averaged 94 cm but this was not statistically significant ($P=0.1815$).

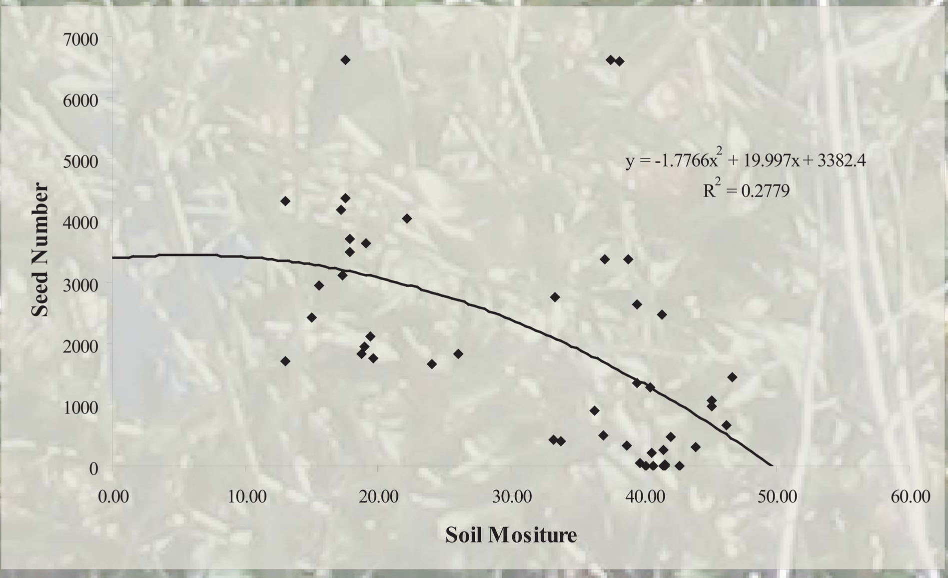

Figure 3. Number of seed produced per inflorescence along a soil moisture gradient.

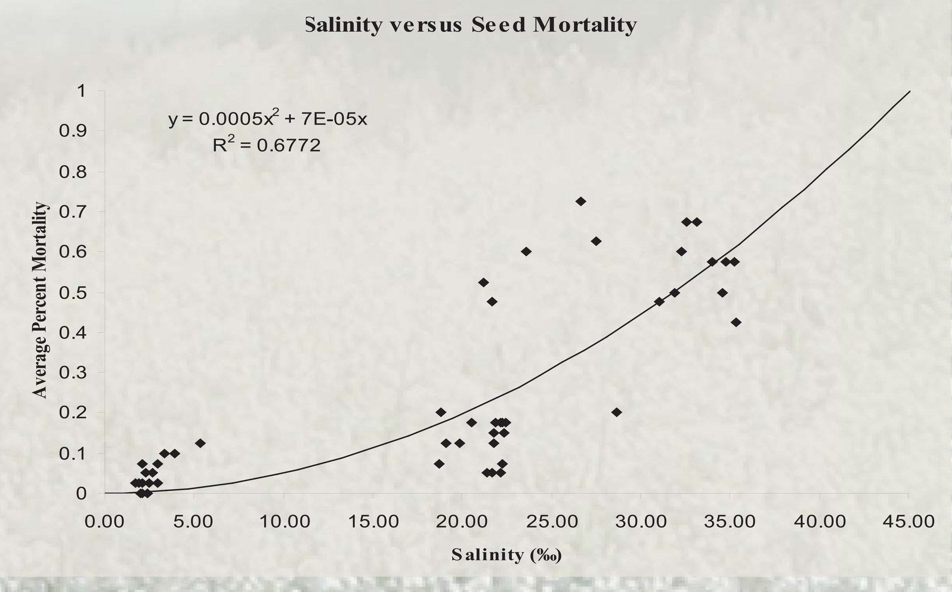

Figure 4. *Lepidium latifolium* seed mortality along a salinity gradient.

DISCUSSION

Although salinity and soil moisture are important factors in predicting the relative success of *L. latifolium*, their effects were muted in the adult life stage. Salinity and soil moisture had no significant impact on inflorescence number or inflorescence height. Although reductions in biomass have been found5 with prolonged exposure to flooded conditions, this study found no significant reduction in inflorescence height or density. This suggests that although total biomass may be reduced, *L. latifolium* maintains a high release point for dispersing seed.

Maintaining a high release point may come at the expense of seed production. Under high moisture, seed production was drastically reduced (Table 1). This reduction manifested as a withering of inflorescences after flowering in wet locations. *Lepidium latifolium* preserves its dispersal potential by maintaining a high release point but reduces the total number of offspring.

This relationship may be explained by the fact that *L. latifolium* have carbohydrates stored in its root system.[10,11,12] In the spring when flowering occurs, stores are high, but as the season progresses these stores wane. In this way *L. latifolium* can endure short periods of stress which imparts early season resistance to anoxic stresses. This is supported by field observations which showed plentiful flowering followed by seed abortion and withering inflorescences, when anoxic stresses are not ameliorated.

Stresses from salinity and soil moisture can also affect the quality of *L. latifolium* offspring. Viability declines drastically with increasing salinity (Figure 4). This decline in viability manifested as a dimpled appearance in seed grown under high salinity conditions. This effect of salinity stress is acting on the seeds themselves as opposed to the parent plants. As evidenced by the aborting of seed rather than produce seed of lesser quality. Since the stress acts on the seed itself, these stresses must occur prior to seed coat hardening. This is supported by the fact that once seed are developed, effects of field exposure are muted (Figure 5). This reduction in seed quantity and quality suggest that the seed life stage is very susceptible to environmental stresses.

The reduction in seed viability in high salinity environments suggests that these sites may have some inherent resistance to *L. latifolium* invasion. Even if adults are able to produce a large number of seeds, these seeds have reduced viability and a decrease in their colonization potential. Therefore, high stress sites may have an increased resistance to *L. latifolium* invasion by exerting stress on both the parent plants and the seed.

Seed dispersal showed very little change from one source to another (Figure 6). It is clear from the study of plant characteristics that factors such as plant height are unaffected. Since *L. latifolium* seed have no specialized seed structures to aid in dispersal, the distance a seed is dispersed is dictated more by the adult than the offspring. Since salinity and moisture stress show no significant impact on adult *L. latifolium*, differences in dispersal distances should not be expected. Therefore, even though salinity and soil moisture have negative impacts on the quantity and quality of seed being dispersed, there appears to be no difference between these seeds in terms of their dispersal distance.

Figure 5. Effects of field exposure on seed viability at three sites in the San Francisco Bay Delta.

CONCLUSION

This study has shown that *L. latifolium* reproductive potential has varying success along gradients of salinity and soil moisture. It has also shown that salinity and moisture stresses act strongly on *L. latifolium* by reducing the number and quality of seed produced while the adult characteristics were unaffected. These results clearly demonstrate that drier freshwater sites have a greater reproductive potential than wetter saline sites.

This study also showed that *L. latifolium* seeds retain viability in the seed bank, and that salinity and soil moisture stresses are often variable. It is reasonable to assume the reproductive potential may build up over time in unfavorable years thereby increasing the reproductive potential in more favorable years which may lead to episodic recruitment.

In addition to providing a glimpse into the invasion potential of *L. latifolium* along salinity and moisture gradients, this study also imparts a set of management goals to reduce and prevent *L. latifolium* invasion. First it suggests that identifying areas most susceptible to invasion is crucial for preventing rapid colonization. It also suggests that when funds are limited, treatment dollars may be best spent in areas with high risk. In this way, this study serves as a means to promote both our scientific understanding of *L. latifolium* as well as our methods for managing it.

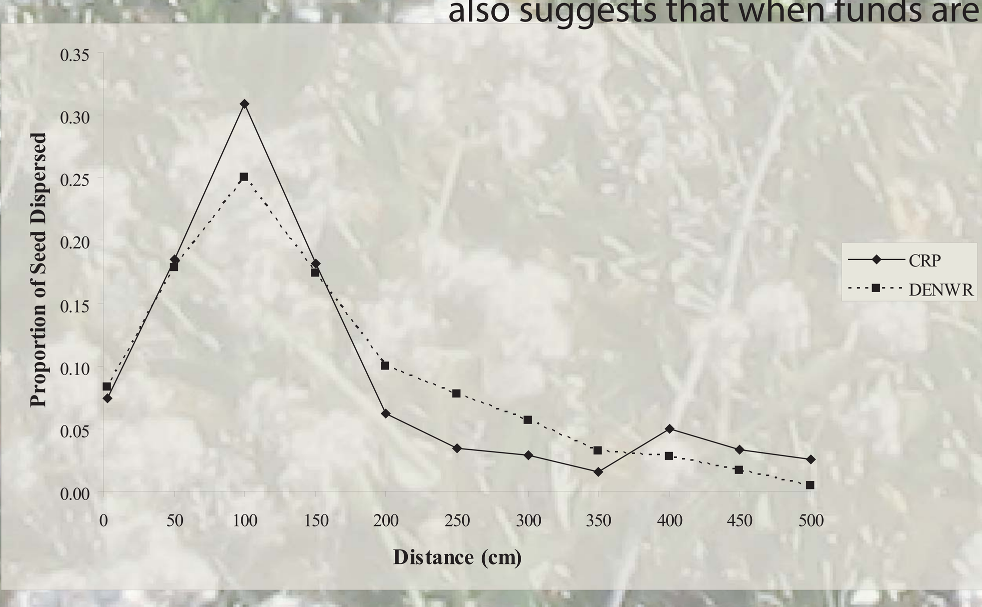

Figure 6. *Lepidium latifolium* dispersal distance at two sites in the San Francisco Bay Delta.

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