DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

Project Information

1. **Proposal Title:**

   DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

2. **Proposal applicants:**

   Chris Rogers, Environmental Science Associates
   Tom Parker, San Francisco State University
   Diana Benner, San Francisco State University
   Joel Trumbo, California Department of Fish and Game

3. **Corresponding Contact Person:**

   Chris Rogers
   Environmental Science Associates
   1000 Broadway #410 Oakland CA 94607
   415 896-5900
   crogers@esassoc.com

4. **Project Keywords:**

   Aquatic Toxicity
   Geographic information systems (GIS)
   Wetlands Ecology

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   Non-Native Invasive Species

8. **Type of applicant:**

   Private for profit

9. **Location - GIS coordinates:**

Latitude: 38.145

Longitude: -121.983

Datum:

Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.

Grizzly Island Wildlife Area, Van Sickle Road, Solano County (field experimental studies). Mapping component of project to include San Francisco Bay and Sacramento-San Joaquin Delta.

10. **Location - Ecozone:**

    2.1 Suisun Bay & Marsh, 2.2 Napa River, 2.3 Sonoma Creek, 2.4 Petaluma River, 2.5 San Pablo Bay, Code 15: Landscape

11. **Location - County:**

    Alameda, Contra Costa, Marin, Napa, Sacramento, San Francisco, San Joaquin, San Mateo, Santa Clara, Solano, Sonoma

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    Yes

    If yes, please list the city: Many cities around San Francisco and San Pablo Bays.

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    5, 6, 7, 8, 9, and others

15. **Location:**

    California State Senate District Number: several

    California Assembly District Number: several

16. **How many years of funding are you requesting?**

    3

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

No

If no, list single overhead rate and total requested funds:

Single Overhead Rate: 15

Total Requested Funds: 337,050

b) Do you have cost share partners already identified?

No

c) Do you have potential cost share partners?

No

d) Are you specifically seeking non-federal cost share funds through this solicitation?

No

If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

No

Have you previously received funding from CALFED for other projects not listed above?

No

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

No

Have you previously received funding from CVPIA for other projects not listed above?

No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

No

Please list suggested reviewers for your proposal. (optional)

21. **Comments:**

Environmental Compliance Checklist

DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No

   b) Will this project require compliance with NEPA?

      No

   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      The project consists of research only.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   <u>CEQA Lead Agency:</u>
   <u>NEPA Lead Agency (or co-lead:)</u>
   <u>NEPA Co-Lead Agency (if applicable):</u>

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   CEQA
   -Categorical Exemption
   -Negative Declaration or Mitigated Negative Declaration
   -EIR
   Xnone

   NEPA
   -Categorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   Xnone

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

      Not Applicable

   b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

LOCAL PERMITS AND APPROVALS

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other

STATE PERMITS AND APPROVALS

Scientific Collecting Permit	Required, Obtained
CESA Compliance: 2081	
CESA Compliance: NCCP	
1601/03	
CWA 401 certification	
Coastal Development Permit	
Reclamation Board Approval	
Notification of DPC or BCDC	
Other	

FEDERAL PERMITS AND APPROVALS

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit

Rivers and Harbors Act

CWA 404

Other

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land. Agency Name: CDFG	Required
Permission to access state land. Agency Name: SLC, DWR	Required
Permission to access federal land. Agency Name: USFWS, BOR	Required
Permission to access private land. Landowner Name: unknown	Required

6. **Comments.**

Land Use Checklist

DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   Yes

3. **Do the actions in the proposal involve physical changes in the land use?**

   No

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   Research only.

4. **Comments.**

Conflict of Interest Checklist

DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

Applicant(s):

Chris Rogers, Environmental Science Associates
Tom Parker, San Francisco State University
Diana Benner, San Francisco State University
Joel Trumbo, California Department of Fish and Game

Subcontractor(s):

Are specific subcontractors identified in this proposal? Yes

If yes, please list the name(s) and organization(s):

Diana Benner	San Francisco State University
Joel Trumbo	CDFG

Helped with proposal development:

Are there persons who helped with proposal development?

Yes

If yes, please list the name(s) and organization(s):

Tom Parker SFSU

Diana Benner SFSU

Joel Trumbo   CDFG

Comments:

Budget Summary

DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

Independent of Fund Source

Year 1												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary** *(per year)*	**Benefits** *(per year)*	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	Distribution and Characterization of Invaded Habitats	1092	85480	included in hourly rates	1800	1000	200	4500		92980.0		92980.00
2	Field and Greenhouse Experimentation on Competitive Ability	425	17000	included in hourly rates	1500	750	200			19450.0		19450.00
3	Herbicide Hazard Assessment	200	19000	3000		2000	30000			54000.0	10,800	64800.00
		1717	121480.00	3000.00	3300.00	3750.00	30400.00	4500.00	0.00	166430.00	10800.00	177230.00

Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary** *(per year)*	**Benefits** *(per year)*	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	Distribution and Characterization of Invaded Habitats	867	71250	included in hourly rates	1200	1500	200	0		74150.0		74150.00
2	Field and Greenhouse Experimentation on Competitive Ability	425	17000	included in hourly rates	1400	750	1000	0		20150.0		20150.00
3	Herbicide Hazard ASsessment	0	0	0	0	0	0	0	0	0.0	0	0.00
		1292	88250.00	0.00	2600.00	2250.00	1200.00	0.00	0.00	94300.00	0.00	94300.00

Year 3													
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	Distribution and Characterization of Invaded Habitats	624	51920	included in hourly rates	1000	2500	500	0	0	55920.0	0	55920.00
2	Field and Greenhouse Experimentation on Competitive Ability	212	8500	included in hourly rates	400	200	500	0	0	9600.0	0	9600.00
3	Herbicide Hazard ASsessment	0	0	0	0	0	0	0	0	0.0	0	0.00
		836	60420.00	0.00	1400.00	2700.00	1000.00	0.00	0.00	65520.00	0.00	65520.00

Grand Total=337050.00

Comments.

Budget Justification

DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

Direct Labor Hours. Provide estimated hours proposed for each individual.

Tom Roberts (project director) - 97 Chris Rogers (project manager) - 436 Martha Lowe (project biologist) - 592 Mark Fogiel (project biologist) - 592 Kelly Runyon (GIS specialist) - 284 Eloise Anderson (GIS technician) - 452 Diana Benner (project biologist) - 1050 Joel Trumbo (herbicide assessment) - 200

Salary. Provide estimated rate of compensation proposed for each individual.

Tom Roberts (project director) - 125/hr Chris Rogers (project manager) - 100/hr Martha Lowe (project biologist) - 65/hr Mark Fogiel (project biologist) - 65/hr Kelly Runyon (GIS specialist) - 100/hr Eloise Anderson (GIS technician) - 65/hr Diana Benner (project biologist) - 40/hr Joel Trumbo (herbicide assessment) - 95/hr

Benefits. Provide the overall benefit rate applicable to each category of employee proposed in the project.

included in hourly rates except Joel Trumbo (10%)

Travel. Provide purpose and estimate costs for all non-local travel.

Travel to Grizzly Island (Solano County) for field experiments and collection of materials for lab and greenhouse experiments - $3,000 Travel to wetland sites throughout SF Bay, San Pablo Bay, Suisun Bay and Delta to map pepperweed poulations - $4,000

Supplies & Expendables. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

Office - 2500 Laboratory - 1700 computing - 2500 field - 2000

Services or Consultants. Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

UC Davis soils analysis - $1,000 Toxicology analysis (CDFG) - $30,000 Photo and printing services - $1,000

Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

None greater than $5,000. GIS mapping unit and supplemental correction beacon expected to cost ~$4,500.

Project Management. Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

Project Director's cost (97 hours, $12,410) and approximatelt 1/2 of project manager's cost (220 hrs, $22,000) would be for project oversight, coordination of team, coordination with funding agency, and presentation of results. Additional costs are associated with preparation annual reports for Task 1 (approximately 150 hrs/yr. $12,000/yr)

Other Direct Costs. Provide any other direct costs not already covered.

No other direct costs.

Indirect Costs. Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

THERE IS NO OVERHEAD ON THE TOTAL BUDGET.

Executive Summary

DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

The proposed project will help CALFED meet key milestones for the MSCS and ERP goals and objectives for At-Risk species and implement non-native species (NIS) management. The project will conduct research on distribution of perennial pepperweed (Lepidium latifolium) in the Bay-Delta, and develop GIS mapping of this region-wide inventory. Additional field data and publicly available information will be incorporated to create a spatial model of invaded habitats. The model will be a valuable asset to continuing monitoring of invaded areas, and will provide a predictive tool to identify habitats at risk of invasion. A second component of the project will consist of field, laboratory and greenhouse experimentation on the mechanisms of invasion by pepperweed, with emphasis on how it modifies its soil environment and reduces the ability of native species to compete with it. Levels of mycorrihzal associations within invaded an non-invaded habitat also will be assayed. The third component of the project will evaluate the fate of herbicides increasingly applied to control pepperweed, and the potential impact of these chemicals on aquatic biota adjacent to treated upland infestations.

Proposal

Environmental Science Associates

DISTRIBUTION AND ECOLOGY OF LEPIDIUM LATIFOLIUM IN BAY-DELTA WETLANDS

Chris Rogers, Environmental Science Associates
Tom Parker, San Francisco State University
Diana Benner, San Francisco State University
Joel Trumbo, California Department of Fish and Game

CALFED Ecosystem Restoration Proposal

DISTRIBUTION AND ECOLOGY OF *LEPIDIUM LATIFOLIUM* IN BAY-DELTA WETLANDS

PROJECT DESCRIPTION

This proposal outlines a complimentary set of studies that confront the issue of perennial pepperweed (*Lepdium latifolium*) invasion in the San Francisco Bay and Sacramento-San Joaquin Delta (the Bay-Delta). Each of the three proposed studies, or tasks, will consist of a separate inquiry that will provide valuable information and understanding of the species, its ecological role in native and restored habitats, and the environmental consequences of efforts to control it.

The three primary tasks of this investigation are:

- To increase documentation of distribution of this species within the Bay/Delta region, and to create a spatial model using GIS to evaluate its occurrence on a continuum from newly-established (*i.e.*, restored) marsh habitats to long-established ones, as well as other site characteristics. The GIS model would not only stand as an inventory of the species distribution, but also would provide insight into conditions that render a site susceptible to invasion.

- To conduct experiments in the field, laboratory and greenhouse to investigate pepperweed's ability to successfully out-compete native marshland species, including the effects of allelopathy and salinity on another native species, and to explore the role of mycorrhizal fungi in below-ground interactions, and

- To conduct ecotoxicological research on the fate of chemical herbicides used to eradicate or control perennial pepperweed, with particular focus on effects on waterways adjacent to treated upland populations.

Each of these primary tasks would be completed by researchers from Environmental Science Associates, San Francisco State University, and California Department of Fish and Game.

PROBLEM STATEMENT

Distribution and Effects on Invaded Habitat

Lepidium lartifolium, or perennial pepperweed, is fast becoming one of the most prevalent weeds in wetlands throughout the Bay and Delta. Perennial pepperweed has been established in California since the 1940's, and currently is found in all but two counties. This extremely competitive weed forms colonies that dominate wetland areas creating nearly complete monocultures once established. It aggressively invades natural habitats as well as recently restored or enhanced locations, especially wetlands, and in so doing may prevent ecosystem restoration goals from being met in those areas. The result in either case is a loss of otherwise native and productive wetlands habitat and reduction in native diversity and habitat quality (Young et al, 1997). Pepperweed poses a serious threat to many native ecosystems and recently restored areas by displacing native vegetation, altering habitat for threatened and endangered species, such as the salt marsh harvest mouse (Trumbo, 1994) or clapper rail and black rail. Pepperweed also may reduce waterfowl nesting in and near wetlands that it invades (Trumbo 1994). This plant exists in all except for two counties in California and has invaded agricultural, riparian and wetland habitats. At present it is listed by Cal Exotic Pest Plant Council as a List-A species, a designation requiring the highest priority for management, control, eradication, and continuing study of demography and ecological characteristics.

Control of pepperweed is a high priority throughout the San Francisco Bay Delta and elsewhere in California and other western states. CALFED's goals lists pepperweed explicitly as a priority for study and control. CALFED agencies have designated contacts for the species (Kim Webb, U.S. Fish and Widlife Service; Joel Trumbo, California Department of Fish and Game). The California Exotic Pest Council (CalEPPC) and the Nature Conservancy recognize classify Perennial pepperweed as a high priority threat to natural ecosystems, particularly wetlands.

The species spreads rapidly by rhizomes, and is easily and inadvertently transported from site to site by seeds or by water. When a source population is near, it rapidly colonizes bare or disturbed soil. Often, both these conditions prevail at recent restoration project sites immediately before and after planting occurred, rendering them highly susceptible to invasion at a time when much of the resources available for restoration may already have been expended. .

The species apparently has the advantage of initiating germination and re-growth from rhizomes earlier in the growing season compared to native marsh plant species. Perennial pepperweed is well-established by spring, giving it a competitive advantage for light and nutrients over native marsh vegetation, which is of particular importance in areas that are being revegetated with native plants. However, the species does not tolerate flooding, which poses one possible solution to the problem.

Mechanisms of Invasion

This research will explore adaptive factors contributing to establishment of dense monocultures of pepperweed in tidal wetland habitats and precluding the re-establishment of native vegetation in areas where control efforts have been successful. This study focuses on the mechanisms by which pepperweed modifies the soil environment in a tidal wetland habitat. We hypothesize four critical aspects of this mechanism may be:

1) *That deep thatch layer associated with established stands may be altering soil conditions to the extent of inhibiting native seedling germination and growth*

   a) *by accumulating excessive salts on soil surface or through production of allelopathic organic compounds, or*

   b) *by preventing light penetration to germinating plants.*

   Pepperweed has been shown to alter its habitat by taking salt ions from deep in the soil profile and depositing them near the soil surface (Blank & Young, 1997). This results in a build up of salts in plant biomass. Young et al (1997) proposed that this "may be extremely significant over prolonged periods".

According to Evenari (1949) mustard oils, potent inhibitors of seed germination and of microorganisms, are produced by all organs of plants belonging to the Cruciferae (Brassicacae). Research conducted by Bieber and Hoveland (1968) found that water extract of *Lepidium virginicum* was very toxic and inhibited seed germination in several species including *Festuca arundinacea*, *Tripolium incarnatum*, and *Lespedeza cuneata*, to name a few.

Old stems take several years to degrade and litter depth can reach upwards of 10 cm (Renz & DiTomaso, 1998a). Few plants besides perennial pepperweed have enough stored energy to grow through this dense litter layer. Renz (2001) suggests in his Nature Conservancy Species Abstract that "even if perennial pepperweed is controlled, it may be necessary to remove the litter to stimulate germination and growth of desirable plant

Greenhouse and field experiments will be conducted to explore these effects.

2) *That since pepperweed is a non-mycorrhizal species, mycorrhizal potential of soils (mycorrhizal fungal spores or hyphae) dominated by pepperweed will decline the longer it is in residence at a site. A decrease in mycorrhizae densities may negatively affect native mycorrhizal species that compete with pepperweed.*

As of yet, the effect of monospecific stands of pepperweed on the composition of soil mycota in tidal wetland areas remains unexamined. Early studies indicated that there were few mycorrhizal fungi occurring in aquatic or wetland plants (Harley 1969, Khan 1974, Powell 1975) but recently, numerous authors have found significant mycorrhizal fungal colonization rates within various wetland ecosystems (Sondergaard and Laegaard 1977, Bagyaraj et al. 1979, Anderson et al, 1984, Farmer 1985, Newman and Reddell 1987, Rickerl et al. 1994). Evidence that arbuscular mycorrhizae influence the growth of native plant species (Aldon 1975; Allen, Sexton et al, 1981; Allen, Smith et al. 1981; Allen, 1982; Wallace 1981; Wallace et al. 1982; Hays et al. 1982) has led to hypotheses that mycorrhizae may regulate plant communities, including composition, competition, and succession (Nicolson & Johnston, 1979; Reeves et al. 1979; Janos 1980; Trappe 1981; Chiariello et al. 1982; Allen 1984).

These mycorrhizal models are critical in light of pepperweed belonging to the generally non-mycotrophic Brassicaceae family (Harley & Smith, 1983). In areas where monocultures of pepperweed have been established for an extended amount of time, mycorrhizal fungal densities may be reduced to such a level as to reduce the ability of native species to compete. Mycorrhizal inoculates have been incorporated into restoration strategies in certain habitats. Smith et al. (1998) found that within a year, prairie plots inoculated with mycorrhizae showed a greater percent cover of native species to plots lacking inoculates. Further exploration into the role of the mycorrhizal fungal community in these tidal habitats may give clues not only to the success of pepperweed but also to factors that may enhance restoration efforts.

3) *That the phenology of pepperweed results in a competitive advantage over native species.*

Renz (2000) (and personal observations) noted that shoots of the pepperweed generally emerge before those of most native species. Young et al (1997) pointed out that “at flowering time, the stands are usually so thick that virtually no light reaches the soil surface”. Blank and Young (1997) state that “a key to its competitiveness in colony form is the large amounts of reserves stored in perennating organs that enable the plant to rapidly produce foliage and thus a high density of plant cover (Grime 1974). This results in reduced sunlight at the soil surface providing an additional competitive advantage (Radosevich and Holt 1984).

Field plots with differential clipping protocols will be established to monitor this variable.

4) *That pepperweed is affecting nutrient cycling to the extent of precluding success of native seedlings.*

Studies by Blank and Young (1997) found notable differences in soil properties between pepperweed -invaded and non-invaded areas. They found extraordinarily high levels of water-soluble ammonium and low C:N ratios in litter layers. Young et al (1997) proposed that “the consequences of this build up on carbon-nitrogen ratios over time may be very significant”. Despite these findings they concluded that it remains “unclear how nutrient cycling, particularly nitrogen cycling, will differ in pepperweed monocultures compared to diverse native communities”. Exploration of this factor will be accomplished through the collection of soil samples for analysis and greenhouse growth studies to examine differential growth in field soil samples collected from areas with dense pepperweed growth and areas with native species.

Location of all field components of this experiment will be coordinated with California Department of Fish and Game employee Joel Trumbo. Initial site locations proposed include Grizzly Island or Mare Island. Research possibilities for Grizzly Island site have been initiated with reserve manager Conrad Jones. Initial phase experiments require very minimal field impact. All greenhouse experiments will be conducted at San Francisco State University. Two greenhouses, one entirely dedicated to research, are available and two laboratory spaces containing most necessary equipment for field and laboratory experiments and data collection are at the disposal of this research project.

The ultimate goal of this research will be to provide a more comprehensive understanding of the mechanisms enabling this plants domination of wetland habitats so that future restoration efforts may take into consideration soil conditions that may preclude attempts at revegetation with native species.

Herbicide Control

To date, with exception of continual flooding, no non-chemical treatments have been found to effectively control pepperweed. However, it also is not known if plants will reestablish if the flooding regime is removed from these areas (Fredrickson & Murray, 1999). The most effective herbicide identified at present, chlorsulfuron, is registered only for non-crop areas in most states and cannot be applied near or over water (Renz, 2001). Further restriction of the use of chemical herbicides in aquatic environments have recently been imposed by the Regional Water Quality

Control Boards. Even with use of the most successful herbicide treatments limited recovery of desirable plants is seen in controlled areas (Renz, 2001).

An additional component of the problem is that little is known of the environmental fate of chemicals used to treat pepperweed, as well as other weeds that invade native habitats. The third primary task of this proposal consists of a study of movement of these chemicals after application and potential impacts on biota.

JUSTIFICATION

The spread of populations in the Bay-Delta has been previously documented (SFEI 1998), but there is a need to continue this process of monitoring and updating the knowledge base of the species' distribution. By their nature, biological invasions are constantly undergoing change, and new

In contrast, there is little known about the ecology of the species. For example:

- The life history of pepperweed includes early germination and establishment relative to the native tidal marsh species with which it commonly occurs. Pepperweed may occupy a reproductive niche that is without a native species counterpart, offering it further competitive advantage.
- While it is known that that pepperweed rapidly colonizes disturbed sites, little is known about the rate of invasion or the actual mechanism by which it reaches sites.
- Plants in the mustard family (Brassicaceae) rarely form mycorrhizal associations, a condition that often confers a competitive advantage on species that invade habitats dominated by native species. How is pepperweed able to invade undisturbed wetland habitats without this competitive advantage?

The tasks described in this proposal will address these gaps in the knowledge of this species and the biology of its invasion. This information will assist public and private land managers with responsibilities to preserve wetlands habitat quality to

- update documentation of current distribution within the Bay-Delta region
- identify conditions that place existing and restored habitats at greatest risk of invasion
- identify modes of establishment and invasion, and it effects on native species when it is established.
- characterize ecological traits that make pepperweed a successful invader

APPROACH

This pepperweed study project is divided into three primary tasks. Each task is designed to answer specific questions, which are summarized in Table 1, to develop a better and more current understanding the species distribution, invasion trends, habitats or areas at risk and ecological characteristics. This information will lead to developing better strategies for control, as well as anticipating and responding to invasions of restoration sites. The first two tasks require field data gathering, analysis and the development of models on the population demography and habitat ecology. Each of these tasks is independent and will be conducted separately by members of the project team. The third task involves education and outreach to provide information to public agencies, land managers, cities, conservation organizations and private individuals with a responsibility or interest in control of the species.

Task 1 – Distribution and Characterization of Habitats

The first component of this plan consists of updating distribution mapping of pepperweed in the Bay Delta region. This effort would add to the information summarized in the San Francisco Estuary Institute's *Introduced Tidal Marsh Plants in the San Francisco Estuary* (SFEI 1998) and other recent inventory work (May, 1998). Extensive field reconnaissance is included in this proposal, and would include surveys by botanists on foot or in small watercraft. The location of pepperweed populations would be recorded using GPS for accurate mapping of the population in relation to other documented sites or native habitat. At the outset, the goal would be to document populations throughout the study area that typify the range of wetland and adjacent upland habitats that the species invades.

In addition to documenting the occurrence of the species at a site, investigators would record information on a suite of site conditions, including

- vegetation composition (qualitative assessment)
- vegetation communities adjacent to the pepperweed invasion site
- tidal regime
- native versus restored marsh
- relative age of site
- relative disturbance of site
- distance to nearest pepperweed population
- adjacent land uses

In addition to field-collected data, existing data would be incorporated into the GIS, including known occurrences of special status species proximate to pepperweed populations, exposure to currents, and site management, especially any history of past herbicide treatment , as available. In addition, examination of populations not invaded may give insight into plants that compete more effectively with pepperweed and/or conditions that favor native species over the invasive.

This information would be incorporated into a GIS using Arcinfo to create a spatial model of the distribution of pepperweed. The model would analyze population locations on the basis of the site descriptors. The GIS would be selectively accessible while under development to encourage participation in the process of documentation. Sites documented by others would be accepted for inclusion in the or GIS if it is reliably documented according to the standards of this project. By maintaining and using the GIS interactively, it would become a valuable management asset. Areas most susceptible to invasion could be identified, especially those that also harbor important biological resources. The effectiveness of various methods of control, as determined by field monitoring by public land managers (for example, CDFG, East Bay Regional Parks, USFWS) could be incorporated into the GIS by modifying the attributes of populations over time.

Task 2 – Field and Greenhouse Experimentation on Competitive Ability of *Lepidium latifolium*

So far, an effective strategy for the management of pepperweed has not been discovered. Certain herbicides have varied success rates, with Telar being the most effective, but several of these have limited range of use in wetland areas and/or require multiple applications over several years. Critical in understanding how to control this invasive species is an understanding of the factors involved in its ability to successfully outcompete native marshland species. The second component of this project entails a combination of field and greenhouse experiments coordinated by a San Francisco State graduate student to address the factors involved in the high competitive ability of this noxious weed. The focus of this research will be to explore adaptive factors contributing to establishment of dense monocultures of pepperweed in tidal wetland habitats and that preclude the re-establishment of native vegetation in areas where control efforts have been successful.

To assess effect of litter layer in relation to salinity:

1. In the field: Soil salt concentrations in will be compared beneath 10-1 m2 quadrats of natives vegetation and 10-1m2 stands of pepperweed monocultures by collecting 5 cc soil cores (0-5 cm depth), extracting salt, and analyzing salt concentrations using a salinity refractometer. . Core sampling will begin in the Fall 2002, before the rains begin, and continue on a monthly basis until natives are seen to be germinating in the spring. An ANOVA will be used for statistical analysis.

2. In the laboratory: Germination experiments will be conducted on pepperweed and marsh gumplant (*Grindelia stricta* var. *angustifolia*) seeds on filter paper in petri dishes. Treatments will include water and four salinity treatments based on range found in the field. Protocol will involve ~ twenty seeds each dish, 5 replicates of dishes for each treatment, and the entire experiment will be repeated three times. An attempt to compensate for the difficulty in accuracy of seed count for *Grindelia stricta var. angustifolia* will be through a weight correlation for each study in which this amount of the species is the goal. A one-way ANOVA will be used for statistical analysis.

3. In the greenhouse: Germination and competition experiments will be conducted on pepperweed and marsh gumplant seeds planted in sand in pots maintained at different concentrations of salinity. Protocol will again involve twenty seeds of each species used in each pot, 5 replicates of each treatment, and the entire experiment conducted three times. A one-way ANOVA will be used for statistical analysis.

To assess affect of litter layer as a source of allelopathic compounds:

1. Litter will be collected from field site prior to winter rains. An initial experiment will use a litter leachate that will be obtained from shaking 5 g of litter for 2 h in 100 ml distilled water. Salinity of the leachate will be determined by a salinity refractometer. Fresh leachate will be prepared for each treatment application.

a) In the laboratory: Germination experiments will be conducted on pepperweed and marsh gumplant on filter paper in petri dishes treated with distilled water (or a saline solution that matches the salinity of the leachate) as a control and litter leachate as treatment. Protocol will involve twenty seeds of each species used in each dish, 10 replicates of each treatment, and the entire experiment will be conducted three times. A one-tailed t-test will be used for statistical analysis.

b) In the greenhouse: Germination and competition will be conducted on pepperweed and marsh gumplant seeds planted in sand in pots treated with either distilled water or leachate, respectively. Protocol will again involve twenty seeds of each species used in each pot, 10 replicates of each treatment, and the entire experiment conducted three times. Growth will be assessed through stem height, number of leaves and above ground biomass after 3- month growing period A one-tailed t-test will be used for statistical analysis.

To assess effect of litter layer in field:

1. In the field: 10-2m x 1m plots will be established in areas with mixed pepperweed and native vegetation. Within each of these plots litter layer will be removed from half of the plot. Percent cover of species will be assessed in these plots quarterly for one year. Statistical analysis will be performed with a within sample t-test.

To assess the affect of pepperweed monocultures on mycorrhizal densities:

1. In the field: Twenty soil sample cores, 5 cc (0-5 cm depth), will be collected from same sites used in field salinity assessment (10 native stands, 10 pepperweed). Soils will be analyzed for spore count using standard sucrose density technique. A 1-tailed t-test will be used for analysis.

2. In the greenhouse: Germination and growth of marsh gumplant will be assessed in soils collected from and distributed between areas of pepperweed infestation used for salinity sample cores. Soils samples will be thoroughly mixed to standardize site variations. Control treatments with no modification will be compared to samples inoculated with arbuscular mycohhrizae. Growth will be assessed through stem height, number of leaves and above ground biomass after a 3- month growing period.

To assess effect of differential phenology:

1. In the field: 27 2m x 1m plots will be established in areas with mixed pepperweed and native vegetation. The 27 plots will be randomly divided into three 9-sample sections. Clipping of pepperweed will be performed on half of each plot within a 9-sample section at two-week intervals after native germination commences. For all plots, identification of native species and percent cover of total native species will be assessed monthly for a 6-month period. A 2-factor ANOVA will be utilized in analysis.

To assess affect of pepperweed on nutrient cycling:

1. In the field: Soil sample cores, 5 cc (0-5 cm depth), will be collected from same 20 quadrats used for field salinity testing. After laboratory preparation of soil samples through sifting to 2 mm and extraction with KCl samples will be sent for analysis to the UC Davis for analysis. for analysis. Analysis of results will be performed using a one-tailed t-test.

   Eighty 5 cc core samples will be collected. Forty of these from areas with pepperweed monocultures and forty for stands of native vegetation. Soil collection will consist of about 120 gallons from sites with pepperweed infestation Collection will be coordinated primarily with site manager with input from Joel Trumbo (CDFG).

2. In the greenhouse: Germination and growth bioassay for pepperweed and marsh gumplant. will be conducted on soil samples collected from within stands of pepperweed infestation and stands of native species. Samples from each respective type of soil will be thoroughly mixed to standardize site variations. Treatments planted with both species will include: watering with distilled water as control, full nutrient treatment, and a treatment with nitrogen or phosphorus as limiting nutrient. Protocol will again involve twenty seeds of each species used per pot, 5 replicates of each treatment, and the entire experiment conducted three times. Growth will be assessed through stem height, number of leaves and above ground biomass after a 3- month growing period. Statistical analysis will be completed using a one-way ANOVA.

Field experiments will require the establishment of 57 plots total. Twenty of these will be square meter plots, 10 in pepperweed and 10 in native vegetation. Core samples and soil samples will be collected from these plots. Litter removal and selective clipping of pepperweed will be required in a total of 37-1 x 2 m plots with mixed pepperweed and native vegetation.

Seed collection needs include collection of approximately 5,500 seeds each from pepperweed and marsh gumplant. Collection will be dispersed throughout the site population, will include small percentages from each individual plant, but will focus on healthy individuals. Collection will be coordinated primarily with the site manager with input from Joel Trumbo (CDFG).

Task 3 – Herbicide Hazard Assessment

At the present time, several different herbicide products provide good to excellent control of pepperweed in many settings. However, the use of these products to control has not been widespread, particularly in wetland settings. This is primarily due to product label restrictions and concern regarding the off-target movement of the herbicide in surface water. This task would combine literature research as well as field sampling to determine the environmental fate and potential non-target impacts of the herbicide products in wetland settings. Of particular interest will be areas where limited research has been conducted. This may include topics such as:

- herbicide impacts to non-target plant species;

- environmental fate in surface water; and
- toxicological impacts to non-target aquatic fauna.

In addition to chemical analyses, toxicity tests using non-target aquatic invertebrates will be conducted. The research and compilation of information for this task will be completed by Joel Trumbo of the California Department of Fish and Game.

FEASIBILITY

Task 1 – Distribution and Characterization of Habitats

This proposal does not presume that a complete inventory of the distribution of pepperweed would be accomplished, but that a significant advance in the known distribution of the species would result. As important will be the supporting documentation of the habitats the species is observed in, and the resulting spatial model that will characterize the invasion. The proposed tasks are entirely within ESA's capability and experience with field assessment and GIS development. This proposal includes purchase of professional mapping grade GPS equipment with supplemental correctional beacon that will improve precision of the logged data points. All other necessary equipment are currently maintained by ESA.

Task 2 – Field and Greenhouse Experimentation on Competitive Ability of *Lepidium latifolium*

Field experiments an collection of seeds and soil will be coordinated with Joel Trumbo (CDFG), and would be located on CDFG-owned land. Laboratory facilities with all equipment and space necessary for described research are available and ready on the San Francisco State University campus. The two greenhouse facilities at SFSU have adequate space and necessities to fulfill experimental requirements. Tom Parker, principal investigator, has extensive experience in isolation and analysis of mycorrhizae as well as inoculate preparation and will supervise all mycorrhizal portions of the experiment. The majority of Task 2 would be completed by a graduate student research assistant dedicated to this project. Soil samples have routinely been sent for analysis to UC Davis by this and other laboratories from SFSU.

Task 3 – Herbicide Hazard Assessment

This component of the project is a continuation of ongoing efforts by CDFG pesticide coordinator Joel Trumbo to evaluate the effectiveness of chemical treatment of invasive plant species.

PERFORMANCE MEASURES

Project performance for all three of the primary tasks will be assessed on a the basis of meeting the proposed schedule (Table 1), which lists the key milestones and their projected date of completion. The distribution mapping task also would include interim an annual status report.

The GIS would be selectively accessible as it undergoes development to ensure its utility at the earliest stage, and to encourage its use by land managers and practitioners of invasive species control.

DATA HANDLING AND STORAGE

Field mapping will be assisted by professional mapping grade hand-held GPS units with expected accuracy of better than 10 meters. This level of accuracy is based on available satellite reception in open marsh and grassland habitats, but will be ensured utilizing differential correction. GPS data will only be taken when PDOP (position dilution of precision) is less than 5. Each GPS session performed by ESA will include GPS of at least one known point and will be differentially corrected.

Metadata will be in FGDC-compliant format. Data dictionaries (definitions of the fields) will be maintained for each attribute table. Attribute tables will be maintained with data important to long-term management and utilization of the information, including source of data (person or organization), accuracy, date, contact information, etc. Distinctions between differentially-corrected and uncorrected data will be maintained. Data will be in "shapefile" format. Legends will be developed for each data layer.

ESA will used the Teale data for county boundaries, bodies of water, streams and other useful reference features for mapping. The coordinate system will comply to either the State coordinate system (called "Teale Albers") or the Federal system for the greater Bay Area (UTM NAD83 Zone 10), as directed by Calfed.

Mapped data will be represented by use polygons throughout. Use a standard small triangle or hexagon for single occurrences, and big irregular polygons for patches of the stuff. Then, as a separate "theme" or layer, maintain a point coverage that is the centroids of all these shapes. Each of these approaches has advantages for certain types of analyses.

The data would be stored on ESA's secure server, with password-protected ftp privileges to select agencies or individuals. Ultimately, another repository in the public sector should be sought so that the data would be widely available and could be integrated with data and mapping efforts by others.

Data for field and greenhouse experiments will be recorded in Microsoft Excel files and analyzed with SPSS or other statistical software at SFSU or CDFG. All data and analysis will be discussed and shared with all parties and funding agencies involved, and made available to other interested entities, i.e., via ESA’s secure server.

Expected Products, Outcomes and Work Schedule

The following table summarizes the major tasks and associated work products and delivery schedules.

Table 1. Task Products/Outcomes and Schedule

Tasks	Product/Outcomes	Schedule (begin work)
Task 1	**Distribution and Characterization of Invaded Habitats**	
	Initiate studies	August 2002
	Field Mapping	Summer and Spring 2002-2005
	Year 1 Report	Submit report and database: June 2003
	Year 2 Report	Submit report and database: June 2004
	Final Report	Submit report and database: June 2005
Task 2	**Field and Greenhouse Experimentation**	
	Collect litter for allelopathy experiments Collect seeds of *Lepidium* and *Grindelia*, clean and store Commence collection for analysis of soil salinity before rains start and continue on a monthly basis until natives begin germinating in the spring Establish 10-2 x 1 m plots in mixed vegetation for field litter experiments. Referred to as litter sites herein.	August 2002
	Commence laboratory and greenhouse litter leachate experiments- 3 month growing time, completion ~May 2003 Establish salinity field plots. Establish phenology field plots.	Winter 2003
	Collect core samples from salinity plots and conduct salinity analysis. Commence studies in litter and phenology plots-completion Collect core samples for mycorrhizal studies, analysis completion	Spring 2003
	Commence greenhouse mycorrhizal studies 3-month growing period Commence greenhouse nutrient studies- 3-month growing period	Summer 2003
	Commence lab and greenhouse salinity experiments-3 month growing period	Fall 2003
	Final litter plots assessment.	Spring 2004
Task 3	**Herbicide Hazard Assessment**	
	Initiate studies	August 2002
	Complete studies and report	August 2003

APPLICABILITY TO CALFED ERP AND SCIENCE PROGRAM GOALS AND IMPLEMENTATION PLAN AND CVPIA PRIORITIES

This project presents opportunities to address ERP goals aimed at non-native invasive species (NIS), on three coordinated and complimentary fronts. These goals will served by efforts to improve knowledge of pepperweed's basic biology and demographics, and ultimately through more effective efforts to control it before it further diminishes valuable habitat for native vegetation and wildlife.

The CALFED Science Program has identified the need to "conduct adaptive management experiments" for the purpose of improving restoration and management efforts (CALFED Implementation Plan 2002 page 14). The experimental components of the proposed project are integral to identifying methods to control pepperweed. CALFED has explicitly identified this plant as a non-native exotic species that is negatively impacting the native flora and fauna.

This project would address several CALFED goals and priorities, paraphrased below:

MR-1. Reduction of the negative biological, economic, and social impacts of established nonnative species in the Bay-Delta estuary and its watersheds. *Lepidium latifolium* highlighted specifically in focus on the control and eradication of NIS. Understanding of how non-native species function, what determines their success in the Bay-Delta system and appropriate eradication strategies; understanding of NIS life histories, recruitment dynamics and responses to different restoration actions; establishment criteria, competitive interactions with natives, and the effects on associated flora and fauna.

DR-5. Develop pilot projects in marsh habitats to develop successful approaches to control of pepperweed.

BR-3. Implement actions to prevent, control and reduce impacts of non-native invasive species. Develop pilot projects in the marsh habitats to develop successful approaches to understanding invasion rates, ecological impacts and control strategies of pepperweed.

RELATIONSHIP TO OTHER ECOSYSTEM RESTORATION PROJECTS

The studies here are conceived to complement ongoing research by others into the distribution and control of invasive species. In particular, the mapping task is intended to provide a more complete picture of the status of invasive plant species in the Bay-Delta, in much the same way as is currently being undertaken with *Spartina alterniflora*. The inquiry into fate of herbicides will inform any contemplated use of these chemicals throughout the Bay-Delta, and issue that is currently at the forefront of debate from the standpoint of potential impacts to water quality. Other CALFED programs, such as the ongoing *Arundo* project, should benefit from the results of this work

SYSTEM-WIDE ECOSYSTEM BENEFITS

The proposed suite of research on perennial peppergrass will substantially enhance the state of knowledge of the species distribution throughout Bay-Delta ecosystems. This work will broaden the understanding of the mechanisms by which perennial peppergrass invades native and restored habitats, will identify areas that are at risk, and identify conditions that render habitats at risk of invasion. It intends to consolidate digital mapping and database and provide it to agencies with a responsibility or interest in implementing control measures, in a similar fashion to efforts currently being undertaken with regard to *Spartina alterniflora.* The project will significantly contribute to regional and system-wide conservation goals aimed at increasing the species and ultimately outlining practicable approaches to controlling it.

QUALIFICATIONS

A qualified team of investigators has been assembled to complete the tasks described in this proposal. At the highest level of organization, the team includes Environmental Science Associates (ESA), a firm specializing in natural resource conservation and planning, the Conservation Biology Program of San Francisco State University, Biology Department, and Friends of San Francisco Bay, a non-profit environmental education and advocacy organization. Qualifications for key personnel are summarized below:

Chris Rogers is a Senior Ecologist and Project Manager with Environmental Science Associates (ESA). He has over 13 years as a research and consulting plant ecologist specializing in the key issues confronting Bay-Delta biological resources, including restoration and enhancement of tidal and freshwater wetlands, management of endangered species, control of invasive species, regulatory and policy issues, and research. Mr. Rogers has supervised field technicians and the collection, collation, and analysis of complex ecological data, as well as the preparation of technical reports. Mr. Rogers will act as project manager for the biological staff, ensure coordination with federal and state agencies, and facilitate communication between all project team members.

Martha Lowe is a biologist and watershed ecologist with expertise in botany, plant taxonomy, habitat assessment, watershed planning and assessment, and ecosystem restoration. Through her graduate work and subsequent professional experience she has developed an in depth understanding of ecological interactions, functions, and processes, especially as they pertain to California's ecosystems. Her field experience includes qualitative and quantitative assessments of ecosystem integrity and plant population dynamics and monitoring *Spartina* invasions in a tidal marsh on San Francisco Bay, as well as conducting rare plant surveys habitat assessments in a variety of ecological settings. Ms. Lowe also has experience in restoration and revegetation project planning and monitoring plan preparation. Ms. Lowe received an M.A. in Ecosystem Restoration and Management from Sonoma State University in August 2000. She completed her undergraduate work at Mills College in 1981.

Mark Fogiel is a plant ecologist specializing in vegetation analysis, rare plant surveys, and restoration planning and monitoring. He is particularly knowledgeable in habitat evaluation in a variety of California ecosystems including tidal and freshwater wetlands, vernal pools, grasslands, oak woodlands, riparian, and Sierra Nevada forests. In addition to conducting many protocol-level rare plant surveys throughout California , Mr. Fogiel has conducted focused studies and inventories of various species involving the mapping and qualifying of habitat and populations found in moderately large geographic areas. Such projects include a study of Mason's lilaeopsis (*Lilaeopsis masonii*) populations throughout the tidal wetlands of Contra Costa County, and a study of several rare plant species throughout the Toiyabe National Forest in California and Nevada. Mr. Fogiel also is well-versed in the biology and control of invasive species, particularly giant reed (*Arundo donax*) and tamarisk (*Tamarix* spp.).

Tom Parker is a Professor of Biology with almost 25 years experience in wetlands, both freshwater tidal wetlands and salt marshes. He is a community ecologist whose research focuses on dispersal, seed bank dynamics, seedling establishment, and mycorrhizal fungal ecology. He has edited two books (*Ecology of Soil Seed Banks*, 1989; *Ecological Scale*, 1999) and has 50 publications. Many of the publications focus on vegetation management and restoration. He is the founder and first acting director of the Conservation Biology program at San Francisco State University. Dr. Parker currently is funded by NSF and USDA-CRI for research on mycorrhizal ecology.

Diana Benner is currently pursuing a Master's degree in Conservation Biology from SFSU. Ms. Benner has been involved in environmental education in the SF Bay Region emphasizing wetland and watershed dynamics and restoration. She has assisted in monitoring and analysis of plant community dynamics in a wetland restored to tidal action in the Contra Costa Mosquito Vector Control District. She has experience in field identification of native and non-native wetland plant species as well as methods for monitoring plant populations. Her undergraduate degree in Marine Biology from U.C.S.C. had a strong emphasis in instrumental analysis and subsequent employment in toxicology laboratory involved extensive laboratory analysis skills. Ms. Benner continued her education between degrees with classes in Wetland Ecology, Hydrology, and Wetland Restoration and plant identification.

Cost

The total cost of this proposal is $337,050 and includes a three-year program to develop and implement the three major tasks identified and described herein.

LOCAL INVOLVEMENT

The principal applicant is Environmental Science Associates, a northern-California based environmental research and consulting firm with offices in San Francisco, Oakland, and Sacramento, and elsewhere. The proposal team includes researchers and faculty from San Francisco State University, which will focus on the adaptive factors contributing to establishment of dense monocultures of *Lepidium latifolium* in tidal wetland habitats. The team also will include California Department of Fish and Game, represented by Mr. Joel Trumbo, a weed control and pesticide specialist with.

COMPLIANCE WITH STANDARD TERMS AND CONDITIONS

The project will comply with all state and federal terms and conditions as identified in the CALFED Proposal Solicitation Package Attachments D and E.

LITERATURE CITED

Allen, El, G. Cunningham. 1983. *Effects of vesicular-arbuscular mycorrhizae on Distichlis spicata under three salinity levels*. The New Phytologist. 93, 227-236.

Allen, E., M. Allen. 1984. *Competition between plants of different successional stages: mycorrhizae as regulators*. Can. J. Bot. Vol. 62, 2625-2628.

Allen, E., M. Allen. 1986. *Water relations of xeric grasses in the field: Interactions of mycorrhizas and competition*. The New Phytologist 104, 559-571.

Blank, R., J. Young. 1997. *Lepidium latifolium: Influences on soil properties, rate fo spread, and competitive stature*. Plant Invasions: Studies from North America and Europe, pp. 69-80.

Grossinger, R., J Alexander, A. Cohen, and J.N. Collins, 1998. *Introduced tidal marsh plants in the San Francisco Estuary, Regional distribution and priorities for control*. San Francisco Estuary Institute, Richmond, CA. November.

Harley, J.L., S.E. Smith. 1983. *Mycorrhizal Symbiosis*. Book published Academic Press, Inc. London.

May, Michael. 1995. *Lepidium latifolium L. in the San Francisco Estuary*. Dept. of Geography, UC Berkeley.

Miller, S., R. Sharitz. 2000. *Manipulation of flooding and arbuscular mycorrhizae formation influences growth and nutrition of two semiaquatic grass species*. Functional Ecology. 14, 738-748.

Parker, V. T. 1992. *Allelopathy in plant communities*. Encyclopedia of Earth System Science, Vol. 1, 71-77.

Parker, V., C. Muller. 1979. *Allelopathic dominance by a tree-associated herb in a California annual grassland*. Oecologia. 37, 315-320.

Renz, Mark. 2001. *Element stewardship abstract for Lepidium latifolium* L. The Nature Conservancy.

Rice, Elroy. 1984. Allelopathey. Book published by Academic Press, Inc. London

Smith, M.R., I. Charvat, R. Jacobson. 1998. *Arbuscular mycorrhizae promote establishment of prairie species in a tallgrass prairie restoration*. Can. J. Bot. 76: 1947-1954.

Templer, P., S. Findlay, C. Wigand. 1998. *Sediment chemistry associated with native and non-native emergent macrophytes of a Hudson River marsh ecosystem.* Wetlands. Vol. 18, No. 1 pp. 70-78.

Trumbo, Joel. 1994. *Perennial pepperweed: A threat to wildland areas. California* Environmental Pest Plant Council News. v.2, n.3:4-5.

Turner, S., C. Friese. 1998. *Plant-mycorrhizal community dynamics associated with a moisture gradient within a rehabilitated prairie fen*. Restoration Ecology Vol. 6 No. 1, pp. 44-51.

Turner, S., J. Amon, R. Schneble, C. Friese. 2000. *Mycorrhizal fungi associated with plants in ground-water fed wetlands*. Wetlands, Vol. 20, No. 1, pp. 200-204.

Young, J., D. Palmquist, S. Wotring. 1997. *The invasive nature of lepidium latifolium: A review*. Plant Invasions: Studies from North America and Europe, pp. 59-68.

Young, J., D. Palmquist, R. Blank. 1998. *The ecology and control of perennial pepperweed (Lepidium latifolium L.).* Weed Technology. V 12:402-405.

Young, J., C. Turner, L. James. 1995. *Perennial pepperweed*. Rangelands 17(4) 121-123.