Invasion dynamics of perennial pepperweed, *Lepidium latifolium*, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Project Information

1. **Proposal Title:**
Invasion dynamics of perennial pepperweed, *Lepidium latifolium*, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary
2. **Proposal applicants:**
Theodore Foin, University of California, Davis
3. **Corresponding Contact Person:**
Ahmad Hakim-Elahi
University of California, Davis
Director of Sponsored Programs Office of Research, 118 Everson Hall UC Davis 1 Shields Avenue Davis CA 95616-8671
530 752-6933
jmorell@ucdavis.edu
4. **Project Keywords:**
Nonnative Invasive Species
Wetlands Ecology
Wetlands, Tidal
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:**
University
9. **Location - GIS coordinates:**
Latitude: 38.118
Longitude: 122.174
Datum:
Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.
Tidal marsh habitat from south San Francisco Bay eastward to Cosumnes River Preserve in the eastern Delta
10. **Location - Ecozone:**
1.4 Central and West Delta, 2.1 Suisun Bay & Marsh, 2.2 Napa River, 2.4 Petaluma River, Code 15: Landscape
11. **Location - County:**
Napa, Solano, Sonoma, Alameda, Contra Costa, Sacramento
12. **Location - City:**
Does your project fall within a city jurisdiction?

No

13. **Location - Tribal Lands:**
Does your project fall on or adjacent to tribal lands?
No

14. **Location - Congressional District:**
7th

15. **Location:**
California State Senate District Number: 4th
California Assembly District Number: 8th

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?**
Yes
If yes, list the different overhead rates and total requested funds:
State Overhead Rate: 10%
Total State Funds: 178700.94
Federal Overhead Rate: 48.5%
Total Federal Funds: 241246.30
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?
Yes
If yes, identify project number(s), title(s) and CALFED program.
not assigned splittail simulation model Lead Scientist s Funds

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
If yes, identify project number(s), title(s) and funding source.

Please list suggested reviewers for your proposal. (optional)

21. **Comments:**
budget total is based on 100% state funds with 10% overhead

Environmental Compliance Checklist

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

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.

Project is experimental research to be done in a laboratory setting, except for field measurements and the herbicide experiment.

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

CEQA Lead Agency: none

NEPA Lead Agency (or co-lead:) none

NEPA Co-Lead Agency (if applicable): none

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

CEQA

-Categorical Exemption

-Negative Declaration or Mitigated Negative Declaration

-EIR

none

NEPA

-Categorical Exclusion

-Environmental Assessment/FONSI

-EIS

none

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 Required. Some obtained, others in process
Rivers and Harbors Act
CWA 404
Other
PERMISSION TO ACCESS PROPERTY
Permission to access city, county or other local agency land.
Agency Name: Solano Open Space Trust, in process
Permission to access state land.
Agency Name: Cal Fish and Game Required, obtained
Permission to access federal land.
Agency Name:
Permission to access private land.
Landowner Name: Solano Land Trust Required, Obtained
6. **Comments.**

Land Use Checklist

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

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

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

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):

Theodore Foin and A. Keith Miles, University of California, Davis; Renee O. Spenst, graduate student.

Subcontractor(s):

Are specific subcontractors identified in this proposal? No

Helped with proposal development:

Are there persons who helped with proposal development?
No

Comments:

BUDGET SUMMARY Project 205DA Invasion dynamics of perennial pepperweed...

Year 1	**2003**										
Task No.	Task Description	Man Hours	Salary	Benefits	Travel	S&E	Services	Other DC	Row Total	IDC	row subtotals
1	CCA		15360	460.8	2377	300	8000	10294	36791.8	3679.18	40470.98
1	CCA	700	5250	157.5					5407.5	540.75	5948.25
3	seed establishment		3840	115.2					3955.2	395.52	4350.72
4	herbicide		7680	230.4		2200			10110.4	1011.04	11121.44
sub totals		700	32130	963.9	2377	2500	8000	10294	56264.9	5626.49	**61891.39**

Year 2	**2004**										
Task No.	Task Description	Hours	Salary	Benefits	Travel	S&E	Services	Other DC		IDC	Total
2	seed dispersal		24960	748.8	3200	1500	4000	10294	44702.8	4470.28	49173.08
2	seed dispersal	160	1200	36					1236	123.6	1359.6
3	seed establishment		5760						5760	576	6336
3	seed establishment	200	1500	45					1545	154.5	1699.5
4	herbicide expt	160	1730.4						1730.4	173.04	1903.44
4	herbicide expt		7680						7680	768	8448
col sub totals		520	42830.4	829.8	3200	1500	4000	10294		6265.42	**68919.62**

2005											
Task No.	Task Description	Hours	Salary	Benefits	Travel	S&E	Services	Other DC		IDC	Total
4	herbicide expt		19200	576	3000	1500		5314.1	29590.1	2959.01	32549.11
4	herbicide expt	320	2400	72					2472	247.2	2719.2
2	seed dispersal	200	1540	46.2					1586.2	158.62	1744.82
2	seed dispersal		9600	288					9888	988.8	10876.8
column sub totals			32740	982.2	3000	1500	0	5314.1		4353.63	**47889.93**

Proposal Totals	
2003	**61891.39**
2004	**68919.62**
2005	**47889.93**
Total	**178700.94**

Budget Justification

INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF WETLANDS IN THE SAN FRANCISCO ESTUARY

Direct Labor Hours and Salary Compensation

This proposal has been expanded to two research assistants (from one), because of the expanded commitment made to research. Rene O. Spenst will have control over the herbicide and seed establishment experiment, at standard compensation (9 months@50%, 3 months at 100%: total stipend $19200). A second RA has been added to assist with the field correlation analysis and to have primary control over seed dispersal and demography. Provision for two undergraduate assistants has also been made at $7.50/hr.

Benefits

Benefit Rate is 3% for all students. Fee remission costs for the Ras have been included under other direct costs.

Travel

3 months per year for a University truck has been included, with extra for travel to meetings and mileage when private vehicles must be used.

Supplies and Expendables

All supplies are directly for the project, mostly in buckets, lumber, and seed trap supplies. Computing and administrative costs are being taken from other sources.

Services or Consultants

Funds are included for endangered species surveys mandated by the permit conditions. The estimated cost is $1000 per site, mostly for harvest mouse and clapper rail surveys.

Equipment

not applicable

Project Management

All aspects of project management are not covered in this budget except for travel. Such costs will be absorbed from other funds.

Other Direct Costs

Fee remissions for RAs are included @ $5147/person/year.

Indirect Costs

A uniform rate of 10% (negotiated state-UC rate) is assumed for all budget calculations.

Executive Summary

INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF WETLANDS IN THE SAN FRANCISCO ESTUARY

The invasive composite, *Lepidium latifolium* (perennial pepperweed), is increasingly recognized as one of the most successful invaders in California ecosystems. Perennial pepperweed has demographic and dispersal characteristics that underscore its successful colonization and dominance of multiple environments. As such, *L. latifolium* represents a threat to many of the tidal wetlands in the San Francisco Estuary, especially those relict wetlands currently slated for restoration.

The objective of this proposal is to determine the demographic and ecological properties which are responsible for its success, in order to support the development of strategies to exclude or control the species. The specific research in this proposal has been designed to test several hypotheses. A field sampling program using correlation analysis should test the ability of elevated salinity and persistent soil saturation to account for the distribution and abundance of *L. latifolium* a range of tidal marshes throughout the Estuary. Previous research suggests these factors are important in the distribution of other tidal marsh species. Field measurement of size-related seed production and wind dispersal of seed will allow measurement of propagule production and dispersal by wind. A laboratory-based experimental study of pepperweed colonization into planted stands of marsh dominants will measure the degree of competitive suppression by different native species, and in conjunction with CCA will test correspondence between competitive results and field distribution. The field herbicide trials will extend earlier experiments into the estuarine environment to examine the long-term impact on pepperweed suppression and the recovery of native plants.

The control of exotics is one of the most important elements in the ERP. We expect the proposed research to contribute an improved, mechanistic, understanding of how *Lepidium latifolium* successfully invades tidal marshes, the environmental determinants of its success, and element constituting effective control strategies.

PROJECT DESCRIPTION FOR 205DA

INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF WETLANDS IN THE SAN FRANCISCO ESTUARY

THE PROBLEM

Successful wetlands restoration is one of the core goals of the CALFED program. Although many specific restoration programs have been proposed and funded, the need for scientifically rigorous experiments with repeatable results and adaptive responses built into the restoration program should remain a major concern of the agency. One of the most serious problems affecting restoration success is the distinct possibility that a restored marsh might be dominated by an undesirable invasive species, an outcome that might be hardly better than the degraded marsh it was intended to replace. Some marsh biologists have even expressed the belief that marsh restoration should not proceed without an effective program to prevent invasion by aggressive exotics (D. R. Ayres, *pers. comm.*).

The threat of invasive plants to the tidal marshes of the lower Delta and San Pablo Bay regions of the San Francisco Estuary is particularly clear for two species. One is smooth cordgrass (*Spartina alterniflora*), a serious problem in fully tidal salt marshes of San Francisco Bay. The other species is perennial pepperweed or tall white top, *Lepidium latifolium*, a tall forb which occurs throughout the Estuary, in alkali sinks, in cool deserts and even annual and perennial grasslands, through all of which it spreads with ease (Mark Renz, *pers. comm.*). Perennial pepperweed is also invading tidal marshes in the San Francisco Bay area, the notable exceptions being isolated, coastal pocket marshes that have no sources of *L. latifolium* propagules.

L. latifolium is a native of Central Asia and southeastern Europe (Young *et al.* 1997). Its worldwide distribution and average abundance apparently are both increasing; new or growing populations have been documented in Norway (Halvorsen and Grostad 1998), the United Kingdom (Burton 1997), the Elbe River Valley (Brandes and Sander 1995), Austria (Melzer 1994) and Spain (Romero and Amigo 1992). In the United States perennial pepperweed is well-established along the Atlantic seaboard and throughout the western states, except for Arizona (Miller *et al.* 1986, Young *et al.* 1996). The invasion of California by *Lepidium latifolium* has been traced to shipments of sugar beets in the 1930s (Robbins *et al.* 1951).

L. latifolium is now widely recognized to be a very dangerous invasive species. The California Department of Food and Agriculture lists *Lepidium latifolium* as a class B noxious weed, the rating used when a species has a known economic impact but varies in its severity so that it is a county rather than state priority. The California Exotic Plant Pest Council classifies it as A-1 – the rating assigned to the most invasive plants of wildlands.

Lepidium latifolium fits the profile attributed to a prototypic invasive species (Baker 1974, Rejmanek 1996). It is a member of the mustard family (Cruciferae), a family known for having many weedy species. *Lepidium latifolium* is a perennial that grows quickly and establishes rapidly in a variety of environments, reaches large sizes and produces numerous small and easily dispersed seed. *L. latifolium* combines the persistence and competitive ability of perennials, even while retaining the high reproductive effort of annuals. A well-established stand may produce up to 16 billion seeds ha^{-1} yr^{-1} (Palmquist, *pers. comm.*). In addition, the species is known to disperse and establish readily from broken rhizomes (Trumbo 1994). The species is phenologically early to develop and notably plastic in its habitat requirements, but also very competitive. Blank *et al.* (2002) reported that *L. latifolium* can compete with *Bromus tectorum* in phosphorus-rich soils by producing large shoots, even though root density is generally sparse. In more depleted soils, root/shoot partitioning increases as *L. latifolium* grows into deeper layers. The authors suggested that *Lepidium latifolium* may be particularly competitive against shallow-rooted species in marsh environments.

While there is some controversy about the mode of reproduction which is more closely associated with its invasive success (see Miller *et al.* 1986), its growth habit, competitiveness, and ability to saturate the local environment with seeds once a few individuals are established leaves little doubt that the species must be kept out of sensitive ecosystems. It remains unclear, however, how this is to be accomplished. Exclusion of *Lepidium latifolium* from tidal wetlands has a particularly high priority because of its potential to dominate the many areas slated for marsh restoration. With *Lepidium latifolium* already present in many marshes, eradication and reduction of propagule sources may have to be emphasized during the transition period from degraded marshlands back to equilibrium tidal marsh vegetation.

The direct consequences of perennial pepperweed for tidal marsh ecosystems are threefold. It can displace native vegetation in the streamside zone (*Scirpus* spp. in particular). In the upper marsh, *Lepidium latifolium* may reduce biodiversity and it threatens several endangered plants that occur in this zone of tidal marshes (*e.g.*, *Cordylanthus mollis*, *Cirsium* ***hydrophilum***). Wherever it occurs, perennial pepperweed likely will degrade habitat for clapper rails and other birds. Although many bird species find stands of perennial pepperweed attractive for nesting, the stems are brittle and breaks easily, and so ultimately may prove to be detrimental to nest survival (Hilde Spautz , *pers. comm.*). Changes in ecological function and energy flow for the marsh vegetation are more speculative but ultimately may prove to be more important. Its aggressive growth, polyhaline tolerance, persistence in face of attempts to eradicate it and its potential for altering the functional role of estuarine vegetation through competitive displacement make it a very serious threat to marsh restoration programs and therefore a very high priority for control.

Present knowledge offers few options for prevention or control. The three most obvious are to do nothing, use herbicides, or a program combining herbicides and vegetation manipulation. Depending on the first option in the hope that *Lepidium latifolium* will decline naturally, appears to be contradicted by the evidence available to date (Young *et al.* 1997, Blank *et al.* 2002). *L. latifolium* seems to be at a breakout threshold, or may be already out of control. A program of aggressive treatment using herbicides has met with limited success to date (see below) but may be most effective when combined with other methods. The third option, based on minimizing the opportunity for invasion, is attractive but requires information about both the invader and the tidal marsh community that is largely unavailable at the present time.

This proposal emphasizes the need for a systematic assessment of the population dynamics of *Lepidium latifolium* with special reference to seed production and dispersal. Developing this information should reveal how much can be expected of the interaction of population biology and herbicide-based suppression. It is clear that a complete answer might not emerge within the three years of this proposal, but we hope that our contribution will advance our understanding of the problem to permit marsh restoration programs to proceed with enhanced prospects for success.

JUSTIFICATION OF THIS PROPOSAL

This proposal has three specific objectives.

- *To determine the properties of tidal marshes, particularly soil saturation and salinity, governing their invasibility by Lepidium latifolium.*

Previous studies have hypothesized that *L. latifolium* can tolerate saturated soil conditions and increasing salinity (May 1995, Young and Turner 1995, Chen *et al.* 2002, Blank *et al.* 2002) but does less well under these conditions. Some useful clues about the factors limiting *L. latifolium* are offered by the known distribution of the species in tidal marshes. *L. latifolium* is not effective in colonizing the middle marsh; its distribution tends to be bimodal, with the largest concentrations found along tidal creeks and in the upper marsh plain. The second pattern to note is that the distribution of perennial pepperweed along tidal creeks contracts toward lower, higher-order streams as one moves downstream in the Estuary.

Foin *et al.* (2000) have developed a conceptual model of marsh dynamics, suggesting that tidal influx combining a regular water supply and routine flushing of salinity plays a major role in the zonation of tidal marsh vegetation. Both the streamside zone and upper marsh plain feature enhanced drainage and periodic flushing of excess salinity; plants that have narrower environmental tolerances but higher growth rates tend to be localized in these areas. Plants of lower productivity and shorter stature, but tolerant of flooding and/or salinity, occur in the mid-marsh, spreading toward both the streamside and upper marsh in fully saline tidal marshes.

The tidal marsh distribution pattern of *L. latifolium* suggests that the same factors are important determinants of its distribution and abundance. We hypothesize *L. latifolium* responds to favorable drainage and salinity dilution along the banks of tidal channels, where it has proven to be an excellent competitor against the native tule vegetation, particularly *Scirpus acutus*. The same conditions exist in the upper marsh, where drainage is good and salinity leaching occurs at least seasonally. Conversely, *L. latifolium* is least competitive where drainage is poor and salinity elevated in the middle marsh zone. Our observations in tidal marshes match well with the known intolerance of *L. latifolium* to soil saturation and rising salinities in desert soils (Blank *et al.* 2002).

- *To determine the combination of reproductive life history strategies and environmental characteristics that are associated with Lepidium latifolium invasibility.*

There is nothing in the literature on pepperweed dispersal at present and no base to build upon, but this area is so important it must be addressed. The stated objective is too comprehensive to be addressed fully within the scope of this research. There are, however, two priority activities which are practical and worthy of our attention at this time. The first is the role of competition in excluding *L. latifolium* at the germination-establishment phase. Although *L. latifolium* is competitive, it is unclear if it requires disturbance to establish, or if seedlings can invade established stands. The second is the dispersal of pepperweed seed from an established stand – in particular size or density thresholds where significant seeds are produced. Both of these have applied as well as basic scientific value. The first is relevant to the potential exclusion of *L. latifolium* from well-established stands and the second will establish the dispersal distance and estimate the potential rate of invasion across the marsh landscape.

- *To evaluate the impact of herbicide treatment on the eradication of Lepidium latifolium and on the recovery of the vegetation community.*

L. latifolium poses a considerable threat to restoration sites, and increasingly so to natural sites as well. In many locales, *L. latifolium* is already well established, minimizing the possibilities for low-cost, highly successful control (Smith *et al.* 1999). With limited other options available, land managers have relied on herbicide intervention. Current control and eradication efforts utilize intensive pesticide, tillage, mowing, and fire regimes (Young *et al.* 1998, Renz, pers. comm.), but with limited success (Table 1). Young *et al.* (1998) found that an application of 2,4-D (as a low volatility ester) reduced pepperweed cover by 98% 10 months after treatment, but that the population recovered to 100% cover in 2 years. Chlorsulfuron, the most effective herbicide, reduced pepperweed cover by as much as 90% 3 years after treatment; in combination with two mowings, reduced cover by 99.5% one year after treatment (Renz and DiTomaso 1999). Use restrictions bar use of the more effective herbicides, specifically chlorsulfuron, in marshes. If herbicides are to be part of the management of pepperweed, glyphosate in combination with vegetation management is the only option at present. Renz and DiTomaso (2001a) found that while mowing increased effectiveness of herbicides in dense infestations, it also reduced the abundance of native plants. Renz and DiTomaso (2002) acknowledge that even the most highly effective herbicide use programs limit re-establishment following treatment. Furthermore, even if control is ultimately achieved, it is not clear how to restore areas in order to prevent reinvasion. Ball and colleagues (N. McCarten, *pers. comm.*) are conducting a study examining how control measures, including herbicide treatments, influence native endangered species in vernal pools in northern California. The outcome of both of these projects should provide a much improved understanding of the merits of herbicide use for pepperweed control. The aggressive nature of this particular invader mandates that herbicides remain at least a treatment option, and even as the only feasible option in some cases. The results obtained by Renz and DiTomaso and by Young *et al.* in Table 1 indicate that a single glyphosate treatment is unlikely to control pepperweed growth in freshwater wetlands. It remains to be seen if perennial pepperweed will be easier to control with less damage to the plant community under higher salinity regimes typical of tidal marshes. This aspect of the research will help guide the development of a comprehensive strategy for herbicide use across the range of tidal wetland conditions found around the San Francisco Estuary.

Table 1. Comparison of most successful control methods, with estimated control one year (and 2-3 years, where available) after treatment.

Treatment	Herbicide	Rate (kg/ha)	Effectiveness (1 yr later)	Effectiveness (2 yr later)	Effectiveness (3 yr later)	Source
Herbicide	Glyphosate	0.6	15%	0%	-	Young *et al.* 1998
Herbicide + mowed once	Glyphosate	3.33	88.75%	-	-	Renz and DiTomaso 1999
Herbicide	Chlorsulfuron	0.11	95%	90%	90%	Young *et al.* 1998
Herbicide + mowed twice	Chlorsulfuron	0.052	99.50%	-	-	Renz and DiTomaso 1999
Herbicide	2, 4-D amine	2.2	95%	0%	-	Young *et al.* 1998
Herbicide	2, 4-D low volatile ester	2.2	98%*	0%	-	Young *et al.* 1998
Disking	-	-	short term reduction	0%	-	Young *et al.* 1998

*after 10 months

In summary, we anticipate the outcome of this project to be a much-improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. As such, this research will provide the biological foundation upon which a control strategy can be built.

RESEARCH PROTOCOLS

Details of the Proposed Research

Objective 1. *To determine the properties of tidal marshes, particularly soil saturation and salinity, governing their invasibility by Lepidium latifolium.*

In order to elucidate environmental factors contributing to *L. latifolium* invasion, correlation analysis will be used to regress streamside species and sampling units against environmental factors. Data will be collected at multiple sites spanning the salinity gradient, ranging from full strength seawater (South San Francisco Bay, San Pablo Bay) to totally fresh water (Cosumnes River riparian zone). We expect to sample at a minimum of 7 locations. The unit of sampling will be meter-square quadrats. A minimum of 24 samples, stratified into each of the three main zones (streamside, midmarsh, upper margin) will be collected at each site. Sampling will be intensive, conducted over a period of four weeks in May 2003 to minimize seasonal differences. If sampling variance is high, a second round of samples may be taken in the same time period.

At each sample location, species composition, percent cover, and selected environmental variables (channel salinity, soil salinity, flooding regime interpolated from tide tables, pH, soil particle size, and percent organic matter) will be recorded. Environmental measurements will be taken with a YSI multiparameter meter and a separate pH meter. A Garmin Vista GPS unit will be used to record the location of each sample site.

Results will be analyzed by an appropriate method of correlation analysis. One such method, canonical correspondence analysis (CCA), allows the user to compare species and distribution patterns and environmental variables in a single step by combining regression with multivariate analysis. The analysis will be run using pepperweed as an environmental factor in order to examine species correlations, and then with pepperweed grouped with the other species to affirm that salinity is the dominant gradient responsible for segregating species and to suggest other factors that may be significant determinants. This analysis is essential for determining whether *L. latifolium* distribution is more closely related to environmental factors or to species combinations. CCA does not perform well with bimodal distributions, however, so other methods of analysis may be chosen depending on trends in the data.

We expect the results to confirm our hypothesis that increasing salinity, possibly with flooding regime as a significant covariate, is the dominant environmental factor limiting successful pepperweed abundance. This hypothesis was originally developed from a 2001 experiment measuring pepperweed growth with different salinity and flooding conditions under controlled conditions. The field sampling study should allow us to test the fit of the model and its consistency, under field conditions, with the experimental results.

Objective 2. *To determine the combination of reproductive life history strategies and environmental characteristics that are associated with Lepidium latifolium invasibility.*

Previous research has shown that once *L. latifolium* invades an area, it establishes quickly, then uses local stands to provide seed sources, expanding its invasion through the marsh using streams as dispersal pathways. One of the outstanding questions about the dispersal of perennial pepperweed is whether or not it differs qualitatively from the marsh edge to the streamside zone. Two principal means for pepperweed dispersal (root fragmentation and seed dispersal) have been documented. The rapid establishment of *L. latifolium* across the western states, and the source of original introduction suggest that seed dispersal in probably the principal means of long distance expansion. *L. latifolium* routinely produces numerous seed, but the role of seed in colonization has not been quantified. Wind and animal dispersal are important mechanisms for pepperweed colonization, particularly so at the marsh plain, but perhaps throughout. On the other hand, erosion and dispersal of rhizome fragments along stream courses may be equally or more important in accounting for colonization of *L. latifolium* in the streamside zone.

The study of dispersal and establishment from rhizome fragments is technically difficult to quantify and will not be attempted in this study. Instead, we will concentrate on the interaction of environmental conditions on seed production and dispersal in the two zones. Specific hypotheses include:

- *L. latifolium* in the streamside zone will grow faster and produce more seed than those in the upper marsh. In tidal marshes, seasonal increase in salinity will limit growth and seed production, especially at the marsh plain.
- Seed dispersal profiles from stands at the streamside will be smaller because of boundary layer restriction of wind in the tule zone.
- Seed dispersal will reach the middle marsh. The decrease of *L. latifolium* in this zone reflects the failure of establishment rather than a limitation of dispersal.

To test these hypotheses requires a demographic profile of individual plants in the two zones, an empirical study of seed dispersal from isolated stands, and an experimental study of establishment.

Demographic comparisons. Demographic profiling will follow the CCA study, which should identify the environmental correlates and differences between marsh zones. We can then follow this up by constructing demographic profiles under different environmental conditions (ranging from high salinity upland to poor drainage inland of the stream bank zone). We will mark small plants and follow their growth and development in the field through the season. Demographic measures include biomass production (through destructive sampling of similar individuals), branch production, leaf area, and seed production.

We expect the measurement of differences along the salinity and drainage gradients to confirm the results from field sampling and CCA analysis. Furthermore, the demographic data should contribute to defining the habitat requirements of pepperweed and improve our understanding of the conditions which promote or inhibit its invasiveness.

Seed dispersal. Seed dispersal is notoriously difficult to quantify. Nevertheless, we will attempt to do so as part of this study. First, we recognize that deliberate introduction of *L. latifolium* into uninvaded marshes is dangerous and unwarranted, despite its attractive scientific advantages. Instead, as part of the demographic comparison study, we will identify new and vigorous stands of *Lepidium latifolium* that are producing seed, but which are isolated enough to substantiate the assumption that a given plant (or discrete stand) is the seed source. Petri dishes coated with Tanglefoot will be set out in various directions and distances from the stand to estimate wind-driven seed dispersal and thereby to provide an initial idea of dispersal distance. This method cannot be used to estimate the impact of animal dispersal or the role of rhizome fragments. At this point of the study, these aspects seem too technically difficult to be feasible.

The dispersal profiles are expected to help define relationships between environment and potential dispersal by wind.

Seed establishment study. This part of the study will consist of an experimental analysis of the role of an established stand on perennial pepperweed invasion. The experiment will be run in an open-air setting designed to provide natural environmental conditions. This experiment separates the physiological response of *L. latifolium* seed to stresses associated with elevated salinities and anoxia in bare plots from competitive effects due to the presence of a stand of vegetation. The design of this experiment has flooding frequency (daily and weekly) and aqueous salinity (0, 10, 20, and 30 ppt) as main effects in a split-plot design, with salinity assigned to the main plots and flooding assigned to the subplots. Within the subplots, *L. latifolium* seeds will either be sown into bare soil, or into a native stand. We have decided that native stands will consist of single species at representative cover and biomass at ground level in the field, rather than stands representing the community. One reason is practicality in the size of the experiment; the second is that scientifically the pure stands permit cleaner inferences to be drawn about competitive responses. Community invasion can be done at a second stage. The identity of the native will be dictated by the salinity treatment so that pairing will be representative of pairs found in nature. Plants will be propagated from root stock. In fresh and low salinity conditions, *Potentilla anserina* would be a likely competitor; followed by *Scirpus acutus* at 10 ppt; *Scirpus americanus* at 20 ppt; and *Salicornia virginica* at 30 ppt. There will be 8 replicates per treatment. *L. latifolium* seeds will be sewn into the appropriate treatment at a constant rate for all experimental units. Appropriate seed rain rate will be estimated from sampling in fresh water and brackish sites the season prior to commencement of this experiment. Seeding density used in the experiment will be based on samples collected from multiple sites.

Multiple parameters of pepperweed growth will be measured. These will include total number of germinated seeds, total number of rosettes, and if bolting occurs, number of stems, height, relative growth rate, and seed set. Experimental results will be analyzed using ANOVA.

We hypothesize that the competitive relationships, in the context of prevailing salinity conditions, will determine the rate of *L. latifolium* growth and its long-term establishment capability.

Objective 3. *To evaluate the impact of herbicide treatment on the eradication of Lepidium latifolium and on the recovery of the vegetation community.*

Herbicide use will undoubtedly play a central role in pepperweed control and eradication efforts. Although herbicides do not offer an ideal solution in eradicating perennial pepperweed, they are one of the only effective options for treating well-established, mature stands. Many studies have examined methods of herbicide application to improve kill rates (Renz and DiTomaso 1999,Young *et al.* 1998), yet none of those studies have provided an in-depth examination of the response by the plant community to herbicide treatment. This is key information for land managers who may be considering herbicide control, especially in tidal marshes where recovery of the vegetation is essential, or else the treatment would simply open the habitat to *Lepidium* seedling establishment.

The experiment will be a randomized complete-block design, blocked among sites and replicated within sites and pairing treated and untreated plots, with each replicate in a concentric design to create a buffer zone around an inner quadrat in the center of the plot. The inner quadrat will be 1 m^2, surrounded by a 3x3 m buffer zone. The treatment would be applied to the entire quadrat, but measurements will be taken only from the inner one. All vegetation in each plot will be hand-clipped and removed at the beginning of the herbicide application to reduce exposure of the native vegetation to the herbicide. In each case the herbicide will be Aquamaster, an approved aquatic formulation of glyphosate, applied when the pepperweed plants have started to regrow and are maximally susceptible to treatment. The remaining elements of the treatments include 1) only the base treatment, for one year only; 2) repeat the base treatment for a second consecutive year; and 3) addition of a neutral mulch, consisting of shredded plastic and organic materials that decompose slowly, to minimize open soil after herbicide treatment. The experiment will be monitored for a period of three years. Species composition will be established by direct counts, as well as by percent cover. There will be at least 8 replicates per treatment and a minimum of six sites, or three pairs, along the estuary's salinity gradient. Results will be analyzed with ANOVA.

The herbicide experiment should permit estimation of recovery by both the native vegetation and *Lepidium latifolium*. It is expected the clipping and removal will minimize exposure of the native vegetation to the herbicide and perhaps accelerate its recovery. The repeated treatments will help deplete the seedbank and eliminate recovering pepperweed individuals, and the mulch may suppress successive cohorts of pepperweed seedlings.

Contribution of the Proposed Research to Pepperweed Management

Lepidium latifolium is increasingly recognized as a major threat to successful tidal marsh restoration throughout the Estuary. The overall goal of this research is to provide additional insight into the environmental responses and competitive relations of *L. latifolium* that can be used to improve control strategies. The various lines of research proposed contribute to the overall goal in the following ways.

Field CCA analysis is expected to provide 1) quantitative confirmation of the bimodal distribution of *L. latifolium* in tidal marshes; 2) insight into the importance of environmental conditions, especially the key factors of soil saturation and salinity, as they vary from marsh to marsh; and 3) initial indications of the importance of particular vegetation types and stands on the distribution and abundance of pepperweed. The competitive experiments will test the predictions generated by CCA and perhaps indicate the importance of mixed stands for pepperweed exclusion/invasion. However, we have deliberately chosen to use single-species stands, at approximate field densities, to better isolate competitive characteristics and improve potential inferences.

The limited research on propagule dispersal emphasizes the measurement of two demographic properties – the influence of size and timing of pepperweed plants on seed production and the influence of wind dispersal on the seed rain. We recognize that this is not adequate to assess propagule dispersal, since neither animal dispersal nor rhizome fragmentation have been accounted for. However, in the context of the work plan proposed here, it seems better to concentrate on what we can do well and recognize that further refinements will have to be addressed later.

The herbicide trials are the link between demographic-ecological characterization and management. Although extensive research has been conducted elsewhere and cited earlier, we expect the herbicide experiments to produce results that will be important in themselves, as well as providing useful links to previous work. The herbicide experiments will 1) provide more extensive information on the response of the native community as well as the weed; 2) identify how these responses change along the estuarine gradient; and 3) help identify which (if any) procedures is more likely to provide satisfactory control with less negative impact on the natives.

We suspect that *L. latifolium* distribution responds more directly to physical factors and is less heavily influenced by competition with the native flora. Whether this is the case directly influences the optimal control strategy. Adopting a policy of ecological management, based on increasing knowledge of *L. latifolium* biology, with a policy of herbicide intervention when exclusion fails is probably the only way to control existing pepperweed populations and to maintain pepperweed-free sites.

FEASIBILITY

This proposal is based on methods that have been well tested in ecology, marsh biology and the field in previous research leading up to this project. The laboratory-based and field survey elements of this proposal are demonstrably feasible and no insurmountable problems are expected to arise therein. Initial reviews of the predecessor proposal have agreed with this assessment.

Like most investigations with a field component in tidal marshes, extensive permitting for access and experimentation is required. We have arranged for permits and permission for access to most of the sites we need. Details are provided in the section on local involvement.

PERFORMANCE MEASURES

The only aspect of this proposal subject to specification of a successful performance evaluation will be the establishment of *Lepidium latifolium* seedlings, both in the herbicide and competitive establishment experiments. Once the treatments are in place, the two experiments will have to be monitored for *L. latifolium* seedlings. The presence of pepperweed seedlings are not sufficient evidence of invasion; the species must grow and even produce seed to meet this condition. Failure to grow into maturity and/or to produce seed is the criterion of failure to invade successfully.

DATA HANDLING AND STORAGE

All data will be stored in a data vault system maintained and backed up in the Computing Facility of the Department of Agronomy and Range Science, University of California, Davis. Results will be posted to our website at agronomy.ucdavis.edu.

OUTCOMES AND EXPECTED BENEFITS OF THIS RESEARCH

If the research progresses as outlined, we hope a testable *L. latifolium* prevention strategy will emerge before the end of the project term. By elucidating the conditions under which pepperweed is favored and by potentially providing the opportunity to exploit vulnerabilities in its life history and population biology to control its spread, we should be able to develop an improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. This can be further tested in the field or implemented without increasing the risk of pepperweed invasion.

Initially, this research will be the focus of Renee Spenst's doctoral dissertation, and as such will be published in standard scientific journals. Provision have been made to include the financial flexibility to expand dispersal studies with a second student if initial measurements are successful. As we begin to understand *Lepidium* responses better, two additional avenues will open up. First, there are manifold opportunities for marsh restoration, which themselves should be conducted in a fashion designed to minimize invasion by *Lepidium*, suggesting the potential for collaboration in future experimental restoration programs. Second, we will begin to place articles in such applied venues such as the Interagency Ecological Report, featuring invasive species. We shall participate in future CALFED science conferences, publish in regular journals, and perhaps produce an electronic manual on planting and environmental management that minimizes the risk of *L. latifolium* invasion.

WORK SCHEDULE

Objective	***Task***	***Timeframe***
1	*field survey using CCA*	*June-September 2003*
2	*measurement of seed dispersal*	*July-October 2004*
2	*growth in competition with native spp.*	*November 2002-October 2003*
3	*herbicide-community recovery trials*	*summer 2003-2004*
3	*monitoring of the herbicide and invasion experiments*	*February 2005-October 2006*

The off-season (November-February) is reserved for data analysis.

APPLICABILITY TO ERP GOALS

The four ERP goals applicable to this proposal are:

Goal 1: *protection and restoration of native biotic communities*
Goal 2: *Rehabilitate natural aquatic and adjacent plant communities to support native members of those areas*
Goal 4: *Protect and/or restore functional habitat types in the Bay-Delta estuary and its watershed for ecological and public values such as supporting species and biotic communities, ecological processes, recreation, scientific research, and aesthetics, including restoration of tidal marsh, sloughs, seasonal and riparian wetlands and protecting tracts of existing high quality wetland*
Goal 5: *Prevent establishment of additional non-native invasive species and reduce the negative ecological and economic impacts of established non-natives in the Bay-Delta estuary and its watershed, including where possible limiting spread or eradication of non-natives*

The proposed research will directly address each of these four goals. *Lepidium latifolium* is specifically identified as a major problem in the Bay-Delta estuary and its watershed. This species poses a grave threat to remaining wetlands in the Bay-Delta system and to proposed restoration projects because it is highly successful across a wide spectrum of wetland habitats. This research seeks to provide a mechanistic understanding of the way in which *L. latifolium* is able to invade a wetland site with respect to the invader and the environmental characteristics of the site. Development of a successful control protocol would help protect remaining intact systems; provide a means for reducing its spread; and prevent the invasion of *Lepidium latifolium* into restoring sites.

PREVIOUS CALFED SUPPORT

I have had support from the Science Advisors funds (30K) to support mathematical modeling population dynamics of splittail, *Pogonicthys macrolepidopterus*. This work is completely separate from this proposal.

SYSTEM-WIDE ECOSYSTEM BENEFITS

This proposal seeks to develop and test the adequacy of a protocol to address the invasibility of tidal marshes, and secondarily to find management schemes which maximize exclusion of pepperweed. To the extent to which this proposal is productive, we can expect to improve restoration by excluding *Lepidium latifolium*, and perhaps develop a protocol that can be used for a larger number of invasive plant species.

QUALIFICATIONS OF THE PRINCIPAL INVESTIGATOR

ABBREVIATED CURRICULUM VITAE
THEODORE C. FOIN

EDUCATIONAL SUMMARY

A.B., Biological Sciences, Stanford University, 1962
Ph.D., Zoology (Ecology), University of North Carolina, Chapel Hill, 1967

CURRENT ACADEMIC POSITION

Professor
Department of Agronomy and Range Science
University of California, Davis 95616
1998-Present

ROUTINE TEACHING RESPONSIBILITIES

ASE 121. Systems Analysis in Agriculture and Resource Management
Ecology 200B. Principles and Application of Ecological Theory.
Ecology 201. Modeling Ecosystems and Landscapes

GRADUATE EDUCATION

Member of the Graduate Groups in Ecology, International Agricultural Development, Horticulture and Plant Biology.
18 MS and 11 PhD students have finished under my direction over the course of my career; 3 PhD and 2 MS are in progress.

RECENT PROFESSIONAL AND PUBLIC SERVICE

Editorial Board, Population and Environment
Yolo County Grand Jury, 1991-92
Member of the following professional societies: American Institute of Biological Sciences, California Botanical Society, Ecological Society of America, International Society of Ecological Modelers, Sigma Xi
Chair of Committee of Science Advisors and member of the Board of Directors, San Francisco Estuary Institute.
Member of Science Review Committee, Regional Wetlands Goals Project, San Francisco Estuary Institute.

RESEARCH INTERESTS

My principal activities fall in the following areas:

- The theory and practice of ecological modeling.
- Management-oriented simulation of rice-weed interactions, with special respect to competition for light. Projects in this area are in progress in California and tropical Asia.
- Ecology and simulation of tidal salt marshes and their inhabitants. Current work is focussed on California clapper rails in the San Francisco Estuary, and their relative dependence upon stream evolution and the vegetation.
- Tidal marsh landscape dynamics of the San Francisco Estuary.

RECENT PUBLICATIONS

Foin, T. C., E. J. Garcia, R. E. Gill, S. D. Culberson, and J. N. Collins. 1997. Recovery strategies for the California clapper rail (*Rallus longirostris obsoletus*) in the heavily-urbanized San Francisco estuarine ecosystem. Landcape and Urban Planning 38:229-243.

Foin, T. C., S. P. D. Riley, A. L. Pawley, D. R. Ayres, T. M. Carlsen, P. J. Hodum, and P. V. Switzer. 1998. Improving recovery planning for the conservation of threatened and endangered taxa. Bioscience 48: 177-184.

Caton, B. P., T. C. Foin, K. D. Gibson, and J. E. Hill. 1998.A temperature-based model of direct-water seeded rice (*Oryza sativa*) stand establishment in California. Agricultural and Forest Meterology 90: 91-102..

Gibson, K. D., T. C. Foin, and J. E. Hill. 1999. The relative importance of root and shoot competition between water-seeded rice and watergrass. Weed Research 39: 181-190.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. I. Development, parameterization, and monoculture growth. Field Crops Research 62: 129-143.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. II. Validation testing of water-depth effects and monoculture growth. Field Crops Research 62: 145-155.

Strange, E. L. and T. C. Foin. 1999. Interaction of physical and biological processes in the assembly of stream fish communities. Pp. 311-337 in: Ecological Assembly Rules: perspectives, advances, retreats. (E. Weiher and P. A. Keddy, eds.) 1999. Cambridge University Press.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. III. Interspecific competition for light. Field Crops Research 63: 47-61.

Sanderson, E. W., S. L. Ustin, and T. C. Foin. 2000. The influence of tidal channels on salt marsh vegetation. Plant Ecology 146: 29-41.

Foin, T. C. 2000. One for models, and models for all. Review of An Illustrated Guide to Theoretical Ecology. Conserv. Biol. 14: 1214-1215.

Gibson, K.D., J.E. Hill, T.C. Foin, B.P. Caton, and A.J. Fischer, 2001. Cultivar interference with the growth of watergrass (*Echinochloa* species) in water-seeded rice. Agronomy Journal 93: 326-332.

Gibson, K. D., A. J. Fischer and T. C. Foin. 2001. Shading and the growth and photosynthetic responses of *Ammannia coccinea.* Weed Research 41: 59-67.

Caton, B. P., A. M. Mortimer, T. C. Foin, J. E. Hill, K. D. Gibson, and A. J. Fischer, 2001. Weed morphology effects on competitiveness for light in direct-seeded rice. Weed Research 41: 155-163.

Gibson, K. D., J. L. Breen, J. E. Hill, B. P. Caton, and T. C. Foin. 2001. California arrowhead (*Sagittaria montevidensis*) is a weak competitor in water-seeded rice (Oryza sativa). Weed Science 49: 381-384.

Sanderson, E. W., T. C. Foin, and S. L. Ustin. 2001. A simple empirical model of salt marsh plant spatial distributions with respect to tidal channel networks. Ecological Modelling 139: 293-307.

IN PRESS

Gibson, K. D., A. J. Fischer, T. C. Foin and J. E. Hill. 2002. Implications of delayed *Echinochloa* spp. germination and duration of competition for integrated weed management in water-seeded rice. Weed Research.
Gibson, K. D., A. J. Fischer, T. C. Foin, and J. E. Hill. 2002. Crop traits related to weed suppression in water-seeded rice. Weed Science.
Caton, B. P., A. M. Mortimer, J. E. Hill, and T. C. Foin. 2001. Water depth effects on the growth and root-shoot dynamics of two rice varieties and two *Echinochloa* spp. Field Crops Research.

A. Keith Miles

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Western Ecological Research Center, USGS
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EDUCATION

Ph.D., Oregon State University, June 1987, Wildlife Ecology
M.S., Oregon State University, August 1976, Wildlife Biology
B.S., Howard University, June 1972, Zoology

PROFESSIONAL EXPERIENCE

June 1997 – present	Research Biologist	USGS, Western Ecological Research Center, CA
Jan 1998 – present	Graduate Faculty	Graduate Group in Ecology, University of California, Davis
Sept 2001 – present	Chair, Ecotoxicology AOE	Graduate Group in Ecology, University of California, Davis
Oct 1993 – June 1997	Research Biologist	National Biological Service, Davis, California
July 1986 - Oct 1993	Research Biologist	USFWS, Patuxent Wildlife Research Center, Laurel, Maryland
June 1978 - June 1986	Wildlife Biologist	USFWS, Oregon Coop. Wildlife Research Unit, Corvallis, OR
March - June 1979	Teaching Assistant,	Department of Fisheries and Wildlife, Oregon State University,
Sept - Dec 1979	Ornithology	Corvallis, OR
March - June 1980	T.A. Ornithology	Corvallis, OR
March - June 1980	Instructor	Los Angeles Community College, Marine Biology, CA.
Aug 1977 - Aug 1978	Staff Biologist	USFWS, Division of Cooperative Research Units, Wash., D.C.
Sept 1976 - Aug 1977	Staff Biologist	USFWS, Division of Wildlife Research, Wash., D.C.
Sept 1976 – June 1977	Instructor, Wildlife	University of the District of Columbia, Wash., D.C.
May 1974 - Sept 1974	Biological Technician	USFWS, Oregon Coop. Wildlife Research Unit, Corvallis, OR

CURRENT INTERESTS

I am responsible for research on the effects of contaminants on wildlife and their habitats. The primary focus of research is on the effects of contaminants on estuarine and marine habitats; particularly prey organisms of wildlife under trust to the United States. Emphasis is on determining consequences of accumulation of contaminants in prey, and discriminating effects caused by contaminants from naturally occurring changes in prey populations. This requires the design and conduct of complex, ecological field experiments, utilizing new or existing techniques.

I conduct studies on the effects of contaminants on the structure of invertebrate and vegetative assemblages and the potential for accumulation of these contaminants among specific prey guilds of migratory aquatic birds and marine mammals. My studies have focused on assemblages at Chesapeake Bay, San Francisco Bay, and the Arctic environment. More recently, I have expanded my research to effects of contaminants on fossorial animals at the Mojave Desert. Results of my research are expected to clarify the role of specific contaminants on the structure and function of marine, estuarine, and desert communities. The results of my investigations are interpreted to manuscripts for publication in scientific journals.

I lead a team of biologists, graduate researchers, and technicians that specialize in field-oriented investigative approaches to contaminants problems. I also serve as advisor for specific projects of the Western Ecological Research Center, e.g., Research Grade Evaluation and Science Advisory Committee.

CURRENT AWARDED STUDIES

"Experimental Effects of a Mosquito Larvicide on Migratory Birds and Their Prey," U.S. Fish & Wildlife Service, March 1998.

"Restoration of Severely Disturbed Habitat to Functional Wetlands," U.S. Navy (USN), August 1998.

"Science Support for Wetland Restoration of Salt Ponds, San Francisco Bay Estuary," Place Based Program, August 1998; October 2001.

"Predation Effects on Ground-Nesting Waterfowl and Shorebirds," NASA, September 2001

"Retention (salt) Pond Ecology and Contaminants," USN, September 1998.

"Monitoring Program for Environmental Contaminants in the Nearshore Marine Ecosystem at Adak Island, Alaska," Cooperative proposal with Estes, Anthony, Jarman written for USN on Aleutian islands and contaminants, June 1998. USN, May 1999.

"Potential Impacts of Contaminants on Wildlife at Edwards Air Force Base," U.S. Air Force, August 1999.

"Effects of Hydrocarbons on Steller Eiders at the Alaska Peninsula," U.S. Fish & Wildlife Service, September 2000.

"Restoration of Wetlands following Remediation of Contaminated Habitat," USN, November 2000.

PROFESSIONAL SOCIETY MEMBERSHIP

Ecological Society of America
Estuarine Research Federation
The Wildlife Society
Northern California Chapter of the Society of Environmental Toxicology and Chemistry
Pacific Estuarine Research Society

JOURNAL ARTICLES (peer-reviewed)

Miles, A.K., Lawler, S.P., Dritz, D., Spring, S. in press. Mosquito larvicide effects on mallard ducklings and prey. Wildlife Society Bulletin.

Davis, Sr., R.D., Diswood, S., Dominguez, A., Engel-Wilson, R., Jefferson, K., Miles, A.K., Moore, E.F., Reidinger, R., Ruther, S., Valdez, R., Wilson, K., Zablan, M.A. in press. Increasing diversity in our profession. Wildlife Society Bulletin.

Anthony, R.G., Miles, A.K., Estes, J.E., and Isaacs, F.B. 1999. Productivity, diets, and environmental contaminants in nesting bald eagles from the Aleutian Archipelago. J. Environ. Toxic. Chem. 18(9):2054-2062.

Miles, A. K., and Roster, N. 1999. Enhancement of PAHs in estuarine invertebrates by surface runoff at a decommissioned military fuel depot. Marine Environ. Res. 47:49-60.

Miles, A.K., and Tome, M.W. 1997. Spatial and temporal heterogeneity in metallic elements in industrialized aquatic bird habitat. Environ. Pollution. 95(1):75-84.

Estes, J.A., Bacon, C.E., Jarman, W.M., Norstrom, R.J., Anthony, R.G., and Miles, A.K. 1997. Organochlorines in sea otters and bald eagles from the Aleutian Archipelago. Marine Pollution Bulletin. 34(6):486-490.

Miles, A. K., and Hills, S. 1994. Metals in the diet of Bering Sea walrus: Mya sp. as a possible transmitter of elevated cadmium and other metals. Marine Pollution Bulletin 28(7):456-458.

Miles, A.K., and Ohlendorf, H.M. 1993. Environmental contaminants in Canvasbacks wintering on San Francisco Bay. California Fish & Game. 79:28-38.

Miles, A.K., Grue, E.C., Pendleton, G.W., and Soares, Jr., J.H. 1993. Effects of dietary aluminum, calcium and phosphorus on egg and bone of European starlings. Arch. Environ. Contam. Toxicol. 24:206-212.

Miles, A.K., Calkins, D.G., and Coon, N.C. 1992. Toxic elements and organochlorines in harbor seals (*Phoca vitulina richardsi*), Kodiak, Alaska, USA. Bull. Environ. Contam. Toxicol. 48:727-732.

Miles, A.K. and Meslow, E.C. 1990. Effects of experimental overgrowth on survival and change in the turf assemblage of a giant kelp forest. J. Exp. Mar. Biol. Ecol. 135:229-242.

Miles, A.K., Estes, J.E., Anthony, R.G., Trust, K. in review. Contaminants in near shore fishes from the Aleutian Island Archipelago; inference of point and non-point sources. Archives Environ. Toxic. Chem.

JOURNAL ARTICLES (In Progress):

Miles, A.K., Watson, J., Konar, B., and Estes, J.E. Elemental concentrations in bivalves in relation to volcanic and military activity, Aleutian Islands, Alaska.
Tome, M.T., and A.K. Miles. Waterfowl use, behavior and contaminant burdens at an urbanized sub-estuary, Chesapeake Bay, Maryland.
Miles, A.K. Concentration of elements at seven sites, Baltimore Harbor, Maryland: relationship to benthic species diversity.
Miles, A.K. Hierarchy of elemental contaminants in prey of waterbirds at San Francisco Bay: distribution and potential effects.

TECHNICAL PUBLICATIONS (peer-reviewed)

Miles, A.K., Lawler, S.P., Hoffman, D.J., Albers, P.A., Melancon, M.J., Dritz, D., Spring, S., Buscemi, D.M. 2001. Experimental Assessment of the Toxicity of the Mosquito Larvicide Golden Bear Oil (GB-1111): (1) Field Evaluations on Duckling, Target, and Non-Target Prey Survival; (2) Laboratory Evaluations on Reared Mallard and Bobwhite eggs, and Wild Redwing Blackbird Eggs. Report to the U.S. Fish & Wildlife Service, Portland, OR.

Miles, A.K. 2000. Ruddy Ducks. In: Goals Project. A Report of Species Recommendations. San Francisco Bay Area Wetlands Ecosystems Goals Project. U.S. Environmental Protection Agency, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland, CA.

Miles, A.K. 2000. Surf Scoters. In: Goals Project. A Report of Species Recommendations. San Francisco Bay Area Wetlands Ecosystems Goals Project. U.S. Environmental Protection Agency, San Francisco, Calif./S.F. Bay Regional Water Quality Control Board, Oakland, CA.

TECHNICAL PUBLICATIONS

Miles, A.K., Dominguez, A. (co-chairs), Davis, R.D., Engel-Wilson, R. Reidinger, R., Wilson, K. 1999. Challenges and Opportunities for Increasing Diversity in the Wildlife Profession and the Wildlife Society: Recommendations for TWS in the New Millennium. Report to the Wildlife Society. 19p.

POPULAR PUBLICATIONS

Erwin, R.M., Anders, V., Miles, A.K. 1990. Industrial strength herons: The black-crowns of Baltimore. Outdoors in Maryland. Spring, p.14.

THESES / DISSERTATIONS

Miles, A.K. 1987. Turf assemblage of a Macrocystis kelp forest: experiments on competition and herbivory. Doctor of Philosophy dissertation, Oregon State University, Corvallis, Oregon. 136pp.
Miles, A.K. 1976. Patterns of migration of mourning doves in the western management unit. Master of Science thesis, Oregon State University, Corvallis, Oregon.

EXAMPLE OF PROFESSIONAL SOCIETY PRESENTATIONS

'A Biological Pipeline for contaminants to the Aleutian Islands' food web?' Miles, A.K., Anthony, R.G., Estes, J.E. Sixth Annual Conference of the Wildlife Society, Austin, Texas, September 1999 .
'Organochlorines in coastal fishes at a closed, near Arctic military installation.' Society of Environmental Toxicology and Chemistry, San Francisco, CA., November, 1997.

‘Polycyclic Aromatic Hydrocarbons in Estuarine Mussels and Shore Crabs at a Closed Military Fuel Depot at San Francisco Bay.’ Society of Environmental Toxicology and Chemistry, San Francisco, CA., November, 1997.

‘Distribution and potential effects of contaminants on prey of aquatic birds at San Francisco Bay.’ The Wildlife Society, Second Annual Conference, Portland, OR 1995.

Symposium organizer and chair. ‘Human Impacts on California's San Joaquin-Sacramento Watershed: Contaminant Effects on Wildlife and Habitat.’ The Wildlife Society, Second Annual Conference, Portland, OR 1995.

"Contaminants in waterbird prey in San Francisco and Chesapeake Bays." Eleventh Biennial International Estuarine Research Federation Conference, San Francisco, CA. 1992.

"Aluminum, calcium, and phosphorus effects on egg and bone of European starlings." Twelfth Annual Meeting of the Society of Environmental Toxicology and Chemistry, Seattle, WA. 1991.

"Caloric value of *Macoma balthica* in San Francisco Bay: an indicator of environmental quality?" Twelfth Annual Meeting of the Society of Environmental Toxicology and Chemistry, Seattle, WA. 1991.

"Effects of overgrowth on the turf assemblage of a giant kelp forest." Annual Benthic Ecology Meetings. Solomons, MD. 1988.

INVITED PRESENTATIONS

“Environmental contaminants in fishes and nesting bald eagles from the Aleutian Archipelago.”
Graduate Seminar Series on Conservation Biology, University of California Davis, February 1999.

"Careers in Government Biological Research." Careers in Conservation Symposium, Northern California Chapter of the Society for Conservation Biology. San Jose Sate University, 1996.

"Spatial and temporal variations in contaminants in Baltimore Harbor, Maryland," and "Oceans to lakes: an overview of aquatic research in the U.S. Fish & Wildlife Service." American Society of Limnologists and Oceanographers' Special Session for Minority Students, Nova Scotia, Canada, 1991.

"The purpose and continued need for long-term ecological research studies." Special Workshop of the Meetings of the American Society of Limnology and Oceanography, Williamsburg, VA, 1990.

"Benthic community structure in a giant kelp forest." Inward to the Sea Festival, George Washington University, Washington, D.C., 1987; American Society of Limnologists and Oceanographers' Special Session for Minority Students, Williamsburg, VA, 1990.

"Ecological research in the U.S. Fish and Wildlife Service." Langston State University, Stillwater, Oklahoma, 1988.

"Experiments on competition and herbivory in a *Macrocystis* kelp forest." Oregon State University, Department of Fisheries and Wildlife, Corvallis Oregon, 1986; Smithsonian Environmental Research Center, Edgewater, Maryland, 1987; State University of New York at Stony Brook, Marine Sciences Research Center, 1987.

"Sea Otters and kelp forest ecology." National Zoological Park, Washington, D.C., 1985; Langston State University, Stillwater, Oklahoma, 1988.

TECHNICAL WORKSHOPS

"Ten years of contaminants research on San Francisco Bay by the Branch of Environmental Contaminants Research." Patuxent Wildlife Research Center, Laurel, MD, and the San Francisco Bay National Wildlife Refuge, Fremont, CA. 1992.

LOCAL INVOLVEMENT

The natural cooperators and beneficiaries of this proposal are the reserve managers and restoration specialists who would benefit from this research. We plan to stay in contact with the following individuals throughout this study.

Napa Valley Watershed, Department of Fish and Game lands
Contact persons: Larry Wycoff, Tom Huffman
Pesticide contact: Joel Trumbo
Permit Status: granted

Don Edwards South Bay National Wildlife Refuge
Contact: Joy Albertson, Clyde Morris
Permit Status: in process

San Pablo Bay National Wildlife Refuge
Contact: Giselle Downard
Permit Status: granted

Cosumnes Preserve
Contact: Becky Waegell
Permit Status: granted

Rush Ranch
Contact: Solano County Open Space Trust, Pam Muick
On-site manager: Ken Poerner
Permit Status: in process

We have access to Concord Naval Reserve and Skaggs Island through the permits issued to co-principal investigator A. Keith Miles.

We have also obtained a permit from the U.S. Department of Fish and Wildlife Service for incidental take of endangered species, including clapper rails, salt marsh harvest mouse, and salt marsh birds beak.

The experiment involving herbicide applications requires special attention. We expect to run this experiment in two or three sites, including some combination of the North Bay -Napa Watershed, Don Edwards South Bay Reserve, and one upriver site. All sites contacted have indicated their cooperation, and some have even indicated they may wish to continue the program after this project has finished. Renee Spenst holds a Qualified Applicator Certificate awarded by the Department of Pesticide Regulation, granted September, 2002.

At the conclusion of this study, we will consider publishing an on-line manual with our results relevant to minimizing *Lepidium latifolium* invasion and controlling established stands in marshes.

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