PROGRESS REPORT

Restoring prairies: A synthesis of studies on vegetation and invasive species in support of effective management (Year two)

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Introduction

Willamette Valley wetland and upland prairies are some of the most endangered ecosystems in the United States, and provide habitat for many federally listed species. These are dynamic systems, subject to ecological succession and invasion by aggressive non-native species, and require active management to maintain management goals. This is true of all Willamette Valley prairies, whether intact, degraded, or reestablished. Yet restoration and conservation efforts often lack experimental validation. Our overall objective is to synthesize the scientific information now available pertinent to the prairie restoration efforts of the West Eugene Wetlands Program (WEWP) and, where there is sufficient support, develop concrete and defensible management recommendations.

Successful ecosystem restoration requires establishing and maintaining native plants. In turn, plant establishment hinges on having suitable environmental conditions, using species with adequate germination and growth rates, and reducing competitive pressure from non-native plants (Figure 1). In *year one* of this project, we synthesized the wealth of plant establishment data during wetland restoration in the West Eugene Wetlands Program. In *year two*, we are building and expanding on these results in several important ways:

- We are *generalizing* these results through the investigation of plant traits (Table 1) that consistently correspond to the patterns of establishment and vigor (Figure 1).
- We are systematically compiling the results from year one and year two of this project into a public *database*. We are adding to this database findings from similar ecosystems, both in the Willamette Valley and elsewhere.
- We are considering further the role of *microsite* variability on seedling establishment patterns.
- We are *synthesizing* these results into scientific conclusions.
- We are *integrating* these results, where there is sufficient support, into concrete and defensible management recommendations

Our goal is to develop an ability to predict key aspects of prairie restoration performance, such as establishment rates, based on species traits, site conditions, and maintenance. These predictions can then be restated as management recommendations, such as which species to sow and site preparation and maintenance regimes to follow to maximize native plant abundance and minimize non-native plant abundance at a given site.

The two components of our project–plant traits and the database–are crucial to this goal.

- Without the generalization that traits allow, understanding of wetland restoration increases slowly and expensively, one case study at a time.
- The organization of the database will increase the power and efficiency of revealing the relationships between plant traits and plant performance. Perhaps even more important is the role of the database as a first step in developing a Web-based expert system for managers wishing to plan wetland restorations.

This report describes our progress to date.

Activities: Willamette Valley Species Database

The Willamette Valley Species Database is a compilation of ecological information on species important in upland prairies, wetland prairies, vernal pools, emergent wetlands, and prairie and wetland restoration. The Database currently contains more than 5000 data points on 128 species. More than 60 of the WEWP species are part of the Database at this point. We will continue to expand the Willamette Valley Species Database to include more species and more traits. See below for details.

Activities: Predicting establishment rates

A focus of our project is developing the ecological understanding necessary to predict seedling establishment rates in restoration projects from readily available plant traits. Preliminary analyses are already promising. We compiled a test set of 22 species analyzed for their establishment rates in WEWP restoration sites (Wilson 2004). The 22 species were selected to include a range of species types, sowing rates, and establishment rates. We extracted for these species nine traits currently available from the Willamette Valley Species Database that might relate to establishment rates (Table 2). Note that these traits are characteristics of the species and are independent of the particular field conditions at the WEWP restoration sites.

Establishment rates varied by plant traits (Table 3). A striking result, even at this preliminary stage, is how Vernal Pool habitats have consistently opposite patterns. For example, annuals tended to have higher establishment rates than perennials in Vernal Pool habitats, but perennials had higher average establishment rates in the *Deschampsia*-dominated and Emergent habitats. Dicot forbs had the highest establishment in Vernal Pool habitats, but graminoids had the highest establishment in *Deschampsia*-dominated and Emergent habitats. Plants with only cauline leaves (leaves attached to the upright stem) had the highest establishment in Vernal Pool habitats, but plants with only long-basal leaves had on the average the highest establishment in *Deschampsia*-dominated and Emergent habitats. A stratification requirement was unimportant in the Vernal Pool habitat, but plants with a stratification requirement for breaking dormancy had much less average establishment rates in *Deschampsia*-dominated and Emergent habitats. We will continue analysis and interpretation on this previously unreported pattern.

We also investigated the relative importance of plant traits in explaining establishment patterns. To do this, we used a stepwise regression of all nine plant traits (Table 2) to select the key, statistically significant traits. Average establishment rates were converted to a modified rank scale for this analysis. Species with establishment rates of zero were separated into three ordered categories: those that established in significant amounts at other sites, those that established at very low rates at other sites, and those that did not establish anywhere. The resulting modified ranks went from 40 (the species with the highest establishment rate) to 1 (no establishment).

For overall establishment rates across all habitats, germination rate (%) was the most important trait explaining field establishment (Table 4). The positive coefficient of +0.23 shows that higher the germination rate under laboratory conditions, the higher the establishment rate in field. This model explained 23% of the variability in establishment rates.

Habitat was a biologically important and statistically significant factor in determining species establishment rates (Wilson 2004). Therefore we repeated the stepwise regression for each habitat (Table 4). In Vernal Pool habitats, both perenniality and maximum height were part of the resulting statistical model. Annuals and plants with greater height potential tended to establish at higher rates. These factors explained a healthy 34% of the variability in establishment rates. *Deschampsia*-dominated and Emergent habitats shared similar patterns. Plants with higher germination rates under laboratory conditions and plants with greater potential height growth tended to establish at higher rates in the field (Figure 2 for Emergent habitats). These two factors explained 34% of the variability in establishment rates in *Deschampsia*-dominated habitats and 39% of Emergent habitats.

These early results suggest concrete recommendations for selecting species to sow in restoration projects similar to those of the WEWP. If high establishment rate is the objective, strive to select species with greater maximum height potential. In Vernal Pool habitats, include many annuals in the sowing mix. In *Deschampsia*-dominated and Emergent habitats, include species with high germinability. When our Willamette Valley Species Database becomes available online, managers will be able to use this information by checking plant species they are considering for inclusion in sowing mixes against their traits and selecting the species that best meet their objectives.

Activities: Measurement of plant traits

Many of the key plant traits (Table 1) are not yet available in the Willamette Valley Species Database or from the ecological literature. We have started a series of studies to ascertain these traits for the WEWP species. The studies include measurements of plant growth under standardized growth chamber conditions, measurement of seed characteristics, and determination of other traits from direct observation or from published references. We will conduct all three types of measurements for high priority species.

Growth chamber procedures will follow the general recommendations of Hendry and Grime (1993). Standardized conditions include specifications for germination media, transfer of germinants, pot size, growing media, nutrient solutions, growing illumination and temperatures, and dates of harvest. The use of standardized conditions allow us to integrate our results with those in the scientific literature. The Willamette Valley Species Database will house both sources of data. Thus managers will have a larger pool of data–ours and the data from the literature–with which to make management and restoration decisions.

Citations

Hendry, G. A. F. and Grime, J. P. 1993. Methods in comparative plant ecology. Chapman & Hall, London.

US Fish and Wildlife Service. 1988. National list of vascular plant species that occur in wetlands. US Fish & Wildlife Service Biological Report 88.

Wilson, M. V. 2004. Patterns of establishment success in West Eugene Wetlands Program restoration sites. Final report to the Bureau of Land Management, Eugene District. 42 pages.

Table 1. Plant traits and the ecological functions or behaviors they correspond to in the field.

Trait	*Function or behavior*
Life history (including perenniality)	plant longevity space-holding ability disturbance tolerance
Growth form	competitive ability
Leaf arrangement	space-holding ability
Wetland Indicator Status	affinity for hydric conditions
Clonality	space acquisition
Height	competitive ability
Seed mass	dispersal distance longevity in seed bank establishment success fecundity
Seed shape and color	longevity in seed bank
Dispersal type	dispersal distance longevity in seed bank
Dormancy breaking mechanism	establishment success longevity in seed bank
Germination rate	establishment success competitive ability
Relative growth rate - unit leaf rate - leaf area ratio - leaf weight ratio - specific leaf area - fresh weight/dry weight ratio - root/shoot allometric coefficient - leaf size (individual leaf area)	competitive ability space-holding ability plasticity stress tolerance leaf longevity
Photosynthetic pathway	resource acquisition phenology
Above-ground biomass	competitive ability fecundity

Trait	*Function or behavior*
Stem density	plant longevity carbon storage
Specific root length	resource acquisition
Mycorrhizal infection	resource acquistion
Onset of flowering	stress avoidance disturbance avoidance
Resprouting ability	disturbance tolerance

Table 2a. Traits possibly related to seedling establishment rates for the preliminary set of species from the West Eugene Wetlands Program. See Table 2b for an explanation of traits terms. NA: Not available.

Species	Perenniality	Growth form	Leaf arrangement	Maximum height (cm)	Wetland Indicator Status	Tyipical germination (%)	Normal height (cm)	Seed mass (mg)	Requires stratification?
Agrostis exarata	Perennial	Graminoid	Long basal	100	FACW	85	70	0.08	no
Beckmannia syzigachne	Annual	Graminoid	Long basal	100	OBL	72	70	0.85	no
Camassia quamash	Perennial	Monocot forb	Long basal	60	FACW	90	45	4.53	no
Carex ovalis	Perennial	Graminoid	Long basal	80	FAC	100	55	0.72	yes
Carex unilateralis	Perennial	Graminoid	Long basal	100	FACW	24	65	0.46	yes
Danthonia californica	Perennial	Graminoid	Long basal	80	FACU-	86	65	4.50	yes
Deschampsia cespitosa	Perennial	Graminoid	Long basal	100	FACW	86	75	0.44	no
Downingia elegans	Annual	Dicot forb	Cauline	40	OBL	93	30	0.23	yes
Downingia yina	Annual	Dicot forb	Cauline	30	OBL	96	18	0.04	NA
Epilobium densiflorum	Annual	Dicot forb	Cauline	95	FACW-	97	50	0.53	yes
Eriophyllum lanatum	Perennial	Suffrutescent	Cauline	28	NL	56	18	0.46	yes
Glyceria occidentalis	Perennial	Graminoid	Long basal	140	OBL	91	115	2.63	yes
Grindelia integrifolia	Perennial	Dicot forb	Both	75	FACW	52	35	3.57	yes
Hordeum brachyantherum	Perennial	Graminoid	Long basal	90	FACW	98	65	5.40	no
Juncus acuminatus	Perennial	Graminoid	Long basal	90	OBL	92	60	0.01	no
Microseris laciniata	Perennial	Dicot forb	Long basal	75	NL	66	40	1.60	yes
Plagiobothrys figuratus	Annual	Dicot forb	Cauline	40	FACW	87	25	0.70	no
Potentilla gracilis	Perennial	Suffrutescent	Long basal	80	FAC	25	60	0.32	yes
Prunella vulgaris	Perennial	Dicot forb	Cauline	50	FACU+	85	30	1.14	no
Ranunculus occidentalis	Perennial	Dicot forb	Long basal	60	FACW	89	35	2.70	yes
Ranunculus orthorhynchus	Perennial	Dicot forb	Long basal	95	FACW-	34	55	3.20	NA
Veronica scutellata	Perennial	Dicot forb	Cauline	40	OBL	60	25	0.20	yes

Table 2b. Explanation of specialized trait terms used in Table 2a and elsewhere.

Germination (%)	The proportion of seed that germinate under suitable conditions.
Stratification	A seed-dormancy-breaking treatment involving cold-moist conditions followed by warm conditions.
Growth form terms	
Graminoid	Herbaceous plant with a grass-like appearance; typically grasses, sedges, and rushes.
Forb	Herbaceous plant that is not a graminoid; broad-leaved.
Suffrutescent	Some but not all woody structures die back during the dormant season.
Leaf arrangement terms	
Cauline	Leaves attached at various points along the stem.
Basal	Leaves attached at the base of the stem. "Long basal" refers to long basal leaves.
Wetland indicator status terms for Region 9(from US Fish and Wildlife Service, 1988)	
OBL	Occurs almost always (estimated probability 99%) under natural conditions in wetlands.
FACW	Usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
FAC	Equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
FACU	Usually occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
NL	Not listed.
+, –	+ indicates the wet side of an status term; – indicates the dry side of a status term.

Table 3. Average establishment rates by plant trait, with standard errors (SE). *n* is the number of species with that trait. *: Significant difference among traits (Kruskal-Wallis test, $\alpha = 0.05$).

Trait		*n*	Overall	Habitat		
				Vernal Pool	*Deschampsia* -dominated	Emergent
Perenniality						
Annual	Mean	5	7.5	21.8*	0.8	0.0
	SE		4.3	12.8	0.4	0.0
Perennial	Mean	17	1.7	0.5*	3.7	0.9
	SE		1.3	0.3	2.9	0.6
Growth form						
Dicot forb	Mean	10	3.9	11.2	0.5	0.0
	SE		2.4	7.0	0.2	0.0
Graminoid	Mean	9	3.1	0.7	6.9	1.8
	SE		2.3	0.5	5.4	1.2
Monocot forb	Mean	1	0.0	0.0	0.0	0.0
	SE		—	—	—	—
Suffrutescent	Mean	2	0.0	0.0	0.0	0.0
	SE		0.0	0.0	0.0	0.0
Leaf arrangement						
Cauline	Mean	7	5.4	15.5	0.6	0.0
	SE		3.3	9.7	0.3	0.0
Long basal	Mean	14	2.0	0.5	4.4	1.1
	SE		1.5	0.3	3.5	0.8
Both	Mean	1	1.4	3.0	1.1	0.0
	SE		—	—	—	—
Requires stratification?						
No	Mean	8	5.2	6.7	7.3	1.5
	SE		3.1	5.9	6.0	1.3
Yes	Mean	12	2.1	5.4	0.7	0.3
	SE		1.6	4.8	0.3	0.2

Table 4. Results of stepwise regression of species traits in explaining species establishment rates in the West Eugene Wetlands restoration sites. The response variable was the modified rank of the average establishment rates. (See text for explanation.) Factors were added only if they contributed significant explanatory power, using a Mallows C_p procedure.

Factor	Coefficient	t value	P
All habitats (R^2 = 23%)			
Germination rate	0.23	2.4	0.03
Vernal Pool habitats (R^2 = 34%)			
Perenniality	-8.24	2.9	0.01
Maximum height	0.15	-1.8	0.09
Deschampsia-dominated habitats (R^2 = 34%)			
Germination rate	0.26	2.7	0.01
Maximum height	0.14	1.7	0.10
Emergent habitats (R^2 = 39%)			
Germination rate	0.28	3.0	0.01
Maximum height	0.16	2.0	0.06

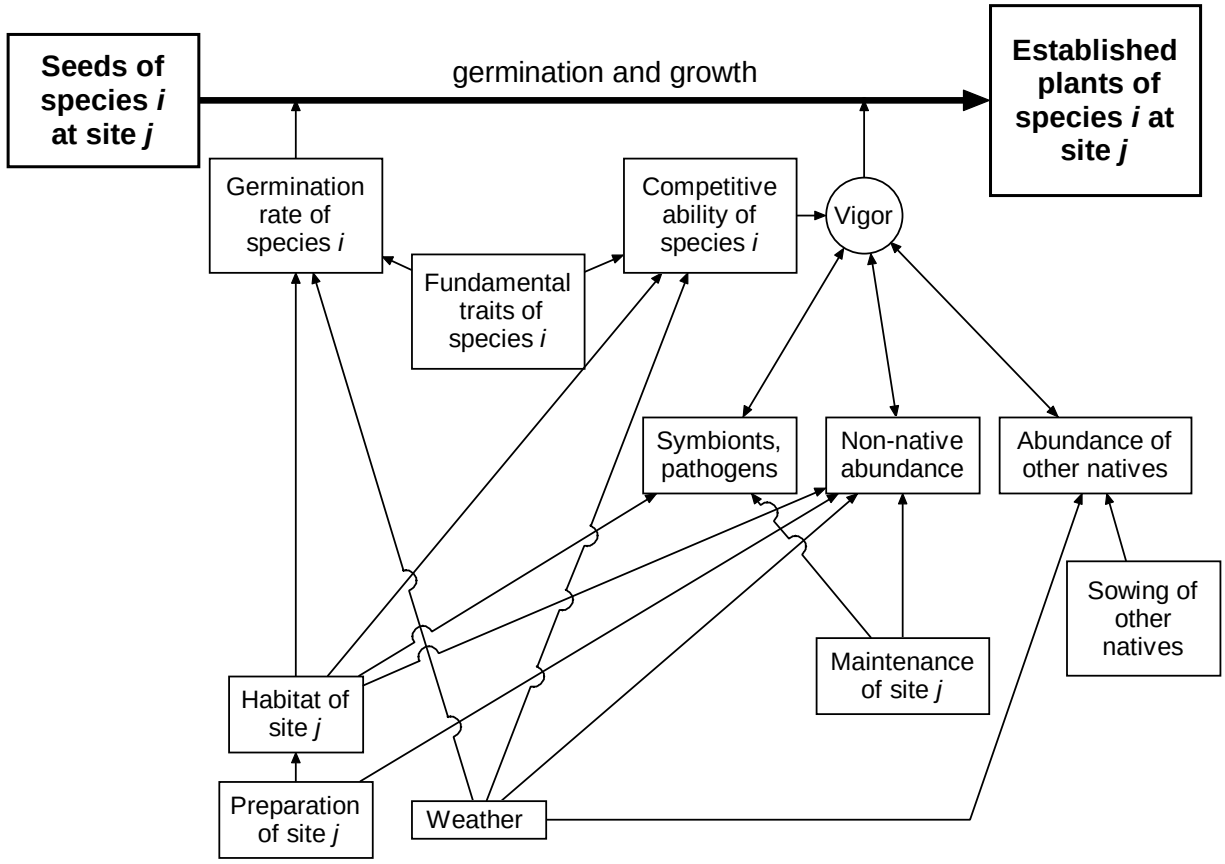

Figure 1. Ecological factors responsible for the success or failure of establishing native plants during wetland restoration. The goal is to find predictable relationships between these factors and plant performance that are general across species traits and conditions of site.

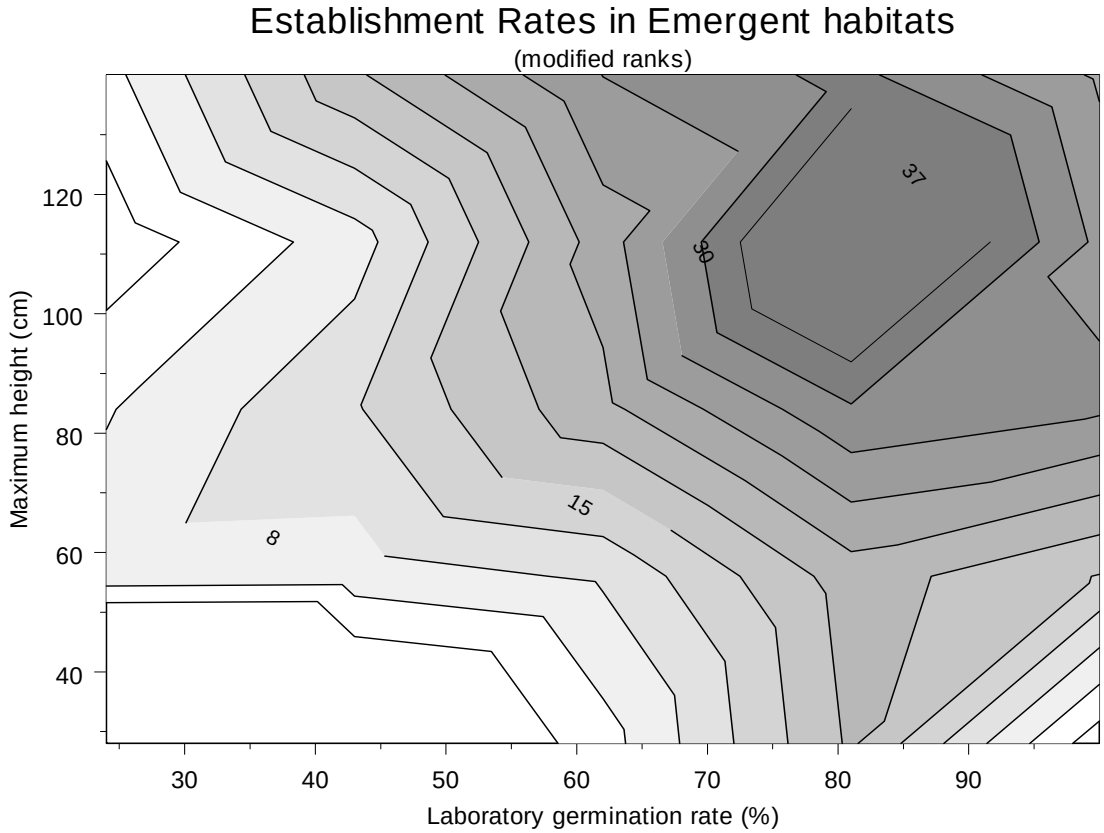

Figure 2. Establishment rates (modified ranks) can be predicted by a species's germination rate under laboratory conditions and its maximum potential height.