Saratoga Horticultural Research Endowment Proposal

Applicant Overview

1. Project Title: *Development of drought-tolerant California native plant materials for predators, parasitoids and pollinators*
2. Project total budget: $25,000
3. Applicant Organization: UC Davis Department of Entomology and Nematology
4. Applicant Address: Department of Entomology and Nematology, One Shields Avenue, Davis, CA 95616
5. Project Location: Davis, CA
6. Principal Investigator: Neal M. Williams
7. Project Manager: Kimiora Ward, kiward@ucdavis.edu
8. Cooperating Entities: Ellen Zagory and UC Davis Arboretum, USDA NRCS, UC Davis Department of Entomology and Nematology, Eric Lonsdorf (Natural Capitals Project, University of Minnesota)

Executive Summary

1. Project Summary:

This project supports the horticultural industry by expanding the palette of native wildflowers used in California gardens, ornamental and other urban landscapes, by identifying drought tolerant species and by optimizing plant materials to benefit bees, predators and parasitoids while minimizing attractiveness to pests. We will accomplish this by comparing data on plant establishment from seed in irrigated and non-irrigated conditions and by assessing the potential of specific plant species to support key pests and natural enemies as well as bees. These data will parameterize an innovative decision tool allowing identification of most cost effective plant species for support of beneficial insects while minimizing pests. We will work with the UC Davis Arboretum to ensure the tool and our analysis incorporate horticulturally-relevant costs and benefits of each species, and we will partner with them to integrate recommendations into the UC Davis Arboretum plant lists (e.g., All-Stars).

2. SHRE priorities addressed:

This project addresses Research and Education Priorities 4 and 5, to develop and/or expand the range of available climate-appropriate plants for regional California gardens and urban landscapes, and to identify and encourage the use of plants that support native beneficial insects, particularly predators and parasitoids.

Needs and Outcomes

Need 1: Identification of drought tolerant plants for California gardens that support beneficial insects, including predators, parasitoids and pollinators, while minimizing insect pests.
Outcome 1: Combined analysis of different native plant species' dependence on irrigation with their attractiveness to pollinators, predators and parasitoids while minimizing pests will provide an expanded and quantitatively validated set of native wildflower recommendations for landscaping in the region.

Need 2: Accessible information on pollinator and beneficial-insect-supporting plants for California gardeners.
Outcome 2: Web-based and printed plant lists of field tested plant species (from Outcome 1) linked to UC Davis Arboretum web and print materials.

Need 3: Increased availability and reduced cost of native wildflowers available for gardens and ornamental horticulture in Northern CA.
Outcome 3: Cost-benefit analysis of different plant species showing ability to provide support for beneficial garden insects per dollar spent. This information will inform producer and consumer choices and thus promote demand for these regionally relevant wildflowers, which will motivate seed vendors and nurseries to increase production and thus help to reduce costs and increase options for obtaining seed and plants. We will reach a wide audience by providing information on plant characteristics through the UC Davis Arboretum, UCCE, NGOs, Master Gardeners, the Native Seed Network and seed vendors we work directly with.

Main Project Narrative

Introduction

Challenges to honey bee health and news of global pollinator declines has not only raised awareness of the importance of restoring pollinator habitat in natural and agricultural settings, it has captured the attention of homeowners and urban land managers and created new demand for horticultural varieties that support bees in urban gardens and landscapes. Urban areas, suburban areas and the urban-rural interface have conservation value for pollinators (Baldock et al. 2015; Threlfall et al 2015), and can be population sources for bees that provide pollination service to urban farms, home gardens (Lowenstein et al. 2015) and adjacent natural lands (Kaluza et al 2016). In addition, growing interest in sustainability and environmental health has led to increased awareness of IPM practices and the desire to tailor garden management and urban greenspaces to promote biological pest control. Many horticultural cultivars support beneficial insects, but native plant species often support a greater diversity of beneficials, are likely to be more tolerant of drought and are adapted to local soils and other environmental conditions. There is also growing interest in the use of native plants for urban and suburban landscaping and greenspace development, for example in public parks, golf course roughs, and bioswales around storm water retention basins and outflow areas.

Native plants are available through seed vendors and a select set of ornamental-plant nurseries, and many of these are recommended for pollinators; however, their relative value for bees and beneficial insects that help to control pests has not been rigorously quantified. Such lack of verification can lead to unmet expectations for homeowner and gardener communities and municipalities who are invested in promoting diverse flora as well as supporting beneficial insects. As such there is a need for high performing, regionally relevant plant species that support beneficial insects and contribute to biological control.

Landowners seek robust information on which species to plant, while seed vendors and nurseries need to know which species to invest in. Identification of native plant species that support beneficial insects, establish successfully, bloom at the right time and are compatible with horticultural management practices can increase cost effectiveness of native horticultural materials and encourage the native seed market.

We have initiated field trials of 45 species of native California wildflowers for their potential to support honey bees, wild bees and butterflies in agricultural landscapes, as well as their attractiveness to other beneficial insects and pests. The species include annuals and perennials with diverse bloom times, flowers and growth forms. We are currently building a decision model to aid plant selection using data from these trials (Williams and Lonsdorf, in prep). The model incorporates information on bloom times, bee visitation and plant costs to determine the most cost effective seed mix for establishment of diverse plant communities supporting pollinators in agricultural landscapes. The objectives of gardens and urban landscapes differ from agricultural lands, but a similar process of identifying plants based on desired characteristics still applies. We propose to leverage our newly collected data set to identify plants that optimize support of both pollinators and natural enemies while minimizing pest liability, and that meet specific criteria for horticultural development, including considerations of cost, ease of establishment, garden management practice and drought tolerance in addition to support of pollinators and other insects.

Statement of goals and objectives (and their relevance to the purpose of the endowment)

Our overall goal is to expand the palette of native plants in use by the native seed and horticultural industry for use in regional California gardens and landscapes. Within this goal we address a series of coordinated objectives.

1. Quantify pollinators, pests and natural enemies associated with specific plant species to identify species that support predators and parasitoids as well as a diversity of bees
2. Quantify establishment success and bloom densities in irrigated vs. non-irrigated conditions
3. Identify key plant traits of importance for use as garden and horticultural plants in California
4. Integrate the potential for support of beneficial insects with potential pest liabilities into decision support tools to optimize plant selection for California gardens
5. Provide recommendations for gardeners as well as to horticulture organizations, nurseries and native seed suppliers for native plant material development

Outline of the proposed research

Background and Previous Research: This project builds on our ongoing work evaluating the contribution of particular plant species to bee forage plantings in agricultural settings. We are currently testing a diverse set of native species for application in almond and row crop settings, and will leverage the resulting data to inform development of native plant materials for horticulture. We planted four replicates of single species test plots in a randomized complete block design in fall 2014 at the Harry Laidlaw Honey Bee Biology Research Facility at UC Davis. These plots are adjacent to an existing horticultural garden (the UC Davis Haagen Dazs Honey Bee Haven Garden) in a location that interfaces rural and suburban areas. As a result, the bee, natural enemy and pest communities are diverse and relevant for diverse horticulture applications (Figure 1).

We targeted 45 California native plant species that bloom at various times of the season, differ in life cycle (annual versus perennial), are adapted to local climate and soils, and are available from native seed producers. These include some species already recommended for pollinator plantings and additional promising species (Table 1). Species are grown in one by one meter plots, with one meter between plots and a minimum of five meters between blocks. We irrigated plots until summer in 2015 and in 2016 we tested plant performance without any irrigation. Annual species and perennial species that did not establish in the first or second year were re-seeded in the second or third year.

From 2015 to present we have been monitoring bloom phenology, honey bee and wild bee use among these plant species. In 2015 and 2016 we also sampled each species for pests and natural enemies. We measured flower abundance weekly for each plant species. During bloom we collected honey bee and wild bee visitors (by species) to each plant species. In 2015 and 2016 during peak bloom for each species we used timed vacuum-samples from each plant species to collect pests and beneficial insects (predators and parasitic wasps). Specimens were identified in the lab.

Figure 1. Replicated plantings of single species test plots at the Harry Laidlaw Honey Bee Biology Research Facility at UC Davis.

We thus have a robust data base on drought tolerant plants and quantitative standardized information on use by beneficial insects and potential pests.

Proposed Research: For the current project we propose to summarize these data and analyze differences among plant species to address the set of coordinated objectives:

Objective 1. *Plant attractiveness for beneficial insects and pests of horticultural importance.* We will summarize the abundances of each insect species on each plant as well as flower abundance per plant species. The relationship between insect species abundances and floral abundance of individual plant species serves as a recognized index of attraction (preference) of the plant to that insect. To test if plant species are differentially attractive for functional insect groups (predators and parasitic wasps, honey bees, wild bees, other pollinators and pests of horticultural importance) we will compare mean numbers of parasitoids, pollinators and pests using a general linear mixed model, with plant species identity and year as fixed effects and block within year as a random effect. We will test for covariation among these different insect functional groups across plant species using pairwise correlation tests. The resulting attractiveness weightings to beneficial versus pest insects serves as way to rank plant species benefit value.

Table 1. Species tested at Harry Laidlaw Honey Bee Biology Facility on UC Davis campus. Species are identified, along with annual or perennial status, phenology and whether they are use in previous mixes or new options.

Species	Common name	Ann/ Per	Color of blossom	BLOOM SEASON												Previously recommended for pollinators	NEW
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Heterotheca grandiflora	telegraph weed	A, P	yellow	*	*	*	*	*	*	*	*	*	*	*	*		
Abronia villosa	hairy sand verbena	A	pink	*	*	*	*	*	*	*	*	*					X
Camissoniopsis cheiranthifolia	beach evening-primrose	P	yellow	*	*	*	*	*	*	*	*						X
Erysimum suffrutescens	suffrutescent wallflower	P	orange	*	*	*	*	*	*	*							X
Abronia maritima	sticky sand verbena	P	pink		*	*	*	*	*	*	*	*	*	*	*		X
Amsinckia intermedia	common fiddleneck	A	yellow		*	*	*	*	*								X
Lasthenia californica	California goldfields	A	yellow		*	*	*	*	*							X	
Lasthenia glabrata	yellowray goldfields	A	yellow		*	*	*	*	*							X	
Calandrinia ciliata	redmaids	A	pink		*	*	*	*									X
Lupinus succulentus	arroyo lupine	A	purple		*	*	*	*								X	
Phacelia ciliata	great valley phacelia	A	purple		*	*	*	*									X
Scrophularia californica	California bee plant	P	dark red		*	*	*	*									X
Collinsia heterophylla	Chinese houses	A	purple		*	*	*										
Gilia capitata	blue field gilia	A	blue		*	*	*										
Nemophila maculata	five spot	A	white/blue		*	*	*										
Phacelia campanularia	desert bells	A	blue		*	*	*										
Sphaeralcea ambigua	desert mallow	P	orange		*	*											X
Nemophila menziesii	baby blue eyes	A	blue			*	*	*	*								
Salvia columbariae	chia sage	A	blue			*	*	*	*							X	
Phacelia tanacetifolia	lacy phacelia	A	purple			*	*	*								X	
Grindelia camporum	gumweed	P	yellow				*	*	*	*	*	*	*			X	
Achillea millefolium	yarrow	P	white				*	*	*	*	*					X	
Clarkia purpurea	purple clarkia	A	pink				*	*	*	*						X	
Eschscholzia californica	California poppy	A, P	orange				*	*	*	*						X	
Limnanthes alba	meadowfoam	A	white				*	*	*								X
Trifolium fucatum	bull clover	A	white/pink				*	*	*							X	
Trifolium gracilentum	pin point clover	A	red				*	*	*								X
Eriophyllum lanatum	woolly sunflower	P	yellow					*	*	*	*						X
Clarkia williamsonii	Fort Miller clarkia	A	pink					*	*	*							X
Lupinus microcarpus ssp. densiflorus	chick lupine	A	yellow					*	*							X	
Madia elegans ssp. densiflorus	common madia	A	yellow					*	*							X	
Malacothrix saxatilis	cliff aster	P	white/pink						*	*	*	*	*	*	*		X
Helianthus bolanderi	Bolander's sunflower	A, P	yellow						*	*	*	*	*			X	
Lupinus formosus	summer lupine	P	purple						*	*	*	*	*			X	
Asclepias fascicularis	narrow leaf milkweed	P	pink						*	*	*	*				X	
Clarkia unguiculata	elegant clarkia	A	pink						*	*	*	*				X	
Oenothera elata	evening primrose	A	yellow						*	*	*	*				X	
Asclepias eriocarpa	woolly pod milkweed	P	white						*	*	*						X
Helianthus annuus	common sunflower	A	yellow						*	*	*					X	
Monardella villosa	coyote mint	P	purple						*	*	*					X	
Phacelia californica	California Phacelia	P	purple						*	*						X	
Solidago velutina ssp. californica	oreja de liebre	P	yellow							*	*	*	*			X	
Helianthus californicus	California sunflower	P	yellow							*	*	*					X
Madia elegans ssp. vernalis	common madia	A	yellow							*	*	*					X
Trichostema lanceolatum	vinegarweed	A	purple								*	*	*			X	

<u>Objective 2</u>. *Drought tolerance*. To quantify establishment success and assess drought tolerance we will compare floral area of each plant species from our replicated plots when plots were irrigated in 2015 to that when plots were not irrigated in 2016. This will allow us to incorporate irrigation needs of each species into the plant selection model.

We will apply a similar general linear mixed model to test for differences in establishment success using floral area or percent cover during bloom as response variables, again with plant species identity and year/irrigation regime as fixed effects and block within year as a random effect. The effect size of the year/irrigation effect will reveal the importance of irrigation for establishment and performance.

Objective 3. *Identify key plant traits for horticulture*. We will partner with Ellen Zagory and staff at UC Davis Arboretum, and build connections with the UC Center for Urban Horticulture to identify key plant traits of importance for use in ornamental horticulture for gardens and other urban landscape applications. While we are analyzing data on benefits to pollinators, the natural enemies of horticultural pests and drought tolerance (Objectives 2 and 3) we will organize a series of meetings with arboretum staff and others to identify key traits required for successful horticultural application/use. For example, ease of maintenance in gardens with minimal need for weed control is desirable, and diverse bloom phenologies are important for ornamental horticulture. We will then add these traits to our selection process and, where possible, directly into the decision tool (Objective 4).

Objective 4. *Integrate beneficial insect, pest liability and horticultural traits into plant selection for pollinator gardens.* Our data on key pests and natural enemies from single-species test plots will be combined with data on pollinator use of plants and with plant-specific seed costs, seeding rate information and other installation and maintenance costs using an optimization model. A preliminary model structure was successfully developed by PI Williams and collaborator Lonsdorf, and uses information on bloom period, bee visitation and plant costs to determine cost-effective mixes. It has not however included critical information on pest risks and beneficial insects that mitigate pest risk or desired horticultural traits. Kimiora Ward will work with collaborator Eric Lonsdorf to further develop the model to incorporate pest and natural enemy characteristics of the plant species. The model will allow us to identify mixes that maximize support of pollinators while simultaneously avoiding species that promote pests. Modeling with different cost scenarios and context-specific pests and pollinators can be used to determine a range of best plant species for use in particular gardening and landscaping contexts.

Objective 5. *Provide recommendations to ornamental horticulture industry and other stakeholders*. Once we have identified a set of candidate plants we will work with UCD Arboretum staff to prepare plant lists in a format that can be presented on UC Davis web pages and provide printed resources that parallel the information in the Arboretum All-Stars booklet. Plant lists will include propagation information, specific growth form, drought tolerance and soil requirements, as well as availability and vendor information.

Project Timeline (July 2017 – June 2018)

- Fall 2017: Summarize existing data on establishment success, floral area, bloom phenology, pollinator, predator, parasitoid and pest use of plants from irrigated plots in 2015 and non-irrigated plots in 2016. Regular consultation meetings with UCD Arboretum staff to ensure consideration of horticulturally relevant plant characteristics (e.g., bloom times, growth habit)

- Winter 2018: Work with Lonsdorf to incorporate these data into ongoing model development for a tool that aids plant selection based on cost and benefit for supporting beneficial insects, and horticulturally important characteristics.

- Spring 2018: Work with UCD Arboretum staff to develop web-based and printed recommended plant lists with information on methods for cultivation and management.

Budget Detail

Budget				
Item	**Quantity**	**SHRE funds**	**Partner Contribution**	**In-Kind**
Salary for SRA Kimiora Ward to undertake data summary, analysis and characterization of specific plant species	8 weeks	$16,000		
Support for K Ward for data collection and collaborator E Lonsdorf on selection model	9 weeks			$18,000
E Lonsdorf - time on model	2 weeks		$6,000	
UCD Entomology Laidlaw Bee Facility	0.6 acres			test plot land
UCD Entomology Department Computer and Office space				$2,000
Salary for Arboretum staff to meet with Ward for consultation on plant traits of horticultural importance and design layout and format for print and web materials	2 weeks	$6,000		
Web team time to compile webpages and link to existing outreach from UC Davis horticultural sites	2-4 days	$2,000		
Print materials		$1,000		
TOTALS		$25,000	$6,000	$20,000 + facilities space

Budget Narrative

Support for Ward, based on an annual base of $67,150 plus fringe benefits and 3% COL increase according to UC Davis policy.

Ellen Zagory's time at the UCD Arboretum for assistance to identify important traits for garden and horticultural plants, and to assist with development of web and printed material.

Web team UCANR staff David Krause - integration of information to UC Arboretum and relevant ANR web pages.

Print materials costs based on UC Davis Reprographics rates - plant recommendations for gardeners, horticultural nurseries and seed vendors.

List of other sources of funding and support

UC Davis Department of Entomology and Nematology

- Provided land for establishment of replicated single species plots and contributed to maintenance of these plots.
- Provides salary time for PI Williams work on the project
- Provides office space and computer for work on data summary and analysis
- $18,000 in matching salary for Ward from USDA NRCS Conservation Innovation Grant (Supporting honey bees and native almond pollinators through improved forage mixes: testing of establishment methods and strategic native plant selection. Covers work with Lonsdorf on updating model for decision tool

Attachments

Literature cited

Baldock. K.C.R, M.A. Goddard, D.M. Hick, W.E. Kunin, N. Mitschunas, L.M. Osgathorpe, S.G. Potts, K.M. Robertson, A.V. Scott, G.N.Stone, I.P. Vaughan, and J. Memmott. 2015. Where is the UK's pollinator biodiversity? The importane of urban areas for flower-visiting insects. Proc. R. Soc. B 282: 20142849. http://dx.doi.org/10.1098/rspb.2014.2849

Kaluza, B.F., H. Wallace, T.A. Heard, A-M. Klein and S.D. Leonhardt. 2016. Urban gardens promote bee foraging over natural habitats and plantations. Ecology and Evolution 6: 1304-1316.

Lowenstein, D.M., K.C. Mattson and E.S. Minor. 2016. Diversity of wild bees supports pollination services in an urbanized landscape. Oecologia 179: 811-821.

Threlfall, C.G, K. Walker, N.S.G. Williams, A.K. Hahs, L. Mata, N. Stork and S.J. Livesley. 2015. The conservation value of urban green space habitats for Australian native bee communities. Biological Conservation 187: 240-248.

Curriculum Vitae

NEAL M. WILLIAMS -- Department of Entomology and Nematology, University of California, 1 Shields Ave., Davis CA 95616, phone: (530) 752-9358 email: nmwilliams@ucdavis.edu

Research Experience

Williams is a bee biologist and pollination ecologist with over a decade of experience exploring the effects of landscape change on the pollination service provided by native bees to crops and native plants; identification of mechanisms underlying changes in native bee populations and behavior of pollinations in complex landscapes. He works in CA to develop of strategies to provide habitat to pollinators, pollination and other ecosystem services.

Education and training

Undergraduate:	University of Wisconsin	Botany / Zoology	BS, 1992
Graduate:	SUNY Stony Brook	Ecology and Evolution	PhD, 1999
Postdoctoral:	University of Calgary	Ecology	1999-2000
Postdoctoral:	Princeton University	Ecology and Evolutionary Biology	2001-2003

Appointments

2013- :	Associate Professor Department of Entomology and Nematology, UC Davis
2009 - 2013:	Assistant Professor Department of Entomology, UC-Davis
2004-2009:	Assistant Professor Department of Biology, Bryn Mawr College

Federal Grants Received (Last 4 years)

2012	USDA NIFA SCRI, *Developing sustainable pollination strategies for U.S. specialty crops,* Davis amount $2,214,182, PI: R Isaacs, PD, **Williams Co-PD**
2012	USDA-NRCS Federal Conservation Innovation Grant, Next steps in pollinator conservation: operations and maintenance, organic habitat restoration, seed mix choices, and assessing conservation effectiveness. Davis amount $93,966. PI: M Vaughn, Co-PD: **N. M.Williams** and multiple other Co-PDs
2014	NSF DEB 1354022: Effects of floral resource dynamics on bumble bee colonies and populations. $437,246. **N. Williams PI.**
2015	USDA NRCS Supporting honeybees and native almond pollinators through improved forage mixes. $74,952 **Williams PI** with KL Ward
2016	NSF DEB 1556885, Exploring the role of dominant species in determining the biodiversity ecosystem function relationship across spatial scales. (Williams Co-PI, R Winfree PI)

Teaching/ Mentoring (Last 4 years)

UC Courses: Animal Biology, Pollination Ecology, Sustainable Agriculture. Post-Doctoral Scholars: Jessica Forrest (2010-2012), Sandra Gillespie (2011-2013), Jochen Fruend (2014), Josh Raup (2015), Claire Brittain (2013-2016), Ola Lundin (2014-2016), Rosemary Malfi (Current). Graduate Students: Ryder Diaz (MSc 2013), Katharina Ullmann (PhD 2014), Ross Brennen, Felix Klaus, John Mola, Maureen Page, Leslie Saul, Margaret Rei Scampavia, Clara Stuligross, Jennifer VanWyk, Hannah Gains, (U Wisc.), Alison Parker (U of Toronto); Undergraduate Students UC Davis: Jessica Drost ('17) Sonja Glasser ('16), Kevin Tahara ('17), Alexi Haack, ('13), Bethany Beyer ('17), Katherine Borchardt ('18)

Invited Presentations (Selected)

Academic

2016 Iowa State University, Department of Entomology

2016 UC San Diego, Department of Ecology

2015 Penn State University, Department of Entomology

2014 Michigan State University Department of Entomology

Department of Biology Florida State University

Ecology Colloquium Florida State University

2013 INIA Research Institute. La Cruz, Chile

2012 Kyushu University, Japan

Dartmouth College, Biology Department

Outreach

2015 California Department of Food and Agriculture (CDFA), Healthy Pollinators Meeting (Keynote)

2014 Australian Almond Conference, Adelaide, Australia (Research Keynote)

California Department of Food and Agriculture, Presentation to the State Board of Agriculture

2013 California State Beekeepers Conference (Research Keynote)

Forage Symposium, California Almond Conference (Keynote - November 2013)

2012 Field Day, Irvine Great Park, Irvine, CA

Synergistic activities

- I co-organize ICPBees project, a multi-institution national project that investigates habitat enhancement within degraded agricultural areas to promote wild and managed bee populations and bolster the pollination of specialty crops throughout North America. As part of these efforts we are developing models to inform land use prioritization and decision support tools for growers

throughout the US. In addition Williams works with a broad group of farmers throughout California and regularly gives extension presentations to grower groups on bee biology, management and pollination.

- With NRCS and The Xerces Society for Insect Conservation I am developing outreach material, including a web site http://www.xerces.org/pollinator-resource-center/, with information for farmers and land managers on how to manage landscapes to promote pollinator diversity and pollination of crops and native plant species. Several elements of this effort are direct extensions of previous NSF support.
- As a core member of the Agricultural Sustainability Institute at UC Davis. I have been an active participant in curriculum development of the new Sustainable Agriculture and Food Systems major. Students come from diverse backgrounds and have far-ranging future goals. The integrated curriculum involves them in scientific inquiry related to biodiversity and sustainable agricultural production. Through individual internships student also have opportunities to engage in basic and applied biological research.

Publications (Last 3 years)

Ullmann, K.S., Meisner, M. H. and **N. M. Williams**. (2016) Impact of tillage on a ground nesting, crop-pollinating bee. Agriculture Ecosystems and Environment. Agriculture, Ecosystems & Environment 232:240-246.

Parker, A.*, **Williams, N. M.**, J. D. Thomson. (2016) Specialist pollinators deplete pollen in the spring ephemeral wildflower *Claytonia virginica*. Evolution and Ecology. DOI:10.1002/ece3.2252

M'Gonigle, L. K., **Williams, N. M.**, Lonsdorf, E., and C. Kremen. (2016) A tool for selecting plants when restoring habitat for pollinators. Conservation Letters 1-7. DOI: 10.1111/conl.12261

Crone, E. E., and **N. M. Williams**. (2016) Bumble bee colony dynamics: quantifying the importance of land use and floral resources for colony growth and queen production. Ecology Letters. 19:460-468.

Rosenheim, J. A., **N. M. Williams**, S. J. Schreiber, and J. M. Rapp. (2016) Modest pollen limitation of lifetime seed production is in good agreement with modest uncertainty in whole-plant pollen receipt. American Naturalist. 187:397–404.

Williams, N. M., Ward, K. L., Pope, N., Isaacs, R. Wilson, J., May, E. A., Ellis, J., Daniels, J., Pence, A., Ullmann, K. Peters, J. (2015) Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States Ecological Applications.

Gillespie, S., R. Long, and **N. M. Williams**. 2015. Indirect Effects of Field Management on Pollination Service and Seed Set in Hybrid Onion Seed Production. J Economic Entomology (2015) 108 (6): 2511-2517

Koh, I., Lonsdorf, E.V., **Williams, N. M**., Brittain, C., Isaacs, R., Gibbs, J., and Ricketts, T.H. 2015. Modeling the status, trends, and impacts of wild bee abundance in the United States. Proceedings of the National Academy of Sciences.

Fründ, J.*, K.S. McCann and **N. M. Williams** (2015) Sampling bias is a challenge for quantifying specialization and network structure: lessons from a quantitative niche model. Oikos: doi: 10.1111/oik.02256

Kleijn, D, Scheper, J, Winfree, R. (2015) Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications 6:7414.

J.R.K. Forrest, R.W. Thorp, C. Kremen, and **N.M. Williams**. 2015. "Contrasting patterns in species and functional-trait diversity of bees in an agricultural landscape", J of Applied Ecology 52: 706-715

Winfree, R., J. W. Fox, **N. M. Williams**, J. R. Reilly, and D. P. Cariveau. (2015) Abundance of common species, not species richness, drives delivery of a real-world ecosystem service. Ecology Letters. doi: 10.1111/ele.12424

Schreiber, S. J., J. A. Rosenheim, **N. W. Williams**, and L. D. Harder. (2015) Evolutionary and Ecological Consequences of multiscale variation in pollen receipt for seed production. The American Naturalist 185:E14–E29

Wilkerson, M. L., Ward, K. L., **Williams, N. M**., Ullmann, K. S., Young, T. P. (2014) Diminishing returns from higher density restoration seedings suggest tradeoffs in pollinator seed mixes. Restoration Ecology online Aug 5, 2014.

Rosenheim, J., Schrieber, S. and **Williams, N. M.** (2014) Parental optimism versus parental pessimism in plants: how common should we expect pollen limitation to be? American Naturalist 184:75-90.

Winfree, R., **Williams, N.M.,** Dushoff, J. and Kremen, C. (2014) Species abundance, not diet breadth, drives the persistence of the most linked pollinators as plant-pollinator networks disassemble. American Naturalist.183:600-611.

Gillespie, S., Long, R., Seitz, N., **Williams, N.M.** (2014) Insecticide use in hybrid onion seed production affects pre- and post-pollination processes. Journal of Econ Entomol 107: 29-37.

Outreach Publications

2014 K Ward, D Cariveau, E May, M Roswell, M Vaughan, NM Williams, R Winfree, R Isaacs, and K Gill. 2014. Streamlined bee monitoring protocol for assessing pollinator habitat. 16 pages, available online http://www.xerces.org/streamlined-bee-monitoring-protocol/

K Ward, D Cariveau, E May, M Roswell, M Vaughan, NM Williams, R Winfree, R Isaacs, and K Gill. 2014. Streamlined honey bee monitoring protocol for assessing pollinator habitat. available online http://www.xerces.org/ update

2013 Brittain, C and Williams, N, Cariveau, D. and R Winfree. Assessing the pollination of your watermelon. Available online http://www.xerces.org/?attachment_id=18321

Brittain, C and Williams, N Guide to Bees Visiting Watermelon in the West http://www.xerces.org/?attachment_id=18321

BIOGRAPHICAL SKETCH

KIMIORA L. WARD
Department of Entomology and Nematology
University of California
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a) Education and Training
2000 M.S. in Botany (GPA 3.86) University of Washington, Seattle, WA
1999 Certificate, Conservation Biology Policy University of Washington, Seattle, WA
1996 Graduate Course in Tropical Ecology Organization for Tropical Studies, Costa Rica
1992 B.S. in Zoology, *cum laude* University of Washington, Seattle, WA

b) Research and Professional Experience

Appointments

2010 – present: Research Associate III – Dept. of Entomology, UC Davis
Manage ten ongoing research projects with a $521,000 annual budget and supervise 11 staff on developing methods and testing the effectiveness of pollinator habitat restoration efforts.

2008 – 2010: Noxious Weed Specialist – King County Noxious Weed Control Program
Coordinated management of invasive riparian weeds on a watershed scale along seven river systems, collaborating with all local stakeholders and conservation organizations.

2006 – 2008: Seed Program Manager– Institite for Applied Ecology
Managed a large, ecoregion-wide seed collection and agricultural production program to develop locally appropriate and genetically diverse native plant materials for twenty species important in prairie restoration.

2005 - 2006: Botanist – PNW Albicaulis Project, USDA Forest Service
Coordinated an interagency effort to develop a conservation strategy for whitebark pine and initiated a cone collection program for gene conservation and restoration of the species.

Honors and Awards
2013 Outstanding Citation for Excellence in Service, UC Davis Staff Assembly
2002 Certificate of Merit, Mt. Baker-Snoqualmie National Forest
2001 Certificate of Appreciation for Leadership, Mt. Baker-Snoqualmie National Forest
2000 Charlotte Cornell Crary Award for Excellence in Teaching Introductory Biology
1997 University of Washington Botany Department Field Research Award
1997 Sigma Xi Grant in Aid of Research: evolution of plant-pollinator interactions
1995 National Science Foundation Graduate Fellowship
1995 Achievement Rewards for College Scientists Fellowship
1992 Sigma Xi Grant in Aid of Research: physiological ecology of short-horned lizards

Federal Grants Received

2015 USDA NRCS Conservation Innovation Grant ($74,952), *Supporting honey bees and native almond pollinators through improved forage mixes: testing of establishment methods and strategic native plant selection*, coauthored with PI N. Williams

2012 USDA NRCS Conservation Innovation Grant Subaward ($93,966) for UC Davis, *Next steps in pollinator conservation: Operations and maintenance, organic habitat restoration, expanding seed mix choices, and assessing conservation effectiveness*, coauthored with Co-PI Claire Kremen

2010 USDA NRCS Conservation Innovation Grant ($343,884), *Development and Validation of Protocols for Assessing Functioning of Pollinator Habitat Plantings for Agricultural Settings*, coauthored with PI Neal Williams

2010 U.S. EPA, Region 10 Puget Sound Watershed Management Assistance Program grant to King County Noxious Weed Control Program ($651,555), *Protection and Enhancement of Riparian Buffers in WRIA 7 through Restoration and Stewardship*

2010 U.S. Fish and Wildlife Service Aquatic/Riparian Restoration and Recovery Projects grant to King County Noxious Weed Control Program ($25,000) for noxious weed removal and riparian corridor restoration in the Skykomish watershed in FY 2010

2008 U.S. Fish and Wildlife Service grant to Institute for Applied Ecology ($53,000) for seed collection and increase of Threatened and Endangered species and butterfly resource plants in 2008

(c) Synergistic activities

Publications

Kleijn, D., R. Winfree, I. Bartomeus, L.G. Carvalheiro, M. Henry, R. Isaacs, A.M. Klein, C. Kremen, L.K. M'Gonigle, R. Rader, T.H. Ricketts, N.M. Williams, et al. (including **K.L. Ward**). 2015. Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications 6:7414

Williams, N.M., **K.L. Ward**, N. Pope, R. Isaacs, J. Wilson, E.A. May, J. Ellis, J. Daniels, A. Pence, K. Ullmann and J. Peters. 2015. Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States. Ecological Applications 25: 2119-2131.

Wilkerson, M.L., **K.L. Ward**, N.M. Williams, K.S. Ullmann, and T.P. Young. 2014. Diminishing returns from higher density restoration seedings suggest trade-offs in pollinator seed mixes. Restoration Ecology 22:782–789.

Kay, K.M., **K. Ward**, L.R. Watt and D.W. Schemske. 2010. Plant speciation on serpentine soils. In: S. Harrison and N. Rajakaruna (Eds.). Serpentine: the Evolution and Ecology of a Model System. Pp. 71-95. University of California Press.

Miller, S.A., A. Bartow, M. Gisler, **K. Ward**, A.S. Young and T. Kaye. 2010. Can an ecoregion serve as a seed transfer zone? Evidence from a common garden study with five native species. Restoration Ecology, no. doi: 10.1111/j.1526-100X.2010.00702.x

Ward, K., M. Gisler, R. Fiegener and A. Young. 2008. The Willamette Valley Seed Increase Program: developing genetically diverse germplasm using an ecoregion approach. Native Plants Journal 9: 335-350.

Huey, R.B., G.W. Gilchrist, **K. Ward**, L. Maves, D. Pepin, and D. Houle. 2003. Mutation accumulation, performance, fitness. Journal of Integrative and Comparative Biology 43: 386-395.

Ellen McEnroe Zagory
Horticulturist and Principle Museum Scientist
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EXPERIENCE AND SKILLS SUMMARY

A professional horticulturist for more than 30 years serving in a variety of capacities as plant propagator, landscape designer, project manager and plant science educator. Current work focus is program development, communications and educational outreach for the UC Davis Arboretum and Public Garden within the office of Campus Planning and Community Resources. Design and plants selection for constructed landscapes that conserve natural resources and provide ecosystem services in urban and suburban landscapes.

EDUCATION

M.S., Environmental Horticulture, 1981
B.S., Ornamental Horticulture, 1975
University of California, Davis, CA and University of Connecticut, Storrs, CT

PROFESSIONAL EXPERIENCE

Director of Public Horticulture (2012-2017) Develop and deliver horticultural messaging on a variety of topics including but not limited to garden design and horticultural plants that thrive with little supplemental summer irrigation, attract invertebrate visitors for pollination support and pest control potential, attract and support hummingbirds and thrive in the unique Mediterranean-type climate of California's Central Valley. Provide design of specialized campus landscapes including La Rue Rd. median, a one mile long turf conversion, and the development and installation of a Pollinator Garden as part of west end Environmental Education and Outreach programming. Provide educational programs for UCCE Master Gardener trainees statewide as requested on best plants and practices for water conservation, Mediterranean garden design,best California native plants in horticultural settings, propagation of California native plants and the UC Davis Arboretum All-Stars list and web resources utilizing recommended plants.

Director of Horticulture (2002 –2012): Direct and administer horticultural functions of the UC Davis Arboretum, including overall responsibility for nursery management, plant production and sale events, grounds maintenance and collections care, and infrastructure and facility maintenance and improvement. Represent the Arboretum as liaison to Grounds Division, Architects and Engineers and Resource Management and Planning in solicitation of continued campus support and good relations with all partners. Provide information and direction for horticultural education message development and act as spokesperson by providing articles, lectures and presentations on appropriate horticulture and plant selection for Central Valley gardening. Develop grant and project proposals and solicit donations and cultivate potential donors. Work in partnership with the California Center for Urban Horticulture team to develop programming and projects in support of best practices for urban horticulture. Act as media contact for newspapers, magazines and television in support of the UC Davis Arboretum promotion and educational goals. Supervise Horticultural Curator, Grounds Supervisor and Nursery Manager.

Collections Development Manager (1993-2002): Prepare grants and manage projects concerning collection maintenance and improvement. Prepare budgets, coordinate team contributions, oversee project management and prepare reports. Plan and coordinate planting design and installation, organize and direct plant propagation, culture and production of unusual plants. Search and obtain species needed via seed and

plant exchange as well as commercial sources. Train and supervise staff in nursery management and operations. Oversee production facility management.

RECENT PUBLICATIONS AND OUTREACH

Publications

WhyWe still Need Low Water landscapes in California and *Life After Lawn: Featured landscapes DeMasi and Bayon* Arboretum review No. 98. Spring 2017. Ellen Zagory. .
Balancing Garden Ethics with Aesthetics and *Feature: Life After Lawn: Introducing Garden Gems* Arboretum Review No. 97. Winter 2017. EM Zagory and KF Hetrick.
Mix and Match Plantings for Easy Care and *Twelve Plants to Mix and Match*. Arboretum Review No 95. Summer 2016. EM Zagory and KF Hetrick. .
Fall is Time to Beautify your Home Habitat and *Life After Lawn --DeGrassi, Kiers, Zagory and Parker Gardens*. Arboretum review No. 96 Fall 2016. EM Zagory and KF Hetrick.
Hummingbirds in Your Garden and *Nature's Hummingbird Feeders.* Arboretum Review No. 94, Spring 2016. Ellen Zagory.
Planning for Pollinators. Arboretum Review No. 93, Winter 2016. Ellen Zagory.
Celebrating Ten Years of the Arboretum All-Stars Arboretum Review No. 92 Fall 2015. Ellen Zagory
Bringing Nature Home Arboretum Review No. 90 Spring 2015. Ellen Zagory.

Lectures

Sustainable Landscaping: Pollinator Gardens. Presentation to Board of Friend of the UC Davis Arboretum. March 2, 2017.
Update on the UC Davis Arboretum All-Star Program (1 hour) and *Creating the Living Landscape* (1 hour) as part of Master Gardener Training: Ornamental Horticulture. Santa Clara County Master Gardener Program. March 23, 2017
Planting with Nature in Mind. California Horticultural Society in SF. May 16, 2016
Introducing Ten Bees and Ten Plants. ANR California Naturalist Program. With KF Hetrick. June 13, 2016.
Life After Lawn: Resources for Transitioning to Low Water Landscaping. City of Davis, Thursday, September 29, 2016
GATEways Program at the UC Davis Arboretum and Public Garden. Linden Garden Club. September 15, 2016. With Garth Lindley.
The Importance of Pollinators, Joint Learning by Leading Training, UC Davis, with Joel Hernandez. October 9, 2016
What's New at the UCDavis Arboretum and Public Garden. Kiwanis Club. October 13, 2016.
All Stars and Whats Going On at the UC Davis Arboretum and Public Garden. Calaveras County Master Gardeners. October 18, 2016