Research Needs for Invasive Plants in California

A Joint Project of:

California Invasive Plant Council

University of California, Davis

& California Department of Food and Agriculture

Compiled by:

Ramona Robison, Ph.D.
University of California, Davis
and California Botany

Published by the California Invasive Plant Council

February 2009

Cal-IPC

Acknowledgments

This report is the compilation of contributions by numerous researchers, land managers, and volunteers who work on invasive plants in California. We thank all of them for spending their valuable time to help us, especially those who agreed to be interviewed and the attendees at the 2005 UC Davis Research Roundtable that started it all. This project was funded by research funds from the Weed Management Area Program managed by the California Department of Food and Agriculture's Integrated Pest Control Branch. Dr. Joseph DiTomaso at UC Davis served as Principal Investigator.

The following individuals contributed written portions of the indicated sections:

- Gina Darin, Risk Assessment (Section 4)
- Jennifer Burt, Adrianna Muir, and Jonah Piovia-Scott, Evaluation of Horticultural Plants for Invasiveness (Section 4)
- Edith Allen, Climate Change and Nitrogen Deposition (Section 5)
- Fraser Shilling, Roadside Impacts (Section 5)
- Lincoln Smith and Mike Pitcairn, Biological Control (Section 6)
- Tara Athan, Economics (Section 8)
- Doug Johnson, Policy and Laws (Section 10)
- Heather Schneider, Cal-IPC Symposium working group
- Elizabeth Brusati, Graduate Student funding appendix

Photo Credits (top to bottom):

UC Riverside graduate student Janet Garcia studies artichoke thistle (*Cynara cardunculus*). Janet Garcia.

Hairy weevil for yellow starthistle (*Centaurea solstitialis*) control. Kathleen Jones, Midpeninsula Regional Open Space District

UC Riverside graduate student Sara Jo Dickens at a prescribed burn on the Santa Rosa Plateau. Carol Bell.

Spotted knapweed (*Centaurea maculosa*). Cole Novotny

Illustrations:

Ryan Jones. Originally published in *The Weed Workers' Handbook* (2004).

Recommended Citation:

Robison, R. 2009. Research needs for invasive plants in California. Cal-IPC Publication 2009-01. California Invasive Plant Council: Berkeley, CA. Available: www.cal-ipc.org

This report is available at www.cal-ipc.org/ip/research/researchneeds.php or info@cal-ipc.org.

Contents

Ageratina adenophora

Executive Summary

Acacia melanoxylon

The Research Needs Assessment project was started in 2005 as a meeting of experts at UC Davis with the goal of bringing together researchers and land managers to discuss major research gaps that hinder efforts to manage invasive plants. The project summarizes existing research pertaining to invasive plants in California through literature review and interviews with researchers and managers, and identifies high-priority areas for future research. Through this effort, we seek to further energize the academic and land management communities by:

(1) Facilitating connections between disciplines by increasing awareness of the range of ongoing research on invasive plants;

(2) Creating a forum for assessing high-priority research needs; and

(3) Guiding future research (especially graduate student projects) toward these high-priority needs.

The need for effective strategies in invasive species research is outlined well in Byers (2002). In brief, the authors emphasize the need for prioritization of invasive species for management purposes so conservation managers can decide where to focus control efforts. California's Noxious and Invasive Weed Action Plan (2005) also identifies the need for this type of research needs analysis.

It is the goal of this report to review research areas and to provide specific suggestions on high-priority topics where future research should be directed.

The information from the original 2005 meeting served as the starting point for this paper, and from there a list of experts in each area was developed by a committee chaired by Cal-IPC. The experts were contacted by telephone and e-mail to provide comments in their area of expertise and their contributions are summarized in this document. Additional comments were collected during a work group at the Cal-IPC 2008 Symposium and those were used to develop the following list of prioritized research needs.

- Study seed biology and seedbank dynamics to support control techniques
- Determine the types and levels of ecological impacts
- Study interactions of wildlife (especially listed species) and invasive plants
- Produce statewide weed maps
- Document which horticultural plants are or are not invasive
- Determine which pathways of entry are facilitating introductions into California
- Determine which BMPs can prevent spread of invasives along transportation corridors
- Develop standards for monitoring treatment methods to generate comparable data sets
- Study techniques to deplete the seedbank for eradication
- Study how to maximize the success of passive and active restoration
- General restoration research
- General economic impacts
- Gather data to quantify the economic cost of invasive plant management
- Quantify the ecosystem service costs of invasive plants

- Study why certain invasive plants are chosen for management and how the management is conducted
- Study policy and laws to improve how they address invasive plants
- Evaluate success of voluntary industry self-regulation versus government regulation

The priority needs touch on all the topic areas in this document and include a broad range of emphasis areas, from impact analysis to specific management strategies. Six of the priority needs focus on the social components of invasive plant management, addressing economic, philosophical and policy issues. The priority needs can be thought of in the context of invasion stages: Arrival, establishment, spread and impact. One priority need addresses pathways of entry, the arrival stage. Management of invasive plants is heavily represented in the priority needs and can be seen as the establishment and spread stages. Several needs listed relate to general management (spread along roads, restoration), and two of them relate specifically to managing the seedbank. Monitoring standardization was also seen as important for determining which management strategies are most successful. Three of the priority needs then address the impacts caused by invasive plants once they arrive, and specifically the impacts on listed species and the overall economic costs to the ecosystem. Two of the priority needs relate to questions about horticultural plants and how those are managed. Although these are not specifically called out as "economic" they do address practices in a multi-million dollar industry. Finally, all of the priority needs listed would benefit from development of statewide weed maps which would aid overall management and prioritization.

The research needs for invasive plants in California presented here are meant to reflect the opinions and expertise of those interviewed as well as those of the larger community. This report is intended as a "living document" and Cal-IPC welcomes suggestions for additional research needs or information that will help us address those identified here.

Introduction

Cynara cardunculus

Purpose

California has approximately 200 invasive plants, species that are not native to the local ecosystem and that cause significant ecological or economic harm (Cal-IPC 2006; Rejmanek *et al.* 1991). These invasive plants are a major concern to the state because they can increase fire danger, block waterways, and reduce habitat for native plants and wildlife, among other damaging impacts. Land management agencies spend millions of dollars annually controlling invasive species in California.

Understanding invasive plants and working to address their impacts requires detailed knowledge on a range of topics, from basic ecology to government policy. Many institutions and individuals in California are working to increase knowledge on these topics. It is the goal of this report to review research areas and to provide specific suggestions on high-priority topics where future projects should be directed. The report focuses on research that has applications to conservation of native habitats and ecosystem processes, and is based on interviews with a range of researchers. The results can guide graduate students and researchers, especially grad students, to the most critical questions on invasive plants in California.

The need for this project is well documented. The California Noxious and Invasive Weed Action Plan (California Department of Food and Agriculture & California Invasive Weed Awareness Coalition 2005) summarizes the overall needs for strengthening the state's approach to invasive plants, including research. A meeting of invasive plant researchers in August 2005 at UC Davis concurred that an effort to identify key research gaps was needed. Topic areas identified by attendees form the basis for this report. At the 2006 Cal-IPC Symposium, an expert panel of presenters discussed the importance of "Bridging the Gap between Research and Management." The work presented in this report attempts to do just that—bridge the gap between academia and land management. It also endeavors to stimulate collaborations between disparate disciplines such as social science, economics, government policy, and theoretical ecology.

There are many challenges—as well as benefits—to bridging this gap.

- Land managers do not often have easy access to peer-reviewed scientific literature, even if articles exist to address their personal management needs. There is a need for communicating academic research results to those in the field.
- Academic research is often driven by broad theoretical questions and the need to conduct and publish studies addressing those questions, which may not address specific management questions.
- At the same time, many "on-the-ground" management projects produce results which are not communicated in forums accessed by the academic research community.
- Both groups have a limited time and energy to communicate with each other, even if forums such as the Cal-IPC Symposium were widespread.

Several authors outline research needs for invasive species. Byers *et al*. (2002) emphasize the need for prioritization of invasive species for focused management. They first list areas where knowledge is needed to enable prioritization then suggest ways of obtaining that knowledge, and finally propose strategies for acting effectively once priorities are set.

Mack *et al*. (2000) outline future research and policy priorities, focusing on the need for research in the epidemiology of invasions and the need for better economic data on the costs of invasions. Ewel *et al*. (1999) focuses on research required before deliberate introduction of a new species into an isolated environment such as Hawaii, but the research needed also applies to unintentional introductions. Richardson

(2004) offers some profitable avenues for future research, including suggestions for characterizing the physiological attributes of invasive plants. Recently Williams and Grosholz (2008) presented a broad agenda for management-oriented research on invasive species in estuarine and coastal environments that also applies to terrestrial habitats. Their research needs fall into many of the same broad categories outlined in this document and the practical nature of the research needs makes the suggestions immediately applicable. Finally, an entire issue of *Diversity and Distributions* (March 2008) provides excellent synthesis covering many areas of invasion biology included in this paper.

This report differs from those listed above by focusing specifically on invasive plant species in California. California's geographic and botanic diversity are matched by its organizational complexity. This report aims to help those working on the ground in California by presenting research questions specifically designed to address land managers' needs. As such, it also assumes effort will be dedicated to communicating findings with those in the field, as well as needs from the field to the researcher community. This is part of Cal-IPC's core mission and operating philosophy. Its annual Symposium, field courses, and publications will all be used to transfer knowledge between the researcher and the land manager.

Methods

The ten research areas addressed here were chosen to represent the breadth of ongoing activities in California invasive plant research and include areas where research is lacking, but where experts considered more research to be critical. This paper was developed with the assistance of numerous contributors. The information from the 2005 meeting served as the starting point, and from there a committee chaired by Cal-IPC developed a list of experts in each area. Forty-five experts were interviewed between February and June 2008. Most were interviewed by phone, but a few were interviewed in person or provided written comments. Appendix A lists the experts interviewed for the project.

Major research institutions are responsible for the bulk of the published literature in this area. University of California campuses at Davis, Berkeley, Riverside, Irvine, Santa Cruz and Santa Barbara, as well as California State universities at Chico and San Luis Obispo, support faculty with active research programs. Private colleges and universities such as Stanford, Mills and St. Mary's also contribute. UC Cooperative Extension provides a wealth of practical information for land managers, and government scientists at California Department of Food and Agriculture, US Department of Agriculture, US Forest Service, and National Park Service also contribute to the field. Finally, local non-profits address issues of concern in their regions and on their lands. A directory containing members of all the groups above was developed as part of this project and is available from Cal-IPC.

Many of the individuals interviewed for this report work primarily as researchers, but participants also represented land management agencies, non-profit organizations and the private sector. An attempt was made to find respondents in all of the ten research needs areas, and to survey experts located throughout California. Some experts outside California were interviewed when their research interests related to broad topics or if they conducted research in California.

This report includes a brief description of each area followed by a summary of research needs addressed in the interviews. During the interviews we discussed broad concepts and research needs, and transcripts were prepared for each interview. Notes from each transcript were then sorted into each of the ten topic areas. In each interview summary section the most common responses were organized by sub-topic. In order to prioritize the research needs, a work group was held at the 2008 Cal-IPC Symposium. Some of the research needs are grounded in theoretical questions that a Ph.D. student might address, while others pertaining to policy questions would be more appropriate for government or NGO researchers. The research needs were not quantitatively prioritized, so the list should be considered a summary of the opinions of the experts surveyed and those who attended the work group.

Appendices to this document include a list of researchers with their areas of expertise cross-referenced to the topic areas described in this report. Finally, information pertaining to graduate student projects and potential funding sources for research is also included.

Next Steps for the Research Needs Assessment

The future of the research needs project will depend upon the willingness of the research and management communities to stay engaged in the process. Another meeting of experts would be useful to maintain the momentum in this effort, specifically addressing the priority needs and identifying funding sources to initiate research projects. Graduate students could be surveyed to gauge the applicability and usefulness of the funding information provided in the appendix. Finally, some of the collaboration needs presented in this document could be addressed at upcoming Cal-IPC Symposia through invited speakers and work groups focusing on economic and social science issues.

The research needs for invasive plants in California presented here are meant to reflect the opinions and expertise of those interviewed as well as those of the larger community. Consequently, we are soliciting additional input from members of the community. For additional information or to contribute please contact Cal-IPC.

1. Biology and Ecology

Arundo donax

Studying invasive plant biology and ecology lays the groundwork for deciding which plants are in fact invasive, by determining the impact of invasive plants on native species and ecosystem processes. This research area also serves as the basic starting point for developing management or control programs.

This topic addresses questions such as where plants can grow, what determines how well they grow and reproduce, and their physiology. Many case studies exist that describe how well a certain invasive plant performs under various temperature or moisture regimes or in different soil types or levels of nutrients. Species most often studied are those that have well-known economic impacts, such as yellow starthistle (Roche *et al.* 1994), or that are amenable to growing in greenhouses for short-term studies. However, when discussing who is cited most frequently in the invasion biology literature, Pysek *et al*. (2006) found that the most-cited studies focusing on single species, with at least 50 citations, address only 14 plants.

Investigations into invasive plant biology can give us clues to the life cycle stages where plants are most vulnerable to control and adaptive management. Depending on the plant, control programs may be most effective at seedling, juvenile, flowering or adult stages. In the case of perennials, it may be the stage when carbohydrate reserves in vegetative reproductive structures are lowest. Seedbank dynamics and seed longevity are also important because some seeds remain viable in the soil for decades, while others survive less than one season. Basic invasive plant biology information is needed to feed into other types of research such as modeling the potential distribution of a species.

Invasive plant biology and ecology connect to all the following sections of this research needs assessment. Here, we address questions specifically related to the factors that contribute to plants becoming invasive.

Research Needs

★ *Study seed biology and seedbank dynamics to support control techniques*

Seedbank management is vital to control and management of invasive plant populations and often there is little research available. One example is a study by Richardson and Kluge (2008) looking at the seedbank dynamics of Australian *Acacia* species in South Africa, including management recommendations. Research could identify techniques that make seeds more vulnerable to management, such as shallow tilling, or burning. Information on the length of seed viability could be studied by burying seed packets at different depths, and then retrieving and testing over time. Seed tolerances to temperature, moisture, soil type, etc. for species where this is not known would also be helpful, especially for species that are not widespread. Another question is whether seed predators, especially of native vs. non-native seeds, decrease invasive plant populations.

Study below-ground ecology to better understand invasions

While scientists tend to study above-ground interactions, more emphasis is needed on below-ground interactions and processes. Some suggested studies are:

- Determine how invasive plants impact nutrient cycling patterns in California plant communities.
- Compare plant/soil/microbe interactions within native and non-native plant communities.
- Examine whether mycorrhizal fungi and grassland quality affect invasions.
- Investigate interactions of invasive plants with soil biota: Do invaders escape from soil pathogens? Are invaders less dependent than natives on mutualistic soil biota?

Use genetics and molecular tools to study geographic origins, taxonomic questions and evolution

More researchers could incorporate molecular tools into their research. Molecular tools can be used to look for geographic origins of invaders; to determine which genotypes to use in restoration; and to determine if hybridization is occurring among invasives or between invasives and natives.

Molecular tools can also be used in taxonomy to determine which species or genotypes are really invading. For instance, horticultural invasions of ivy have historically been referred to as English ivy (*Hedera helix*), but recent research has indicated several different ivy species are involved (Clarke *et al.* 2006). This may have additional value in identifying suitable biocontrol agents for specific species.

It would be useful to study how invasive plants have evolved to fit their invaded range. If evolution has occurred, it is likely to have happened due to new selection pressures after a plant's arrival and before it becomes invasive. Some research has been done on this topic, but there is still a lot that remains to be studied, much of which can be studied using molecular tools.

Determine which factors allow a plant to become invasive

Comparing invasive and non-invasive members within families or other taxonomic groups can isolate particular characteristics that enable a plant to become invasive (Grotkopp & Rejmanek 2007). Determining such factors could greatly help risk assessment that aims to predict which plants could become invasive. Some suggested measurements that are not widely used include: light absorption in native vs. introduced tree canopies; studies of water use efficiency of natives vs. invasives; nutrient cycling to understand how plants change ecosystems; and physiological tolerances to varying shade levels pertinent to management questions. Plasticity in the native range of a species may be useful in determining whether it will become invasive.

Conduct biological research to support predictive modeling

Many of the inputs needed for modeling the potential range of a given plant species are specific growth parameters of invasive plants. These can be estimated from their existing range, but more accurate information may be derived from greenhouse studies. Such information could help refine predictive modeling capabilities.

Compare greenhouse and field studies to determine if comparisons are valid

Greenhouse studies are useful for isolating particular variables for testing. However, field conditions involve a large number of interrelated variables, so it is often unclear how well data from greenhouse studies and other controlled experiments translates to the field. Thus, comparing results from greenhouse studies and field studies could help determine how to best interpret greenhouse studies. This might be especially important for invasive plants that escaped from ornamental plantings, where most information comes from horticultural studies.

Determine which plant communities are most vulnerable or resistant to invasion

This topic is summarized as it relates to California in Rejmanek *et al.* (1991) and Bossard and Randall (2007). Vernal pools and coastal marshes were once thought to be resistant and are now invaded (Bossard & Randall 2007). Serpentine grasslands were resistant to invasion in the past, but now are being invaded by annual grasses like goatgrass (Meimberg *et al.* 2006). What is causing the changes, is it climate change, nitrogen deposition, rapid evolution of invasives or other factors? Vegetation types could be prioritized for study based on their invasibility. Are disturbed habitats more invaded, and environmentally stressful habitats less invaded?

Study native and invasive plant interactions

How and to what extent do native plants persist within an invasion? Are natives less effective competitors? Which native plant species hold on in these situations and how can they be encouraged? How can we promote the natives so they can gain an advantage over the invasive plants? In a species mix, how competitive are native species as compared to invaders?

Additional References

Baskin & Baskin 2006; DiTomaso & Healy 2003, 2007; Radosevich *et al.* 2007; Rejmanek *et al.* 2005a; Robbins *et al.* 1951; Whitson *et al.* 1992

2. Ecological Impacts

Brassica rapa

Invasive plants can impact wildland systems through alteration of ecosystem processes, displacement of native species, support of other non-native animals, fungi or microbes, and alteration of gene pools through hybridization with native species (Bossard *et al.* 2000; Richardson *et al.* 2000). The different ecological effects of an invader can occur at the ecosystem, community or population level (Gordon 1998). Empirical documentation of ecosystem-level effects of invasive plants is scarce in the literature and much information is anecdotal (Gordon 1998). Some notable studies include: light levels and their effect on *Tradescantia* density (Standish 2002; Standish *et al.* 2001); *Bromus tectorum* ecology and genetics (Rice & Mack 1991a, b, c), and *Spartina alterniflora* hybrid transformation of California marshes (Ayres & Strong 2001; Ayres *et al.* 2008).

In addition to ecosystem effects at the whole plant or population level, hybridization can occur among native and invasive species with genetic consequences including increased hybrid vigor, increased polyploid success, swamping of native plant genes, changes in allele frequencies, changes in flowering time effecting native pollinators, swamping of natives with invasive plant pollen, and movement of trans-genes from crops to invasive plants. Molecular techniques are now used to address many of the ecological questions posed by invasions. These tools can help managers determine which species are actually invading, trace the geographic origin of the invader, and in turn determine the best location from which to import a biological control agent.

Strayer *et al.* (2006), reviewing the long-term ecological effects of invasive species, suggest that an important factor to consider is time since invasion. Four factors modulate the effects of an invasive plant over time: changes in the invader, changes in the biological community, changes in the abiotic environment, and interactions between the invading species and other variables that control the ecosystem (Strayer *et al.* 2006).

Research Needs

★ *Determine the types and levels of ecological impacts*

We need more information on abiotic impacts, impacts on higher trophic levels, soil biosphere and mycorrhizae interactions, and impacts to pollinators and other invertebrates and endemic species. Are there cumulative effects of a group of species invading an area? What are invasive plant impacts by habitat type? What are population and community level impacts of invasive plants?

★ *Study interactions of wildlife (especially listed species) and invasive plants*

Documentation is needed to quantify positive or negative invasive plant effects on wildlife. Do wildlife use invasive plants and to what extent? Studies could quantify reproductive success, nesting success, toxicity to wildlife using invasive plants as habitat, etc. A method needs to be developed to evaluate the ecological costs and benefits of invasive plant control with respect to wildlife.

Study the genetic impacts of invasive plants

Are genes of native plants being lost (swamped out or just removed) by invaders? What are the genetic implications of genetically modified plants (e.g. glyphosate resistance and potential gene transmission to related invasive plants)?

Study how ecological impacts vary over time and space

How do impacts vary with time and abundance of invasive plants? One specific example is on the population level impacts of the invasive vine *Tradescantia* in the understory of a New Zealand forest (Standish 2002;

Standish *et al.* 2001). Researchers found that increased light levels in areas with *Tradescantia* infestations increased *Tradescantia* biomass and decreased seedling survival of native plants. A similar study in California could look at Cape ivy (*Delairea odorata*).

Document the secondary ecological effects of control and eradication projects

Studies are needed to determine if specific invasive plant management practices cause long-term ecological impacts. Does removal of one invasive species facilitate establishment of another? Foodweb studies would also be helpful to predict what may happen when a widely distributed invasive plant is removed or reduced significantly. A cost/benefit analysis is also needed.

Determine if acceptable thresholds for invasive plants exist and how to maintain them

This concept was summarized at the Cal-IPC 2008 Symposium by Randall (2008). Do certain densities allow invasive and native plants to co-exist and ecosystems to function? How are these threshold levels determined and maintained? Which invasive plants are relatively benign in that they do not cause ecological impacts to invaded communities?

Establish and monitor permanent plots to track spread of invasive plants

Permanent plots are needed in grasslands and elsewhere to study long-term changes in the biological and abiotic community. This will help study the rate of spread and also quantify the ecological impacts. California could build a network of monitoring stations to document long-term trends with invasive plants, using existing Long Term Ecological Resource (LTER) locations, University of California Natural Reserves, Nature Conservancy lands, Forest Service Research Natural Areas, or land management trust lands.

Additional References

Bossard & Randall 2007; Lambrinos 2002; Martinez-Ghersa & Ghersa 2006; Radosevich *et al.* 2007; Rejmanek *et al.* 2005a; Rejmanek *et al.* 2005b; Stohlgren *et al.* 2001; Strayer *et al.* 2006

3. Distribution, Biogeography and Range Modeling

Bromus diandrus

In order to prioritize the management of invasive plant populations, it is important to know where they are, why they are able to grow there, and where and how quickly they are likely to spread. The first question can be answered with mapping, either on the ground or with interpretation of aerial photographs (remote sensing). The discipline of biogeography addresses why certain plants occur where they do over time, and the third question – where the invasive plants will go – can be addressed through modeling. The methods of collecting invasive plant distribution data and storing it for analysis are addressed in the *California Weed Mapping Handbook* (2002). That type of distribution information will be necessary for modeling the potential range of priority plants. Development of these maps was seen as a priority research need during development of this document.

After a non-native species is introduced to a new environment it has three possible fates. The founder can be extirpated, it can naturalize but not become widespread, or it can persist in low numbers then increase rapidly (Heywood 1989; Mack 1985). The period before rapid increase is often referred to as the lag phase (Moody & Mack 1988), but there is no consensus on how to tell if an introduced species in the lag phase will eventually die off, remain in small numbers, or expand exponentially. Mathematical models have been used to try and determine which species are in the lag phase and have the potential to shift toward exponential growth (Mack 1996; Williamson 1989) and which known invasive plants are likely to spread further. Some models use a comparison of the home range climates of an invader with those in its new location (CLIMEX) (Holt & Boose 2000; Sutherst 2003; Sutherst *et al.* 1999), while others employ logistic regression or genetic algorithms (GARP and MAXENT) and require only presence data to run the model (Anderson *et al.* 2003; Phillips *et al.* 2006; Underwood *et al.* 2004).

Specific research needs on the biogeography of naturalization are presented in Pysek and Richardson (2006). They suggest research on measures for quantifying propagule pressure to determine naturalization rates. “The proportion of aliens that successfully naturalize within regions would provide us with better understanding of the invasion process” (Pysek & Richardson 2006).

Research Needs

Test different detection methods to support Early Detection and Rapid Response (EDRR)

Compare different survey methods for detection of newly introduced invasive plants such as remote sensing, aerial photograph interpretation, ground surveys, and low level helicopter surveys. Studies on the size of sweep width needed when mapping or controlling an invasive plant would also be useful. For example, a closer distance is needed to detect an invasive grass among other grasses, than is needed to detect a flowering pampas grass or broom plant. In wildland systems, more time is often spent accessing populations than treating them.

Collaborate with researchers studying basic life history to build more robust models

Experimental studies are needed to provide data that can be incorporated into models. For example, temperature tolerances for seeds, seedlings and other vulnerable life stages are needed in order to run models and often there is no information available. Distributions may be limited by water availability, winter temperature tolerance, pre-existing plant community or a variety of other factors. This information is also important for risk assessment and screening at borders.

Determine if climate cycles are driving invasive plant establishment

What are the time cycles of invasive plant establishment? Is it a 7 or 10 year cycle of wet/warm periods or is the cycle determined by other factors? Is the time cycle of invasion more important for species with small populations in the establishment phase? Are certain plants more abundant in wet or dry years and can this knowledge lead to targeted management programs?

Study the spread stage of invasion and prioritize management using mathematical models

Analyze the dispersal process and how it contributes to the rate of spread using modeling. What demographic traits contribute to rapid spread? What are the differences between natural spread and human-mediated spread? What is the role of infrequent long-distance dispersal events? Mathematical models can also be used to prioritize populations for management. Model landscapes in GIS can compare long-term effects of EDRR given different management strategies.

Study whether some invasions are dying out over time

We need more information on why some invasive plant populations increase then seem to decline over time. Does this happen with some plants and not others? What are the mechanisms regulating the decline? Is this due to evolution, changes in soil pathogen loads, or other factors?

Study propagule pressure as it relates to rate of spread

The challenges relating to propagule pressure from invasive plants are outlined in Martinez-Ghersa (2006). We need to know how much is coming in, what genotypes are being introduced and where they are going.

Study what makes benign species suddenly increase in abundance

For example, *Parentucellia viscosa* grew at a low population level in coastal northern California then suddenly expanded dramatically. Are the causes genetic, environmental, or multiple introductions of new genotypes? Multiple introductions of invasive genotypes contribute to the success of introduced plants (Hufbauer & Sforza 2008; Meimberg *et al.* 2006).

Additional References

Distribution and biogeography in general Groves 2006; Pysek & Richardson 2006; Wilson *et al.* 2007

Invasive plant mapping Barnett *et al.* 2006; California Department of Food and Agriculture 2002

Modeling types MAXENT (Phillips *et al.* 2006); State factor model, pathway analysis (Barney & Whitlow 2008); GARP (Anderson *et al.* 2006a; Anderson *et al.* 2003; Baskin & Baskin 2006; Crossman 2003; Drake & Bossenbroek 2004; Eiswerth *et al.* 2005a; Levine 2003; Moody & Mack 1988; Peterson 2001; Peterson *et al.* 2003; Peterson & Vieglais 2001; Phillips *et al.* 2006; Sanchez-Flores 2007; Underwood *et al.* 2004); CLIMEX (Holt & Boose 2000; Kriticos *et al.* 2003a; Kriticos *et al.* 2003b; Pattison & Mack 2008; Sutherst 2003; Sutherst *et al.* 1999; Worner 1988)

4. Risk Assessment and Predictive Systems

Eucalyptus globulus

In general, risk assessment is a decision tool employed when there is a small chance of a potentially catastrophic event occurring after implementing a new technology or process. Typically risk assessment is the first step in identifying measures to minimize the risk at each stage of the process in question (Byers *et al.* 2002). Risk analysis can be conducted either before a plant is introduced to a geographic area (pre-border screening), or after it has been introduced but has not yet spread widely (post-border prioritization and management). The stages where risk assessment is needed for invasive plants are:

1. Arrival (risk of organism arrival through different pathways)
2. Establishment (risk of organism forming viable, reproducing populations)
3. Spread (risk of organism expanding its extent), and
4. Impact (risk of species having a measurable effect on existing species or communities).

Invasive plant risk assessment includes activities in two areas: The science of determining criteria for assessment and assigning priorities within a risk assessment framework, and the policies for implementing findings. Risk assessment systems and predictive models of potential spread require information on the biology and ecological impacts of invasive plant species. Research is needed to refine and test risk assessment systems for plants that do not have much information known about them. Models are also needed which minimize "false positives" in which a safe plant is labeled an invasive risk. Risk assessment systems should be tested with multiple data sets to refine the systems, and to demonstrate their effectiveness to decision makers, industry and the public.

Several risk assessment systems are currently in use. The Pheloung weed risk assessment system in Australia (Pheloung *et al.* 1999) uses information on a taxon's current weed status in other parts of the world, climate and environmental preferences, and biological attributes and is designed to be operated by quarantine personnel via a user-friendly computer interface. In the United States, Weed Risk Assessments (WRAs) are conducted by PERAL (Plant Epidemiology and Risk Analyst Laboratory), the risk analysis group at USDA-APHIS, focusing upon WRAs for species that may be listed as Federal Noxious Weeds. PERAL conducts three types of WRAs: (1) screening commodities that may be imported for consumption for potential weediness, (2) New Pest Advisory Group evaluations of the weediness potential of recently discovered or established species, and (3) upcoming evaluations of taxa for possible designation as "Not Allowed Pending Pest Risk Assessment."

Efforts to develop additional screening methods for a Hawaiian weed risk assessment system were initiated in 1998. The Hawaiian WRA is a modified version of the Australian WRA. Some questions were modified to address local conditions and concerns, and a second screening was added to reduce the number of outcomes in the "evaluate further" category (Daehler *et al.* 2004). The system was tested by evaluating plant species found on planting lists for Hawai'i, and comparing Hawaiian WRA predictions with assessments of actual plant behavior made by field experts who were asked to classify plants as major weeds, minor weeds, and non-weeds. The Hawaiian WRA correctly identified 95% of major pests; it also correctly identified 85% of non-pests. Another paper compared the Pheloung model to a group of invasive and non-invasive species in Florida and found that it gave a high level of predictive accuracy. (Gordon *et al.* 2008c).

The horticultural industry has been an important pathway for the introduction of many known invasive plants. Reichard (1997) determined that 85% of invasive woody plants in the United States were introduced for landscape trade, and estimated that there is the potential for more than 1,000 new invasive plants to be introduced through this pathway (Reichard & White 2001). Cal-IPC is a member of the California Horticultural Invasives Prevention (Cal-HIP) partnership, which brings together the horticulture industry, environmental groups, public gardens and arboreta, scientists, and government agencies to collaborate and find practical, lasting solutions. Their website is www.plantright.org.

Research Needs

★ *Document which horticultural cultivars are or are not invasive*

Solid research, with consistent, up-to-date methodologies, is needed to prove whether cultivars of certain invasive plants are invasive and to predict which new cultivars contain traits that make them likely to invade, and in which regions or habitats. Other research goals for this topic are to determine the potential invasiveness of hybrid cultivars, the security of infertile hybrids (whether they are stable or could revert back to fertile cultivars), and identification of specific propagation techniques that can reduce invasiveness. A standardized list is needed to divide horticultural species into a range from "does not naturalize" to "known to naturalize in certain regions" to "invasive in wildlands."

Study which methods are most successful for screening at borders and determine which plants should be screened

New technologies are available for screening and those should be studied to determine effectiveness. For instance, New Zealand now screens for any living tissue at their border. Screening methods could then be improved based on research results. New models are also needed to determine which species should be screened out at the border. Many of the invasive plants coming in are classified as "needs more information" in existing models and some of those data gaps could be filled with greenhouse studies. The Cal-IPC Inventory may be used to analyze which taxonomic groups pose the greatest risk and if trends can be found to use in screening species for risk assessment.

Determine which pathways facilitate introductions into California

Pathways refer to the route of entry for invasive plants, such as roads, horticultural introduction, or other commerce. Research is needed on which pathways lead to the most introductions and consequently need more active screening procedures.

Develop a list of plants which have already been introduced and their introduction dates

A comprehensive list of what has been introduced and when it arrived is needed to calculate lag time and rate of spread. Information is needed not only for species but also for horticultural varieties and cultivars. The Consortium of California Herbaria website (ucjeps.berkeley.edu/consortium) includes specimens of many introduced plant species, but does not have information on the method or frequency of introduction.

Investigate which species should be on regional early detection watch lists

Research is needed on which species should be on the regional EDRR watch lists. California is in the process of starting Early Detection Networks, beginning with the San Francisco Bay Area. Once the Bay Area network is activated it can serve as a model for Early Detection Networks throughout the state and information on newly expanding weeds can be shared.

Additional References

Anderson *et al.* 2006a; Anderson *et al.* 2006b; Briese 2005; Byers *et al.* 2002; Crossman & Bass 2008; Gordon *et al.* 2008a; Gordon *et al.* 2008b; Gordon *et al.* 2008c; Kerns & Ager 2007; Lambdon *et al.* 2008; Leung *et al.* 2005; Lodge & Shrader-Frechette 2003; Lodge *et al.* 2006; Pheloung *et al.* 1999; Sheppard *et al.* 2005; Skurka Darin 2008; Strauss *et al.* 2006

Horticultural Risk Assessment

Anderson *et al.* 2006a; Baskin 2002; Burt *et al.* 2007; D'Antonio *et al.* 2004; Mack 2005; Okada *et al.* 2007; Reichard & White 2001; Reichard 2004; Vitousek *et al.* 1997

5. Climate Change and Other Human-Caused Factors Aiding Invasion

Carduus pycnocephalus

In addition to introducing plants to new areas, humans contribute to invasions in a wide variety of ways. We contribute to secondary invasions, allowing plants to establish and thrive where they might fail without our intervention (Groves 2006; Kowarik 2003; McNeely 2006; Nelson *et al.* 2006; Wilson *et al.* 2007). Some of the areas identified during the 2005 Research Roundtable meeting were climate change, changes in fire frequency, nitrogen deposition and transportation corridors.

Many changes in invasive plant distribution and abundance are possible under different global climate change scenarios. These are reviewed in Theoharides and Dukes (2007), and generalized research needs for climate change are outlined in Rogers and McCarty (2000). Management strategies for climate change in forests are outlined in Millar (2007). Specific changes expected in California are described by the California Climate Change Commission:

> Climate change is expected to result in warmer temperatures year-round, accompanied by substantially wetter winters. Changes in temperature and precipitation patterns would also shift California's current climate zones, and thus habitats associated with these zones, northward by approximately 100 - 400 miles, as well as upwards in elevation by 500 - 1500 feet. Global climate change would alter the composition, structure and arrangement of the vegetation cover of the state (forest and wildland). Species distribution would move geographically as the climate changes, with forest stands, woodlands and grassland species predicted to move northward and higher in elevation. The entire vegetative community may be affected if non-native invasive species occupy sites and replace native plants (California Climate Change Commission 2008).

Specific effects of climate change that have been documented to affect invasive species include elevated CO_2, elevated temperature, and changes in precipitation regime. For instance, a field experiment on elevated CO_2 in the Mojave Desert showed increased production of the invasive red brome (Smith *et al.* 2000), and the fertilizer effect of CO_2 has been suggested as one reason why some invasive species such as cheatgrass brome have become so abundant (Strain & Smith 1985). The interactive effects of elevated CO_2 on grass production reduce soil moisture, and promotes shrub invasion (Polley *et al.* 2003). Elevated temperature over the past 50 years is the cause of exotic understory shrub invasions at increasing elevations in the southern Swiss Alps (Becker *et al.* 2005; Walther *et al.* 2002). Models describing vegetation impacts of changing climate have been criticized because of their simplicity (Jeschke & Strayer 2008). It is difficult to take into account all of the interacting variables, thus requiring monitoring and further research to understand how invasive species will respond.

In many areas, humans have altered natural fire regimes (DiTomaso & Johnson 2006). In some cases the fire frequency interval is shortened and in others the interval between fires has lengthened. These changes in fire frequency have increased invasive plant abundance as described by Brooks *et al.* (2004):

> One way invasions can affect native ecosystems is by changing fuel properties, which can in turn affect fire behavior and, ultimately, alter fire regime characteristics such as frequency, intensity, extent, type, and seasonality of fire. If the regime changes subsequently promote the dominance of the invaders, then an invasive plant–fire regime cycle can be established. As more ecosystem components and interactions are altered, restoration of preinvasion conditions becomes more difficult. Restoration may require managing fuel conditions, fire regimes, native plant communities, and other ecosystem properties in addition to the invaders that caused the changes in the first place.

Atmospheric nitrogen deposition alters the structure and function of terrestrial ecosystems because nitrogen is often a primary limiting nutrient on overall productivity (Cione *et al.* 2002; Fenn *et al.* 2003). Many invasive plants thrive in areas with increased nitrogen, making this issue particularly relevant for invasive plant researchers. The California Energy Commission prepared a comprehensive report on the subject (Weiss 2006) which suggested research in three broad areas: Estimates of nitrogen deposition, ecosystem impacts, and education and public awareness.

Roads and utility corridors promote the dispersal of exotic species by altering habitats, stressing native species, and providing movement corridors (Trombulak & Frissell 2000). Research by Gelbard and others has shown that improved roads can act as conduits for the invasion of adjacent ecosystems (Gelbard & Belnap 2003; Gelbard & Harrison 2005; Parendes & Jones 2000). Roadsides are areas receiving management of vegetation height, to some degree vegetation composition, and for some areas management of storm-water runoff. Highways pose the greatest threat to areas immediately adjacent to them because of their and the number of cars traveling down the roadway. However, major and minor roads are the primary network of transportation corridors around the state, invading and traversing every ecosystem in the state. Roadsides have soil conditions, hydrologic conditions, and disturbances that are different from the surrounding environment. This may prove a barrier for invasion of certain species outward from the road-side, but because it is a highly-disturbed environment, it is more likely that the roadsides are actually invader cultivation areas, with traffic movement, wind, and water providing the spreading mechanisms along and away from the roadway. UC Davis now has a Road Ecology Center actively engaged in research about roads as pathways for invasive plants (roadecology.ucdavis.edu).

Research Needs

★ *Determine which Best Management Practices (BMPs) can prevent spread of invasives along transportation corridors*

Many maintenance practices are known to spread invasive plants, but it would be useful to know which practices spread specific plants and how those practices could be changed to discourage spread. A scientific comparison of BMPs that documented how each practice is spreading certain plants and how those practices could be improved to reduce spread would be useful. Additionally, studies documenting which species should not be used along roads and in restoration projects due to demonstrated invasiveness (Williamson & Harrison 2002) would be useful.

Study how protected areas management should differ under climate change

Long-term adaptive management programs using a broad range of native genotypes are needed to determine the best approach to long-term management. It is not known which native plant communities will be the most stable and if the number or type of invasive plants present will pose a risk. It is also not known if native plants will be able to migrate as quickly as invasives. Future management approaches will depend on the outcome of these types of studies.

Develop climate change models that are useful for adaptive management

Climate change information and models also need to be useful to field practitioners. The interactive effects of elevated CO_2, moisture, and temperature changes on invasive species distributions can now be added to predictive models. For example, the CLIMEX model already contains a climate change scenario, which can be used to predict how invasive plants may increase or decrease their current distribution.

Study fire effects and fuels management in a wider variety of habitats

More information is needed on fire fuel management in grasslands, chaparral, and coastal sage scrub, especially in Southern California. Specifically, how do invasive plants alter fire frequency and intensity in these communities?

Study use of native plants in fire safe landscaping to discourage weed growth

Which native species can be planted that reduce invasion, but also meet brush clearance requirements? For instance, will planting low growing ruderal natives help keep out invasives?

Study changes caused by nitrogen deposition to specific vegetation types

Some of the vegetation types, which may be experiencing changes, are: vernal pools, serpentine grasslands, deserts, coastal sage scrub and creosote scrub. Vernal pools may be converting to grassy swales dominated by non-native grasses and if this is the case practical remedies are needed. In serpentine grasslands, nitrogen deposition may be causing greater productivity, and studies are needed to find out if grazing or fire can reverse the trend. Other questions include: Is vegetation type-conversion from shrubland to annual grassland caused by nitrogen deposition? Is the frequent fire caused by increased exotic grass production promoted by nitrogen deposition? Will these effects be reversible when regulations to reduce nitrogen deposition are implemented?

Additional References

Esque & Schwalbe 2002; Groves 2006; Kowarik 2003; Lambdon *et al.* 2008; Mack *et al.* 2000; McNeely 2006; Nelson *et al.* 2006; Vitousek *et al.* 1997; Wilson *et al.* 2007

Climate Change

Bella 2007; Chornesky *et al.* 2005; Higgins & Richardson 1999; Nelson *et al.* 2006; Raven & Yeates 2007; Rogers & McCarty 2000; Theoharides & Dukes 2007

Fire Frequency

Brooks & D'Antonio 2002; Brooks *et al.* 2004; D'Antonio 2000; D'Antonio *et al.* 2002; DiTomaso & Johnson 2006; Levine *et al.* 2003; Suding & Gross 2004

Nitrogen Deposition

Cione *et al.* 2002; Fenn *et al.* 2003; Weiss 1999, 2006

Transportation Corridors

Barney 2006; Falge *et al.* 2004; Harper-Lore 2001; Jodoin *et al.* 2008; Parendes & Jones 2000; Trombulak & Frissell 2000

6. Control and Management Methods

Centaurea solstitialis

Many control strategies for invasive plants start with single species management and evolve into more integrated management strategies, often referred to as Integrated Pest Management (IPM). Integrated pest management incorporates all the "tools" in the invasive plant management "toolbox" including mechanical, cultural, chemical, and biological control methods. In order to design the most effective IPM program, it is necessary to first prioritize which invasive plants should be managed, and then choose the most effective control methods available. After a control project is initiated, it is also important to consider the long-term effects on an ecosystem caused by the chosen control program. As a discipline we have generalized methodologies (upstream/downstream and eliminate populations in high quality habitat), but often these have not been tested for effectiveness in a variety of ecosystems.

Biological controls hold special potential, and have unique research needs. We list research needs for this management method in a separate section later in this chapter.

Invasive plant management occurs in a social as well as biological context and some management practices, particularly the use of herbicides, are controversial. The social and political aspects of invasive plant management and suggested studies are described in the Social Issues section.

Research Needs

★ *Study techniques to deplete the seed bank for eradication*

Shallow tillage or selective watering and disking may be effective for this, but few studies are available in wildland systems. Prescribed burns could also be used to flush the seedbank. An understanding of soil seedbank longevities for individual species is also needed. This information could help calculate the length of time needed to eradicate a population.

★ *Study how much monitoring data to collect in order to determine project status and develop monitoring standards to generate comparable data*

Use a cost-benefit analysis to determine the amount of monitoring data to collect. Klein (2006) described easy to use "quick and dirty" methods at the Cal-IPC Symposium which could be adapted to a wide variety of management situations. Consistent plot sizes should be used in different plant community types so that multiple research data sets can be combined for metanalysis.

Develop integrated and regional approaches to invasive plant management

In general, more holistic, long-term, watershed or larger regional approaches to vegetation management using multi-species perspectives and integrated pest management (IPM) are needed. Methods are especially needed for invasive plant problems without chemical management solutions. Integrated techniques could help determine the best time to manage with burning, mowing or grazing given different combinations of species.

Study herbicide persistence in natural areas and non-target impacts

More studies on herbicide and adjuvant persistence in natural areas would be informative. For instance, what is the herbicide decomposition rate in cool, shaded soils in different community types? While studies are available on herbicide persistence in forested ecosystems, more information is needed for grasslands and other California habitats.

Study native plant susceptibility to herbicides

We know which invasive plants are killed by certain herbicides, but we often do not know which native species are or are not susceptible. This information would be helpful to tailor an approach to a specific site. Field trials with herbicides to determine what comes in naturally after spraying selective herbicides would also be useful.

Document and prepare for herbicide resistance in natural communities

Herbicide resistance is not known to be caused by wildland management practices, but resistant invasive plants can move in from agricultural or other heavily herbicide managed systems. If resistant invasive plants are encountered, protocols should be available for managers to use.

Determine how flaming can be used as an effective management tool

Few replicated management studies are available on flaming. Most studies are small scale and focus on only a few weed species (Bossard *et al.* 2005). The species and habitats it can be effective on should also be addressed. The return interval needed for repeated flaming treatments is also not known.

Study types of grazing and timing needed to discourage invasive plant establishment or spread

Grazing may have a necessary ecological role in managing healthy annual, perennial and mixed grassland communities. Marty (2005) studied the effects of cattle grazing on diversity in ephemeral wetlands and found that grazing helped maintain native plant and aquatic diversity in vernal pools containing non-native plants. Additional studies are needed in the types of grazing and the timing necessary to discourage invasive plant establishment and spread in grasslands. Interactions of timing and intensity of grazing in different combinations could also be studied. What are the impacts of intensive grazing on non-target species if invasive plant management is the goal? What is the impact of intensive grazing on oak regeneration? What happens to an area after intensive grazing? Studies could look at use by birds, insects, or soil microbes with and without grazing.

Develop techniques for timed high intensity grazing to manage specific weeds

Techniques are needed to facilitate timed, high intensity grazing for invasive plant management. When this technique is used for medusahead or another invasive how long will it take to re-infest the grazed area? What should be done after invasive plant control with grazing since it does not produce a "clean slate"? Another question is how to minimize the dispersal of invasive plants by grazers while utilizing them to control invasive plants.

General study questions regarding grazing

- Does patch burning benefit weed control by encouraging grazing?
- What are the benefits and drawbacks of goat grazing?
- How can grazing be introduced to fallow land where it was never used (such as southern California open space or former crop areas)?

Determine which management techniques can substitute for ecological processes

A diversity of techniques are needed to managed California habitats, but which management techniques can replace processes which are no longer functioning or cannot be used in urban areas? For example, how and in what habitats are cutting or mowing equivalent to burning? What timing should be used? Can grazing replace fire? Can fire replace flooding in some systems?

Study how to manage for acceptable thresholds of invasive plants in rangeland

This question is a high priority in rangeland systems since invasive plants often cannot be eradicated, but can be managed at tolerable levels. Ranchers can reduce invasive plant populations by rotating control methods across their ranch over several years. Research-based recommendations on how to manage invasive plants at a ranch scale (thousands of acres) would be useful.

Additional References

Bossard *et al.* 2000; D'Antonio *et al.* 2004; D'Antonio & Thomsen 2004; DiTomaso & Healy 2003, 2007; DiTomaso & Johnson 2006; Mack *et al.* 2000; National Invasive Species Council 2007; Radosevich *et al.* 2007

Development of Biological Control Agents

Classical biological control (biocontrol) involves the use of animals, fungi or other microbes that prey upon, consume, or parasitize a target species (Bossard *et al.* 2000). Target species are frequently non-natives whose success in new environments may be due in part to the absence of their natural predators and pathogens. The biocontrol "agent" is often imported from the native range of the invasive plant and introduced by a government agency after a rigorous screening process. One common example is ***Chrysolina*** *quadrigemina* (St. Johnswort beetle), which was released in 1945/46 to control St. Johnswort (*Hypericum perforatum*) in California (McCaffrey *et al.* 1995).

Biocontrol is most successful for widespread invasive plants. Biological control agents are not likely to completely eliminate a target population. Development of agents for release is also expensive because it requires exploration in the native range of the target invasive plant and years of screening by government scientists before a release can be approved. However, the outcome can be highly cost-effective once the program is implemented.

Currently, research is underway in California on new and recently introduced biological control agents for saltcedar, yellow starthistle, Russian thistle, arundo, Cape ivy, French broom, teasel, medusahead, spotted knapweed, squarrose knapweed, diffuse knapweed, field bindweed, Scotch thistle, water hyacinth, and water primrose.

Outside the United States, research in classical biological control of invasive plants has been very active in Australia, New Zealand, South Africa and Canada. Some invasive alien plants that are targeted in California have also been targeted in one or more of these countries. This situation has resulted in international cooperation of research and funding (e.g., the International Broom Initiative), and use of biological control agents in California that were previously evaluated and released in other countries (e.g., *Chrysolina* beetle to control St. Johnswort) (McCaffrey *et al.* 1995). However, we usually have to evaluate more non-target plant species than in these other countries either because of regulations protecting native flora or because of the existence of more species that are closely related to the target invasive plant. Australia and New Zealand have highly developed regulatory systems, which could serve as models for our federal system (Sheppard *et al.* 2003).

Research Needs

Study the non-target impacts of biocontrol releases

What happens after a biocontrol is introduced? Post-release monitoring of the entire invertebrate and plant community is needed before and after a release. How often are biological control programs successful in meeting their stated goals?

Study biocontrol as part of an integrated management strategy

Some studies have shown that biocontrol can be more effective when used in combination with other approaches. Determine which types of mechanical and chemical management are compatible with specific biocontrol agents.

The following specific research projects were suggested by Lincoln Smith and Ray Carruthers, USDA ARS, and Mike Pitcairn, CDFA:

- Develop new biological control agents for tall whitetop (*Lepidium latifolium*), Russian thistle (*Salsola* spp.), and Italian thistle (*Carduus pycnocephalus* & C. *tenuiflorus*).
- Test host specificity and potential impact of natural enemies of giant reed (*Arundo donax*) already established in California. This project would complement an existing ARS project to discover and test new biological control agents from overseas.
- Develop mass rearing methods to increase availability of new biological control agents to release (e.g. using *Ceratapion basicorne* on yellow starthistle).
- Determine the relative role of biological control agents and plant competition on the decrease of a target invasive plant (e.g., yellow starthistle).
- Develop a list of high priority invasive plants to target with biological control. The list could be focused on the impact of the target weed and the feasibility of its control.
- Determine the geographic distribution and impacts of the blackberry rust (*Phragmidium violaceum*) on the weedy Himalaya blackberry in California.
- Increased efficacy and host-specificity testing of the broom psyllid (*Artytinnis hakani*) from France against native lupines.
- Assessment of the efficacy and host-specificity of the new broom mite against native non-targets, especially lupines (to be conducted in Washington State with actual field populations of mites).
- Impact assessment on *Euhrychiopsis lecontei* weevils attacking Eurasian watermilfoil and native milfoils in California.
- The affect of native flea beetle (*Lysathia ludoviciana*) defoliation on native and exotic *Ludwigia* and development of methods of environmental manipulation (water management primarily).
- Dispersal and impact of the saltcedar leafbeetle (*Diorhabda elongata*) in new target watersheds in California.
- Assess the impact of the exotic psyllid, *Arytainilla spartiophila*, on Scotch broom population dynamics in California.
- Assess the impact of the gall fly, *Urophora stylata*, on bull thistle population dynamicds in the coastal counties of northern California.

Additional References

Andreas *et al.* 2007; Babendreier 2007; Blossey 1995; Briese 2005; Carruthers & D'Antonio 2005; Denslow & D'Antonio 2005; DeWalt 2006; Kriticos *et al.* 2003a; Mack *et al.* 2000; McCaffrey *et al.* 1995; Rejmanek & Pitcairn 2002; Sheppard *et al.* 2003; Sheppard *et al.* 2005

7. Restoration

Conium maculatum

Restoration projects generally focus on the goal of a restored ecosystem, not on managing specific invasive plants. Research efforts in this area often focus on:

- What happens after control and management efforts are over?
- If ecosystem processes are restored, will the native plant community re-establish itself?
- What type of reference site should be chosen?
- How to choose the new stable state to aim for, and then how to get there?
- How long do you control an invasive plant before you can start restoration?
- How to choose between complete eradication of all invasives, and replacing one invasive with something that will allow ecosystem function to be restored?

The choice of a restoration target state is often based on assumptions about pre-European vegetation types. Re-creating past habitat states may not be possible or even desirable (Hobbs & Harris 2001; Trowbridge 2007). Where ecosystem processes have been altered, site restoration likely will require both control of the invaders and recovery of processes (Gordon 1998). Development of techniques for restoring invaded sites will require substantial research in most communities (Gordon 1998). Seastedt (2008) suggests, "Management actions should attempt to maintain genetic and species diversity and encourage the biogeochemical characteristics that favor desirable species." These types of restoration projects can involve either active or passive restoration methods. Passive restoration involves natural recruitment of desirable species from the residual community or seedbank, whereas active restoration requires introducing desirable vegetation into the area through seeding, plug or pole planting, or other method. Many philosophical questions regarding restoration were addressed during interviews and the results are summarized below.

Research Needs

★ *Study how to maximize the success of passive and active restoration*

When should passive versus active restoration be used? Passive restoration has ecological as well as economic benefits if it can be designed successfully. For active restoration, would an increase in native plant seeds or propagules at the beginning of a restoration project improve the outcome? The need for active restoration of natives after a landscape-scale control project is outlined in Erskine Ogden and Rejmanek (2005). An example study could take two degraded areas, restore them and monitor what comes back in each, looking at the whole food web. Would different treatments at an infestation boundary allow natives to re-establish and decrease invasive plants?

Determine the most feasible target community based on the starting state of an ecosystem

What is the best way to restore ecosystem functions and ecological processes given the disturbed and highly managed state of most California ecosystems? Research should focus on areas where there are impacts to natives or ecosystems.

Study the best species to plant given the status of the restoration area and the weeds present

Which combinations of plants when introduced will persist? Which native species are least competitive with invasives and can management practices help them persist or increase populations? What species should not be planted in revegetation or restoration projects (Williamson & Harrison 2002)?

Study how to increase abundance of native plants in areas with invasive plant infestations

When developing planting lists, remnant natives may offer clues to what occurred there in the past. Which invasive and native species can co-exist? Insight into this question is contained in (Seastedt *et al.* 2008). Evaluate more native species such as sedges and rushes in their ability to keep invasive plants out. Which natives can effectively be used in competitive plantings? What are the best spatial planting techniques, islands, rows, uphill, etc.?

Document what happens after restoration projects using standardized monitoring techniques

What are the ecological impacts to a community after a restoration project? Most projects are monitored 3 to 5 years and then left alone. Monitoring and assessment of projects is needed 6 or more years after completion to see if invasive plants are returning. For example, what is the fate of the understory community in riparian restoration projects after the monitoring period is over? Permanent plots are also needed to follow what happens on a longer timescale. Impacts to non-target organisms should also be considered.

Determine how to incorporate soil restoration into the whole restoration process

Organic matter and perhaps other components need to be replaced in disturbed soils. Nutrient cycling, mycorrhizae and bacteria, and the presence or absence of a soil crust are other factors to consider. The belowground interactions between plants should also be studied. What biotic and abiotic soil changes remain after an invasive plant is removed by a control method? Do these soil "legacies" affect the success of restoration?

Additional References

Anderson 1995; Bossard & Randall 2007; Brigham 2004; Carlsen *et al.* 2000; Cione *et al.* 2002; Corbin & D'Antonio 2004; Daehler 2003; D'Antonio & Meyerson 2002; D'Antonio *et al.* 2002; D'Antonio & Thomsen 2004; Hobbs 2007; Hobbs & Harris 2001; Holmes *et al.* 2005; Miller & Hobbs 2007; Pickart & Sawyer 1998; Pysek & Richardson 2006; Seastedt *et al.* 2008; Standish *et al.* 2001; Trowbridge 2007; Young *et al.* 2005; Zavaleta *et al.* 2001

8. Economic Impacts


Ailanthus altissima

There are three facets to the economics of invasive plant research:

1. "Accounting": measuring the economic impact of various management alternatives,
2. "Decision analysis": deciding what management actions are preferred, and
3. "Policy": determining policies or programs to achieve an optimal economic state, with respect to invasive plants.

The purpose of an economic assessment is to measure the differences between management options. First, the impact of the invasive plant population on the goods or services in question must be determined. Once the physical impact is determined, the problem is one of valuation. Valuation of market goods and services is relatively straightforward. Valuation of non-market goods and services, including ecosystem services such as regulation of water flow or soil retention, is much more difficult but is critical to complete accounting of the economics of invasive plants. There are a number of approaches to non-market valuation, including contingent valuation, avoided costs, and relative valuation. In addition to evaluating costs and benefits in the present, it is necessary to predict the effects over time of a management decision. Mathematical or ecological economic models may be used to make such predictions. The final piece of accounting information needed is the direct cost of the management option. The cost information can then be used to prioritize actions and make management decisions.

There are at least three gaps inhibiting the application of economics to invasive plant management. One is the lack of access to data. This gap could be resolved by publishing an online compendium of economic resources tailored to the needs of invasive plant managers. Data needed includes the value of the goods and services and the percentage impact to these goods and services of individual species and collections of invasive species. Second is the lack of a framework for invasive plant management and policy-making that includes nonmarket evaluation and multiple-criteria decision-making under uncertainty. Third is the lack of case studies showing application of these techniques to manage invasive plants. These techniques are more widely applied to invasive animals and diseases, and should be equally applicable to invasive plants.

In 2008, the USDA Economic Research Service (ERS) compiled an Economic Brief titled *Integrating Invasive Species Prevention and Control Policies* (Livingston & Osteen 2008). The ERS report focuses on the economic and biological research needed to support the decision making process for resource allocation to invasive species control programs. In some cases resources should be allocated for prevention before an invasive species establishes, and in other cases control after introduction should be the focus. They state "keeping detailed records about the estimated size of an invasion, control costs, and the numbers of organisms removed – or acreage cleared – will enable decision makers to modify control programs as needed to improve program efficacy and economic efficiency."

Most of the interview responses focused on the accounting aspects of invasive plants – gathering economic data to justify management and encourage funding of programs.

Research Needs

★ *Gather data to quantify the economic cost of invasive plant management*

The most commonly cited figures are based on costs for control of only a few plants (Pimentel *et al.* 2000; Pimentel *et al.* 2005). We also need better information on the costs involved in management activities. UC Extension scientists study the costs per plant and how to scale up a project, but this is not widely done.

★ ***Quantify the ecosystem costs of invasive plants***

What are the costs to the ecosystem of invasive plants, also known as ecosystem services valuation? Scientists have good information for control costs in agricultural systems, but not in natural areas. Without the cost information we struggle to develop realistic budgets. One example of cost accounting for invasive plants comes from the recreation days lost to boaters from aquatic invasive plants. Another example was a study showing cost of water used by *Tamarisk* (Zavaleta 2000). We also need to answer the cost question where no agricultural or economic link already exists.

Study successful collaborations between economists and ecologists

Successful collaborations have involved ecological or agricultural economists with background in natural resources and ecologists with local ecosystem knowledge. The studies quantify each step in an ecological process then calculate a replacement.

Additional References

Barbier & Knowler 2006; Buhle *et al.* 2005; Eiswerth *et al.* 2005a; Eiswerth *et al.* 2005b; Finnoff *et al.* 2007; Finnoff & Tschirhart 2005; Levine & D'Antonio 2003; Lodge *et al.* 2006; Lonsdale 1994; Margolis *et al.* 2005; Perrings 2005; Pimentel *et al.* 2005; Saphores & Shogren 2005; Shogren & Tschirhart 2005; Williams & Grosholz 2008

9. Social Issues

Delairea odorata

Decisions to support public efforts to manage invasive plants are made in a social and political context. In order to effectively plan and implement invasive species management programs, land managers need to understand the different viewpoints of diverse groups such as: environmental activists, landowners, local land stewardship groups, volunteers and volunteer managers, neighbors of natural areas, gardeners, nursery industry, agricultural commissioners, small business owners and contractors engaged in stewardship work, lawmakers, Native American groups and many others. We need to understand the barriers to using different control methods. For instance, many groups have concern with the use of herbicides to control invasive plants. Managers need to devise effective strategies for getting the word out about invasive plants and their threats and they must be aware that how they frame the debate makes an important difference to their target audience (Larson 2005; Norgaard 2007).

Community-based stewardship is a new direction for invasive plant management and it involves working with community members to determine which projects they are interested in and implementing those. California's demographics will be changing dramatically in the future, and with those changes the need to outreach to diverse local communities will increase.

Research Needs

★ *Study why certain invasive plants are chosen for management and how the management is conducted*

What we decide to protect is tied to our concept of terms such as immigrant, invasive, and non-native (Coates 2007; Klinger 2007). Once we decide what to protect, should we develop "native plant zoos" with representatives of what used to be here? Which plants in the "zoos" will be able to persist and which will be most vulnerable to invasion?

Study motivations for participation in volunteer stewardship programs

Community based approaches are often used to develop restoration and volunteer stewardship programs. These programs start with what a community wants for a project, not just what "science" thinks must be done. What motivates people to volunteer and how can the larger community become involved? What are characteristics of successful, long-term volunteer programs? What keeps people involved? What need does volunteering fulfill? For instance, what barriers are there to participation? Why does everyone come out for Coastal Clean-Up Day but not continue throughout the year? The Golden Gate National Recreation Area serves as a good model for volunteer stewardship programs.

Determine the best vocabulary to use to deliver specific messages about invasive plants

We need to understand how vocabulary used in an outreach message affects a person's understanding of and reaction to an issue. The words invasive, exotic and non-native all have connotations and should be chosen carefully. What are the results of using fear-based messaging versus focusing on positive outcomes? Most invasive plant work focuses on the native communities we are trying to protect, not the invasive plants themselves, but messages often focus on the invasives only. The political effectiveness of arguments for doing invasive plant projects needs to be improved.

Study the best ways to collect and discuss the results of invasive plant management programs

In order to communicate with invasive plant project funders and policy makers, managers need to develop more effective ways to present management data. One approach is to count all the individual plants removed in a specific location over time. When the number approaches zero, the effort can be used to demonstrate success. One drawback to focusing on this type of reporting alone is it does not capture the need for prevention and EDRR efforts.

Study why different communities use or do not use herbicides and how perceptions change over time

A comprehensive investigation of regional attitudes toward herbicide use would be helpful in regional planning. Norgaard (2007) presents the details of one community's experience, but it is situation and community specific. Perhaps there are regional approaches, which can be documented which could help with designing projects in other areas.

Study successful collaborations between scientific groups and the general public

What are the best approaches for education and community involvement between groups? California's demographics are changing and the invasive plant community will need to reach out to diverse communities to stay relevant. There are many gaps to be bridged, beyond those between scientists and the land management community. In order to make the technical details understandable studies should be summarized for the general public and made widely available. Much of invasive plant work involves politics, defined as "how things get done." Those implementing invasive plant projects should be aware of the opportunity for opposition and why this happens.

Additional References

Finnoff *et al.* 2007; Foster & Sandberg 2004; Gobster 2000; Gobster & Hull 2000; Harris & Deane 2005; Hobbs 2007; Holloran *et al.* 2004; Keen *et al.* 2005; Lackey 2001; Larson 2005; Norgaard 2007; Robbins 2004a, b; Schroeder 2000; Simberloff 2003; Stocklmayer *et al.* 2005; Vining *et al.* 2000; Walkerden 2005

10. Policy and Laws

Cortaderia spp.

Policy and laws, from the national to the local level, set the context within which invasive plants are managed. For instance, prevention activities rely in large part on regulation and inspection for pest plants.

In California, noxious weeds are defined in the California Agricultural Code, and policy for pest plants is set by the Department of Food & Agriculture. Invasive plants are also cataloged by Cal-IPC in its Inventory (Cal-IPC 2006). This list does not carry legal weight, though it is cited frequently in planning documents, and the state's Weed Management Area (WMA) program employs state funds to work on these plants. The state's Noxious and Invasive Weed Action Plan (2005) lays out a blueprint for short- and long-term policy actions, but is not being fully implemented. An increasing number of states are producing such strategic plans. Many are also forming state interagency coordinating bodies to facilitate implementation of these plans. At the federal level, the National Invasive Species Management Plan focuses on five strategic goals: prevention; early detection and rapid response; control and management; restoration; and organizational collaboration (National Invasive Species Council 2007).

In addition to these planning efforts, organizations and researchers have contributed valuable information on the structure, players and roles involved in addressing invasive plants through policy and laws. The Environmental Law Institute (2002) published a report on a range of policy tools in place in state governments across the US. Lodge *et al.* (2006) likewise summarize the range of functions required for comprehensive government programs.

The general needs identified in these plans, reports and studies are consistent and at this point, well established. However, translating these general needs to the particular situation in California has not been adequately explored. The state's organizational landscape and existing legal structure are unique, and have significant inertia. Understanding how to change these productively is an important research need.

Research Needs

★ *Evaluate success of voluntary industry self-regulation versus government regulation*

Voluntary programs seek to make changes without regulation, but does this approach work for invasive plant management? Policy and social science research is needed to address the effectiveness of voluntary measures versus regulation for invasive plants in the horticultural trade. Social science or marketing research would also help biologists understand how industry groups select plants for sale and whether invasiveness is considered during that process. Scientists should work with industry to come up with an agreeable list of alternatives to invasive plants currently being sold. An economic analysis of the new alternatives for business/research would also be helpful. For instance, PlantRight seeks to prevent invasive plant introductions through horticulture by working on public education with the nursery industry. Florida and other states have similar programs, while some states have passed bans on specific plants. How successful are these approaches? What are the pros and cons of each approach?

Study successful state interagency coordinating bodies on invasive species

Many states, including Oregon, Washington, Arizona and Hawaii, have created state interagency coordinating bodies to lead implementation of strategic initiatives on invasive species programs. In what ways have they succeeded and failed? California formed an Invasive Species Council in February 2009. What lessons could be learned from other states?

Evaluate the functionality of California's Noxious Weed List in addressing invasive plants

The noxious weed list is primarily agricultural in origin, and does not include most invasive plants listed by Cal-IPC. The species on the list need to be reevaluated in a transparent manner to determine which list they should be on.

Compare success of the California Weed Management Area program with similar efforts

WMAs represent a new level of organization for addressing invasive plants in California. Other states have used similar programs and may have lessons which could be applied to California. Are the ways the California WMA program and individual WMA performance could be improved based on similar models?

Study how to include invasive plants in other invasive species programs

How have other states addressed the need to combine invasive plants and other invasive species programs? How have other education programs worked and what makes a program effective?

Study how land management decisions should shift under climate change

Broad collaborations between ecologists, policy makers, economists and stakeholders will need to be established for future land management decisions under climate change. New institutions may need to be established to manage lands across boundaries. Studies of successful collaborations could be initiated now in preparation for future management changes.

Additional References

Gordon 1998; Gordon *et al.* 2008b; Lackey 2001; Leung *et al.* 2005; Lodge & Shrader-Frechette 2003; Lodge *et al.* 2006; Margolis *et al.* 2005; National Invasive Species Council 2007; Reichard 1997; Westbrooks & Eplee 1996

Prioritizing the Research Needs


Cotoneaster spp.

Summary of Working Group at Cal-IPC 2008 Symposium

During the 2008 Cal-IPC Symposium a working group discussed prioritizing the research needs identified in interviews. Overall the working group identified the need for outreach and collaboration with social scientists and economists. Most of the attendees were biologists; therefore it is notable that the highest rated topic area was economic impacts, indicating the need to focus future efforts in this area. Focusing on economic impacts can help explain invasive plants to the general public and policymakers in order to build support to for management project. Collaboration was also seen as necessary between research scientists and policy makers in order to bring scientific results into the public policy arena. A list of the individuals attending the workshop is included in the Appendices.

The working group discussed the distinction between academic research, appropriate for graduate students and faculty, and policy research conducted by government or non-government organizations. Most academic researchers must focus on projects suitable for eventual publication in a peer-reviewed journal. Most of them are not interested in participating in policy discussions or risk their reputations as objective researchers if they do so.

Facilitating discussion and exchange of information between academics and land managers was also a broad focus of discussion. Without access to peer-reviewed journals, non-academics will not be able to use the latest research findings in their work. The group suggested trying to set up a university adjunct or courtesy appointment for someone within a larger organization. Some departments within National Park Service and other government agencies have access. As in the interviews for the project, a synthesis of information on biology and ecology and ecological impacts was seen as a priority for both of those topic areas. An example of a synthesis is the *Ecological Flora of the British Isles* (see Additional Needs section).

Participants prioritized the specific research needs listed under each topic

- Study seed biology and seedbank dynamics to support control techniques
- Determine the types and levels of ecological impacts
- Study interactions of wildlife (especially listed species) and invasive plants
- Produce statewide weed maps
- Document which horticultural plants are or are not invasive
- Determine which pathways of entry facilitate introductions into California
- Determine which Best Management Practices can prevent the spread of invasives along transportation corridors
- Develop standards for monitoring treatment methods to generate comparable data sets
- Study techniques to deplete the seedbank for eradication
- Study how to maximize the success of passive and active restoration
- Gather data to quantify the economic cost of invasive plant management
- Quantify the ecosystem service costs of invasive plants

- Study why certain invasive plants are chosen for management and how the management is conducted
- Evaluate success of voluntary industry self-regulation versus government regulation

The priority needs can be thought of in the context of invasion stages: Arrival, establishment, spread and impact. One priority need addresses pathways of entry, the arrival stage. Management of invasive plants is heavily represented in the priority needs and can be seen as the establishment and spread stages. Several needs listed relate to general management (spread along roads, restoration), and two relate specifically to managing the seedbank. Monitoring standardization was also seen as important for determining which management strategies are most successful.

Six of the priority needs focus on the social components of invasive plant management, addressing economic, philosophical and policy issues. Three of the priority needs then address the impacts caused by invasive plants once they arrive, and specifically the impacts on listed species and the overall economic costs to the ecosystem. Two of the priority needs relate to questions about horticultural plants and how those are managed. Although these are not specifically called out as "economic" they do address practices in a multi-million dollar industry. Finally, all of the priority needs listed would benefit from development of statewide weed maps which would aid overall management and prioritization.

After identifying priority needs, the research and policy community will be able to move forward with identifying funding sources and answering some of the questions posed in this document.

Additional Needs

Synthesis and Accessibility

Overall, synthesis of research in biology and ecology, ecological impacts, control and management, restoration and social issues related to invasive plant management was commonly mentioned in interviews and scored highly during the work group ranking. Academic research results need to be made available to the larger management community in order to keep the lines of communication open in both directions. Results from land managers also need to be published in newsletters or other web-accessible locations so they are available to the larger community. This need for accessibility of information and the need for information exchange between weed scientists and others was recently highlighted reviewed (Browne *et al.* 2009). Some specific suggestions for synthesis are included below.

Many of those interviewed for this project suggested that a comprehensive synthesis of research on invasive plant biology and ecology is needed to support land managers who may not have access to academic databases and need information on many plants. This type of synthesis would also be useful to researchers interested in performing meta-analysis. One suggested example of a synthesis is the *Ecological Flora of the British Isles.* The database contains many types of ecological information, covering habitat, distribution, morphology, physiology, life history and associated organisms (Fitter & Peat 1994). Standardized review techniques similar to those developed for medicine could be used to pull information from similar studies and compare the results. A third suggestion was to try a social networking application like Wikipedia to pull information together. Users could generate information and observational information could be included.

A synthesis of treatment techniques and the biology and ecology of key species was commonly mentioned during interviews. This was a common response from participants in the Broom Management Workshop held in Marin County in early 2008. Best Management Practices for some invasive plants and an easily accessible way to disseminate the information are also needed.

A review of treatment strategies for different plant life history strategies would also be useful. For instance, what are the optimum treatment return intervals for different life stages and plant types? Seedbank or mature adults need different management strategies. Plants with a long-lived seedbank may not need to be monitored every year after treatment, but will have to be checked long term. Plants with a short-lived seedbank would need to be checked more often, but would be considered eradicated sooner. To manage plants with below ground reserves, return frequently and exhaust the reserves. Treatment could be based on times of allocation to different organs and carbohydrate transport to root/flowering etc.

Additional synthesis needs:

- In general, managers need a compilation of neutral herbicide impact information for management decisions.
- We need research on which eradication programs have been successful, why they were successful where others failed, and what aspects of an invasive plant species or population lend themselves to eradication.
- A systematic review and synthesis of social issues relating to invasive plants is needed.

Education and Training

During the development of this report, the following needs for education and training were identified.

Education and outreach on horticultural invasives

What information is currently distributed to horticulture professionals and the general public, and is it effective? We need invasive plant curricula for programs that train future horticulturalists, in Environmental Horticulture and Landscape Architecture departments at universities, and classes for Master Gardeners and certified nursery professionals. For the general public, social science research is needed to determine the best ways to change attitudes and practices about horticultural plants.

Modeling for land managers

Models need to be adapted so that they can be used by land managers. Managers would like to know what invasive plants are coming to their area and which should be priorities for control. Modeling is also needed for prioritization at the Weed Management Area level.

Training on delivering a group message

The invasive plant management community could learn to take advantage of windows of opportunity in our community to spread a message. For example, we could learn to be "on message" by incorporating information on the Plant Right Campaign into our daily work and communications. We can also learn to be more effective communicators about the risks posed by invasive plants and the perception of those risks as compared to others.

Grazing education

Some invasive plant managers need to be educated on the basic facts of grazing. This type of training could be made available through UC Cooperative Extension or organizations focused on range management.

Training in effectiveness monitoring

Invasive plant managers need an easy way to monitor the effectiveness of eradication and restoration projects. A generic monitoring plan could be developed for managers to complement a control program. It would include which ecological factors managers should monitor in order to determine if their efforts are impacting the system or portions of it. What would serve as an ecological sentinel? Quick site –specific species assessment methodology to help with prioritization and control would also be useful.

Conclusions

Interviews with 45 researchers, land managers and policy makers focused on most of the topic areas identified in this report. Not surprisingly, those interviewed focused on their areas of expertise, though most offered additional insights into areas outside their field. The most frequently commented on areas were: Ecological Impacts, Control and Management, and Restoration. Many of the respondents touched on topics related to the social issues area. Some of the topic areas received few comments, such as roads as pathways in the Human Pathways and Prevention section, perhaps reflecting the lack of ongoing work and focus in those areas.

Some of the research needs identified bridged several topic areas. The most commonly addressed topic was the need for synthesis of existing scientific information, mentioned in the Biology/Ecology, Ecological Impacts, Control and Management, Restoration and Social Issues topic areas. Another topic addressed in several sections was thresholds for invasive plants, mentioned in the Ecological Impacts, Control and Management, Economic, and Social Issues topic areas. Thresholds addressed different things in each section. In some cases they referred to size or density of plant populations that would cause ecological impacts. In other cases thresholds were meant to address the size of a plant population that would inspire economic or social action. The impact of management practices to non-target species was a topic of discussion in the Control and Management, Restoration, and Social Issues sections. Invasion pathways and vectors were mentioned in the Ecological Impacts, Economics, and Risk Analysis sections. The use of molecular research tools for addressing research questions in several topic areas was mentioned, as was the need for basic biological information to feed into risk assessment and distribution models.

Overall, synthesis of research in biology and ecology, ecological impacts, control and management, restoration and social issues related to invasive plant management was commonly mentioned. Academic research results need to be made available to the larger management community in order to keep the lines of communication open in both directions. Results from land managers also need to be published in newsletters or other web-accessible locations so they are available to the larger community.

The research needs identified in this document have already been useful in providing topic areas for a new WMA research mini-grant program initiated in 2008. The four topic areas were developed using preliminary findings from this effort. The four priority topic areas were: 1) Flushing the seed bank; 2) Little to no management research conducted to date; 3) Restoration; and 4) Wildlife and invasive plant interactions.

The future of the research needs project will depend upon the willingness of the research and management communities to stay engaged in the process. Another meeting of experts would be useful to maintain the momentum in this effort, specifically addressing the priority needs and identifying funding sources to initiate research projects. Since graduate students were not specifically targeted in development of this document, they could be surveyed to gauge the applicability and usefulness of the funding information provided in the appendix. Finally, some of the collaboration needs presented in this document could be addressed at upcoming Cal-IPC Symposia through invited speakers and working groups focusing on economic and social science issues.

Appendix A.
Invasive Plant Experts in California
With additional researchers who contributed to this report

First Name	Last Name	Affilliation	Topic Areas Addressed in Research	Interviewed for or Contributed to Research Needs Document
Edith	Allen	UC Riverside Botany & Plant Sciences	1, 5, 7	X
Maria	Alvarez	Golden Gate National Recreation Area	1, 3, 6, 7	
John	Anderson	Hedgerow Farms	1, 6, 7	X
Lars	Anderson	USDA-ARS/Weed Science Program, UC Davis	6	
Tara	Athan	Mendocino Coast and Inland WMAs	3, 4, 8	X
Debra	Ayres	UC Davis Evolution and Ecology	1, 2, 3	
Joe	Balciunas	USDA-ARS Albany	6	
Michael	Barbour	UC Davis Plant Sciences	1, 2, 3, 6	X
Jacob	Barney	UC Davis Post Doc	1, 4, 6, 10	
Cameron	Barrows	UC Riverside Ctr for Conservation Biology	2	
Carl	Bell	UC Cooperative Extension	1, 6	X
Alison	Berry	UC Davis, Plant Sciences Road Ecology Center	5	
Carla	Bossard	St. Mary's College	1, 2, 6	X
Shannon	Brawley	Cache Creek Conservancy	9	
Christy	Brigham	National Park Service	1, 2, 6, 7	X
Matthew	Brooks	USGS Western Ecological Research Center	1, 3, 4, 5, 6, 7	X
Elizabeth	Brusati	Cal-IPC	1, 4, 10	X
Mark	Buckley	Environmental Incentives	5, 8, 9	
Jennifer	Burt	UC Davis	4, 9	X
Vanelle	Carrithers	Dow AgroSciences	6, 7	
Ray	Carruthers	USDA-ARS/Albany	1, 6	
David	Chang	Santa Barbara County Dept of Agriculture	1, 2, 4, 6, 7	
Joanna	Clines	US Forest Service	1, 2, 4, 6, 7, 9, 10	
Carla	D'Antonio	UC Santa Barbara	1, 2, 3, 4, 7	
Gina	Darin Skurka	UC Davis and CDFA	3, 4, 10	X
Jason	Davison	UNR Reno Cooperative Extension	1, 5	
Deanne	DiPietro	Sonoma Ecology Center	3	
Joe	DiTomaso	UC Davis Plant Sciences	1, 3, 4, 6, 10	X
Morgan	Doran	UC Cooperative Extension	1, 6	X
Tom	Dudley	UC Santa Barbara Marine Science Institute	1, 6, 7	X
Mark	Eiswerth	University of Wisconsin	8	
Norman	Ellstrand	UC Riverside Botany & Plant Sciences	1, 2	
Jennifer	Erskine-Ogden	UC Davis Ecology and Evolution	1, 2, 4, 6	X
Valerie	Eviner	UC Davis Plant Sciences	5, 7	X
Sharon	Farrell	Golden Gate National Parks Association	1, 6, 7, 9	X
Alison	Fisher	USDA-ARS Albany	6	
Dan	Gluesenkamp	Audubon Canyon Ranch	1, 2, 3, 4, 5, 6, 7, 9, 10	X
Doria	Gordon	The Nature Conservancy	2, 10	X

First Name	Last Name	Affilliation	Topic Areas Addressed in Research	Interviewed for or Contributed to Research Needs Document
Brenda	Grewell	USDA, UC Davis	1, 6	
Ted	Grosholz	UC Davis Environmental Science and Policy	1, 4	
Susan	Harrison	UC Davis Environmental Science and Policy	1, 5	
David	Headrick	Cal Poly San Luis Obispo	6	
Mike	Hogan	Integrated Environmental Restoration Solutions	7	X
Ingrid	Hogle	SF Invasive Spartina Project	1, 3, 6, 7	
Pete	Holloran	UC Santa Cruz	4, 6, 8, 9	X
Jodie	Holt	UC Riverside Botany & Plant Sciences	1, 2, 4, 7	X
Rachel	Hutchinson	UC Davis, Information Center for the Environment	1, 3, 4, 5, 6, 7	
Tim	Hyland	CA Dept of Parks and Rec	6, 7	
Marie	Jasieniuk	UC Davis Plant Sciences	1, 2, 3	X
Karen	Jetter	UC Davis Agricultural Issues Center	8	
Doug	Johnson	Cal-IPC	1, 2, 4, 5, 8, 9, 10	X
Scott	Johnson	Wilbur-Ellis Company	6	
Mike	Kelly	Friends of Los Penasquitos Canyon Preserve	1, 3, 6, 7	
Drew	Kerr	SF Invasive Spartina Project	1, 3, 6	
Janet	Klein	Marin Municipal Water District	1, 2, 6, 7, 8, 9, 10	
Karen	Klonsky	UC Davis Agricultural and Research Economics	8	
John	Knapp	Native Range, Inc.	1, 3, 4, 5, 6, 7, 9	X
Marla	Knight	US Forest Service	6, 9	
Guy	Kyser	UC Davis Plant Sciences	1, 2, 6, 7	
Emilio	Laca	UC Davis Plant Sciences	1, 6, 7	X
Adam	Lambert	UC Santa Barbara Marine Science Institute	6	
John	Lambrinos	Oregon State University, Dept of Horticulture	1, 3, 5, 7	
Tom	Lanini	UC Davis Plant Sciences	1, 6	X
Gretchen	LeBuhn	San Francisco State	8	
Elizabeth	Leger	U Nevada Reno	2, 7	
Sam	Leininger	UC Davis Plant Sciences	1, 3, 4, 5, 7	
Michael	Lennox	UC Cooperative Extension	7	
Jonathan	Levine	UC Santa Barbara	2	X
Richard	Mack	Washington State University	1, 2, 3, 4	X
Jaymee	Marty	The Nature Conservancy	1, 2, 3, 6, 7	X
Peter	McEvoy	University of Oregon Corvallis	2, 6	
Julian	Meisler	Laguna de Santa Rosa Foundation	1, 6, 7	
Adrianna	Muir	UC Davis Ecology	1, 8	X
Rosamond	Naylor	Stanford University	5, 8	
Mark	Newhouser	Sonoma Ecology Center	1, 6, 7	
Peggy	Olofson	SF Invasive Spartina Project	1, 3, 6	
Scott	Oneto	UC Cooperative Extension	1, 6	
Steve	Orloff	UC Cooperative Extension	1, 6	
Dane	Panetta	Biosecurity Queensland	1, 4, 6, 10	X
Ingrid	Parker	UC Santa Cruz	2, 3	X
Sophie	Parker	The Nature Conservancy	1, 2	X
Bruce	Pavlik	Mills College	4, 7, 9, 10	X
Andrea	Pickart	Humboldt Bay NWR/USFWS	1, 5, 6, 7	X

First Name	Last Name	Affilliation	Topic Areas Addressed in Research	Interviewed for or Contributed to Research Needs Document
Carri	Pirosko	CA Dept. of Food and Ag.	1, 6	X
Mike	Pitcairn	CA Dept. of Food and Ag.	1, 3, 6	
Jim	Quinn	ICE, UC Davis	3	
Steve	Radosevich	Oregon State University, Dept of Forest Science	1, 2, 3, 6	
John	Randall	The Nature Conservancy, UC Davis Plant Sciences	1, 4, 6, 10	X
Michael	Rauterkus	UC Riverside, Dept of Botany and Plant Sciences	1	
Sarah	Reichard	University of Washington	1, 2, 4, 7	
Marcel	Rejmanek	UC Davis Evolution and Ecology	1, 2, 3, 4, 6, 7	X
Kevin	Rice	UC Davis Plant Sciences	1, 2, 6, 7	X
Ramona	Robison	UC Davis	1, 3, 4, 7, 10	
Rick	Roush	UC Davis	1, 2, 6	
Andy	Sanders	UC Riverside Botany & Plant Sciences	3	
Jean-Daniel	Saphores	UC Irvine Civil and Environmental Engineering	8	
Kristina	Schierenbeck	CSU Chico Biological Sciences Dept.	2	X
Steve	Schoenig	CA Dept Fish and Game	3, 4, 5, 6, 8, 9, 10	X
Mark	Schwartz	UC Davis Environmental Science and Policy	2, 3	
Thomas	Scott	UC Riverside Earth Sciences	2, 3, 5, 6, 7, 10	
Fraser	Shilling	UC Davis Road Ecology Center	1, 2, 3, 5	X
Bobbi	Simpson	National Park Service	6, 7	X
Christina	Sloop	Laguna de Santa Rosa Foundation	1, 2	
Lincoln	Smith	USDA-ARS Albany	1, 2, 3, 4, 6, 7	X
David	Spencer	USDA-ARS Davis	1, 6	X
Renee	Spenst	Ducks Unlimited	1, 4, 5, 6	
Robert	Steers	UC Riverside	1, 4, 5, 6, 7	
Scott	Steinmaus	Cal Poly San Luis Obispo	1, 2, 3, 6, 7	X
Tom	Stohlgren	Colorado State University	3, 4	X
Sharon	Strauss	UC Davis Evolution and Ecology	2	X
Don	Strong	UC Davis Evolution and Ecology	1, 2, 5, 6, 9	
Katharine	Suding	UC Irvine Ecology & Evolutionary Biology	1, 2, 3	
Joel	Trumbo	CA Dept of Fish and Game	6	
Mandy	Tu	The Nature Conservancy	1, 2, 3, 6, 7, 10	
Susan	Ustin	UC Davis Land, Air and Water Resources	3	
Peter	Vitousek	Stanford University	2, 4	
George	Vourlitis	CSU San Marcos	1	
Giles	Waines	UC Riverside	1, 2	
Stuart	Weiss	Creekside Center	1, 2, 5, 6, 7, 10	
Virginia	White	UC Riverside; Riverside Community College	1, 4, 5, 6, 7	
Andrea	Williams	National Park Service	1, 3, 6	
Susan	Williams	UC Davis, Bodega Marine Lab	1, 9, 10	
Rob	Wilson	UC Cooperative Extension	1, 6	
Dave	Wood	CSU Chico Biological Sciences Dept.	2, 5, 7	X
Truman	Young	UC Davis Plant Sciences	7	X
Erika	Zavaleta	UC Santa Cruz Environmental Studies Dept.	2, 5, 8	X

Appendix B. Attendees at 2008 Symposium Working Group

Afifa Awan, California Department of Fish and Game
Lois Berg Stack, University of Maine
Michael Bower, UC Davis
Christiana Conser, Sustainable Conservation
Gina Darin, UC Davis and California Department of Food and Agriculture
Michael Gordon, Mattole Restoration Council
Ted Grosholz, UC Davis
Sarah Haskinson, UC Davis
Jodie Holt, UC Riverside
Julie Horenstein, California Department of Fish and Game
Brent Johnson, Pinnacles National Park
Laura Jones, Yosemite National Park
Guy Kyser, UC Davis
Heather Schneider, UC Riverside/Cal-IPC Student Chapter
Claudia Street, Glenn County Resource Conservation District
Lynn Webb, Cal Fire, Jackson State Forest
Marit Wilkerson, UC Davis
Andrea Williams, National Parks Service
Andreana Yribe, California Department of Food and Agriculture

Ramona Robison, Doug Johnson and Elizabeth Brusati, Cal-IPC and report authors

Appendix C.
Graduate Student Funding and Outreach

This section contains a summary challenges inherent in funding for research on invasive plants in California. It also includes a list of funding sources and ends with a perspective from one agency researcher on how graduate students could work with his agency. The Cal-IPC Student Chapter will work with Cal-IPC to distribute this report to students and identify sources of funding for invasive plant research.

Funding Challenges and Sources

Funding for invasive plant research suffers from three basic problems (besides the chronic competition for funding among agencies at both the state and federal levels). First, much of the money allocated for pest research is directed towards insects. Second, the state has not honored its commitment to match federal funds. Finally, despite the long list of topics that need researching, there is a lack of university researchers equipped to study these questions.

The State of California allocates most pest funding toward insect pests rather than weeds. This may result from differences in the way the two impact crops. Weeds remain relatively stable from year to year, while insect pests fluctuate widely. An outbreak of an insect can wipe out a crop in one year, while weeds are more insidious. Most state biocontrol money is directed toward the Mediterranean fruit fly and similar pests. In addition, insect and weed control projects occasionally conflict with each other. For example, the state is funding efforts to control the eucalyptus borer in southern California.

The lack of funding for weed science research and lack of weed science researchers causes a chicken-and-egg situation in California universities. Agencies such as USDA that traditionally fund research into both agricultural and wildland weeds pay little overhead to schools, making university deans reluctant to have their faculty pursue such grants. In some cases, funding is available but laboratories lack the staff to do the work. At least one state lab has turned away grants because it did not have enough people to manage existing proposals, let alone write new ones. The California State University system's Agricultural Research Institute provides grants for researchers at Cal Poly – San Luis Obispo, Cal Poly-Pomona, CSU Chico, and CSU Fresno.

The most effective way to improve funding in California may be to influence the research priorities of federal agencies and their allocation of existing funds. For example, USDA has a larger research program in California than the California Department of Food and Agriculture. It may require lobbying the program to direct more biocontrol research funds to invasive plants. Within federal agencies, a cross-cut budget item may be useful. The president chooses priorities (and has chosen invasive species as one of them in the past) and invites agencies to submit proposals.

Invasive plant research programs for graduate students:

USDA National Research Initiative

- Supports (1) high priority fundamental and mission-linked research of importance in the biological, environmental, physical, and social sciences relevant to agriculture, food, and the environment and (2) competitively awarded research, extension, and education grants addressing key issues of national and regional importance to agriculture, forestry, and related topics.

- Very competitive
- Funded the New England Invasive Plant Atlas, a program for regional and national pest alerts, integrated pest management training
- www.csrees.usda.gov

National Science Foundation

- Has funded invasive plant research that includes basic research, such as evolution of plants after introduction of biocontrol agents, ecological consequences of the hybrid *Spartina* swarm in San Francisco Bay, and invasive hybrids of other species.
- www.nsf.gov

University of California Integrated Pest Management, Exotic Pests and Diseases Program

- Suspended funding for 2009-2010 budget cycle, may reinstate in future pending State budget situation
- www.ipm.ucdavis.edu

California State University Agricultural Research Institute

- Research consortium for Cal Poly San Luis Obispo and Pomona, CSU Chico, CSU Fresno
- Funding ranges from $5,000 seed grants to full grants up to $150,000
- Pre-proposals due August
- Projects have included yellow starthistle biocontrols, burning to control medusahead, riparian ecosystem management
- http://ari.calstate.edu

California Sea Grant

- Although it focuses on marine systems, it has funded projects on tamarisk and arundo
- www.csgc.ucsd.edu

California Department of Food and Agriculture Research Mini-Grants

- Started in 2008, this program awards grants of up to $5,000 through partnerships with local Weed Management Areas (WMAs)
- www.cdfa.ca.gov/phpps/ipc/weedmgtareas/wma_index_hp.htm

California Weed Science Society Scholarships

- Academic scholarships of $2,000 are available for undergraduate and graduate students.
- Internships of $3,000 for an 8-week full-time internship with a University of California farm advisor or other off-campus research personnel with responsibilities in weed or invasive plant management are available
- www.cwss.org/index.htm

Other graduate student Funding (not specifically on invasive plants):

Environmental Protection Agency, Science to Achieve Results (EPA STAR)

- Master's and Ph.D. students
- 100 awarded annually, up to $37,000/year for three years
- http://es.epa.gov/ncer/rfa/#CurrentStar

National Estuarine Research Reserve fellowships

- Master's and Ph.D. students
- Must work on one of the National Oceanic and Atmospheric Administration's research reserves.
- California reserves are San Francisco Bay, Elkhorn Slough, and Tijuana Estuary.
- $20,000/year for up to three years
- www.nerrs.noaa.gov/Fellowhip/welcome.html

National Science Foundation Fellowships

- Ph.D. students only
- Three years
- www.nsf.gov

CalFed

- Grants for projects focusing on the California Bay-Delta system. CalFed Fellows Program offers fellowships for graduate students.
- http://calwater.ca.gov/calfed/contracts_and_grants.html

University of California system

- UC students only
- Mathias Grants for work on UC Natural Reserve sites
- http://nrs.ucop.edu

California State University System

- CSU only
- CSUPERB, a CSU biotech organization
- www.csuchico.edu/csuperb

Sigma Xi Grants-In-Aid-of-Research

- Small grants for one year
- www.sigmaxi.org

Garden Club of America

- Grants of several thousand dollars in horticulture, rare plants, restoration, wetland plants, etc. Deadlines and amount vary by scholarship.
- www.gcamerica.org

California Native Plant Society

- Small grants from local chapters
- Must relate to native plants
- www.cnps.org

Northern California Botanists

- $1,000 scholarships awarded to undergraduate and graduate students enrolled in botany, plant ecology, or other plant-focused program as a full-time student at one of northern California's colleges or universities.
- www.csuchico.edu/biol/Herb/norcalbot/scholarships.htm

Davis Botanical Society

- http://herbarium.ucdavis.edu/society.html

Other funding sources (not specifically for students):

Audubon California Landowner Stewardship Program.

- The program's goals are to conduct research projects that evaluate and improve the effectiveness of restoration methods, evaluate the interaction between native habitats and agriculture, and create land management opportunities that benefit ranchers and farmers.
- http://ca.audubon.org/LSP/html/research.html

Kearney Foundation of Soil Science at UC Davis

- Offers grants for soil projects. Its mission is "Understanding and managing soil-ecosystem functions across spatial and temporal scales."
- http://kearney.ucdavis.edu

Packard Foundation grants in conservation and science

- www.packard.org/categoryList.aspx?RootCatID=3&CategoryID=61

Switzer Foundation

- The foundation offers fellowships and project grants to nurture the next generation of environmental leaders.
- www.switzernetwork.org/

San Francisco Foundation, San Francisco Bay Fund Program

- Includes grants for restoration projects
- www.sff.org/programs/environment/san-francisco-bay-fund

Western Sustainable Agriculture Research and Education – WSARE

- SARE is a program of the U.S. Department of Agriculture that functions through competitive grants conducted cooperatively by farmers, ranchers, researchers and ag professionals to advance farm and ranch systems that are profitable, environmentally sound and good for communities.
- http://wsare.usu.edu

Other Funding ideas suggested in interviews:

- California Association of Nursery and Garden Centers
- California Coastal Conservancy, grants for restoration project related to climate change
- California Department of Transportation (CalTrans)
- Central Valley Project Improvement Act (CVPIA) restoration projects
- Nature Conservancy Oren Pollack Grasslands Grant - internal TNC grant for six western states
- Nature Conservancy Collins Research Fund for stewardship
- Resource Conservation Districts
- Water agencies in Southern California
- State bonds

How to work with a federal agency on weed research

The following suggestions come from Matt Brooks, a researcher with the USGS Western Ecological Research Center (www.werc.usgs.gov/invasivespecies).

- Student Career Experience Program (SCEP): These Federal agency jobs allow students to work as an employee half time and they are guaranteed future position with the federal government
- Agencies hire field crews every season in February or March: Get summer field experience as a Biological technician, work goes until September or October
- Student Conservation Association (SCA) International: Students work in summer for 16 weeks, most are between their bachelors and grad school
- Find a USGS research scientist and work with them as a mentor: Mentoring or an internship with people you are interested in working with can lead to future employment. Students can learn skills to apply for a research grant or approach a professor to work on a proposal for a federal student position.
- USGS advertises open positions on list-serves

References

Anderson N. O., Galatowitsch S. M. & Gomez N. 2006a. Selection strategies to reduce invasive potential in introduced plants. *Euphytica* 148: 203-216.

Anderson N. O., Gomez N. & Galatowitsch S. M. 2006b. A non-invasive crop ideotype to reduce invasive potential. *Euphytica* 148: 185-202.

Anderson P. 1995. Ecological restoration and creation: a review. *Biological Journal of the Linnean Society* 56: 187-211.

Anderson R. P., Lew D. & Peterson A. T. 2003. Evaluating predictive models of species' distributions: criteria for selecting optimal models. *Ecological Modeling* 162: 211-232.

Andreas J., Zimmerman T. J., Fagerlie D. L., Gaolach B. W., Whaley D. K. & Wilson T. W. 2007. Successful biological control of invasive plant species in Washington. U S Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR: 51-52.

Ayres D. R. & Strong D. R. 2001. Origin and genetic diversity of *Spartina anglica* (Poaceae) using nuclear DNA markers. *American Journal of Botany* 88: 1863-1867.

Ayres D. R., Zaremba K., Sloop C. M. & Strong D. R. 2008. Sexual reproduction of cordgrass hybrids (*Spartina foliosa* x *alterniflora*) invading tidal marshes in San Francisco Bay. *Diversity and Distributions* 14: 187-195.

Babendreier D. 2007. Pros and cons of biological control. *In: Biological Invasions.* Ecological Studies, Vol. 193 (ed. W. Nentwig) pp. 403-418. Springer-Verlag, Berlin, Germany.

Barbier E. & Knowler D. 2006. Commercialization decisions and the economics of introduction. *Euphytica* 148: 151-164.

Barnett D. T., Stohlgren T. J., Jarnevich C. S., Chong G. W., Ericson J. A., Davern T. R. & Simonson S. E. 2006. The art and science of weed mapping. *Environmental Monitoring and Assessment*.

Barney J. N. 2006. North American history of two invasive plant species: phytogeographic distribution, dispersal vectors, and multiple introductions. *Biological Invasions* 8: 703-717.

Barney J. N. & Whitlow T. H. 2008. A unifying framework for biological invasions: the state factor model. *Biological Invasions* 10: 259-272.

Baskin C. C. & Baskin J. M. 2006. The natural history of soil seed banks of arable land. *Weed Science* 54: 549-557.

Baskin Y. 2002. The greening of horticulture: new codes of conduct aim to curb plant invasions. *Bioscience* 52: 464-471.

Becker T., Dietz H., Billeter R., Buschmann H. & Edwards P. J. 2005. Altitudinal distribution of alien plant species in the Swiss Alps. *Perspectives in Plant Ecology, Evolution and Systematics* 7: 173-183.

Bella E. 2007. Invasive plant expansion into biogeoclimatic envelopes under current climate and global climate change scenarios in Alaska. U S Forest Service Pacific Northwest Research Station General Technical Report PNW-GTR: 141-142.

Blossey B. 1995. A comparison of various approaches for evaluating potential biological control agents using insects on *Lythrum salicaria*. *Biological Control* 5: 113-122.

Bossard C., Moore K., Chabre C., Woolfolk A., King J. & Johanek D. 2005. A test of repeat flaming as a control for poison hemlock (*Conium maculatum*), Cape ivy (*Delairea odorata*) , and periwinkle (*Vinca major*). *In*: Proceedings of the California Invasive Plant Council Symposium (ed. G. Skurka) pp. 29-34. Cal-IPC.

Bossard C. C. & Randall J. M. 2007. Nonnative plants of California. *In: Terrestrial Vegetation of California* (eds. M. G. Barbour, T. Keeler-Wolf & A. A. Schoenherr) pp. 107-123. University of California Press, Berkeley.

Bossard C. C., Randall J. M. & Hoshovsky M. C. 2000. *Invasive Plants of California's Wildlands*. University of California Press, Berkeley, CA.

Briese D. T. 2005. Translating host-specificity test results into the real world: The need to harmonize the yin and yang of current testing procedures. *Biological Control* 35: 208-214.

Brigham C. A. 2004. Diversity and invasibility in ecological restoration. *Ecological Society of America Annual Meeting Abstracts* 89: 63-64.

Brooks M. L. & D'Antonio C. M. 2002. Fire and other forms of disturbance: Are they similar and do they have similar effects on invasive plants. Ecological Society of America Annual Meeting Abstracts 87.

Brooks M. L., D'Antonio C. M., Richardson D. M., Grace J. B., Keeley J. E., DiTomaso J. M., Hobbs R. J., Pellant M. & Pyke D. 2004. Effects of invasive alien plants on fire regimes. *Bioscience* 54: 677-688.

Browne M., Pagad S. & De Poorter M. 2009. The crucial role of information exchange and research for effective responses to biological invasions. *Weed Research* 49: 6-18.

Buhle E. R., Margolis M. & Ruesink J. L. 2005. Bang for buck: cost-effective control of invasive species with different life histories. *Ecological Economics* 52: 355-366.

Burt J., Muir A., Piovia-Scott J., Veblen K., Chang A., Grossman J. & Weiskel H. 2007. Preventing horticultural introductions of invasive plants: potential efficacy of voluntary initiatives. *Biological Invasions* 9: 909-923.

Byers J. E., Reichard S., Randall J. M., Parker I. M., Smith C. S., Lonsdale W. M., Atkinson I. A. E., Seastedt T. R., Williamson M., Chornesky E. & Hayes D. 2002. Directing research to reduce the impacts of nonindigenous species. *Conservation Biology* 16: 630-640.

California Climate Change Commission. 2008. Frequently asked questions about global climate change. Available: www.climatechange.ca.gov/publications/faqs.html.

California Department of Food and Agriculture. 2002. *California Weed Mapping Handbook*, California Department of Food and Agriculture, Sacramento, CA.

California Department of Food and Agriculture & California Invasive Weed Awareness Coalition. 2005. California Noxious and Invasive Weed Action Plan pp. 45.

Cal-IPC. 2006. California Invasive Plant Inventory. Cal-IPC Publication 2006-02. California Invasive Plant Council, Berkeley, CA. Available: www.cal-ipc.org.

Carlsen T. M., Menke J. W. & Pavlik B. M. 2000. Reducing competitive suppression of a rare annual forb by restoring native California perennial grasslands. *Restoration Ecology* 8: 18-29.

Carruthers R. I. & D'Antonio C. M. 2005. Science and decision making in biological control of weeds: Benefits and risks of biological control. *Biological Control* 35: 181-182.

Chornesky E. A., Bartuska A. M., Aplet G. H., Britton K. O., Cummings-Carlson J., Davis F. W., Eskow J., Gordon D. R., Gottschalk K. W., Haack R. A., Hansen A. J., Mack R. N., Rahel F. J., Shannon M. A., Wainger L. A. & Wigley T. B. 2005. Science priorities for reducing the threat of invasive species to sustainable forestry. *Bioscience* 55: 335-348.

Cione N. K., Padgett P. E. & Allen E. B. 2002. Restoration of a native shrubland impacted by exotic grasses, frequent fire, and nitrogen deposition in southern California. *Restoration Ecology* 10: 376-384.

Clarke M., Reichard S. & Hamilton C. 2006. Prevalence of different horticultural taxa of Ivy (*Hedera* spp., Araliaceae) in invading populations. *Biological Invasions* 8: 149-157.

Coates P. 2007. *American Perceptions of Immigrant and Invasive Species: Strangers on the Land.* University of California Press, Berkeley, CA.

Corbin J. D. & D'Antonio C. M. 2004. Effects of exotic species on soil nitrogen cycling: Implications for restoration. *Weed Technology* 18: 1464-1467.

Crossman N. 2003. Predicting the spread of the invasive European Olive (*Olea europaea* L.) in South Australia. *In*: School of Geography, Population and Environmental Management. Flinders University.

Crossman N. D. & Bass D. A. 2008. Application of common predictive habitat techniques for post-border weed risk management. *Diversity and Distributions* 14: 213-224.

Daehler C. C. 2003. Performance comparisons of co-occurring native and alien invasive plants: Implications for conservation and restoration. *Annual Review of Ecology Evolution and Systematics* 34: 183-211.

Daehler C. C., Denslow J. S., Ansari S. & Kuo H. 2004. A risk-assessment system for screening out invasive pest plants from Hawaii and other Pacific islands. *Conservation Biology* 18: 360-368.

D'Antonio C. & Meyerson L. A. 2002. Exotic plant species as problems and solutions in ecological restoration: A synthesis. *Restoration Ecology* 10: 703-713.

D'Antonio C. M. 2000. Fire, plant invasions, and global changes. *In: Invasive Species in a Changing World* pp. 65-93. (eds. H. A. Mooney & R. J. Hobbs) Island Press, Washington, D.C.

D'Antonio C. M., Bainbridge S., Kennedy C., Bartholome J. & Reynolds S. 2002. Ecology and restoration of California grasslands with special emphasis on the influence of fire and grazing on native grassland species. Department of Integrative Biology, UC Berkeley, Berkeley, CA.

D'Antonio C. M., Jackson N. E., Horvitz C. C. & R. H. 2004. Invasive plants in wildland ecosystems: merging the study of invasion processes with management needs. *Frontiers in Ecology and the Environment* 2: 513-521.

D'Antonio C. M. & Thomsen M. 2004. Ecological resistance in theory and practice. *Weed Technology* 18: 1572-1577.

Denslow J. S. & D'Antonio C. M. 2005. After biocontrol: Assessing indirect effects of insect releases. *Biological Control* 35: 307-318.

DeWalt S. J. 2006. Population dynamics and potential for biological control of an exotic invasive shrub in Hawaiian rainforests. *Biological Invasions* 8: 1145-1158.

DiTomaso J. M. & Healy E. A. 2003. *Aquatic and Riparian Weeds of the West*. University of California Division of Agriculture and Natural Resources Publication 3421, Oakland, CA.

DiTomaso J. M. & Healy E. A. 2007. *Weeds of California and other Western States*. University of California Division of Agriculture and Natural Resources Publication 3488, Oakland, CA.

DiTomaso J. M. & Johnson D. W. 2006. The use of fire as a tool for controlling invasive plants pp. 56. Cal-IPC publication 2006-01, Berkeley, CA.

Drake J. M. & Bossenbroek J. M. 2004. The potential distribution of zebra mussels in the United States. *Bioscience* 54: 931-941.

Eiswerth M. E., Darden T. D., Johnson W. S., Agapoff J. & Harris T. R. 2005a. Input-output modeling, outdoor recreation, and the economic impacts of weeds. *Weed Science* 53: 130-137.

Eiswerth M. E., Singletary L., Zimmerman J. R. & Johnson W. S. 2005b. Dynamic benefit-cost analysis for controlling perennial pepperweed (*Lepidium latifolium*): A case study. *Weed Technology* 19: 237-243.

Environmental Law Institute. 2002. Halting the Invasion: State Tools for Invasive Species Management. Available: www.eli.org/Program_Areas/invasives/invasives_form.cfm

Erskine Ogden J. & Rejmanek M. 2005. Recovery of native plant communities after the control of a dominant invasive plant species, *Foeniculum vulgare*: Implications for management. *Biological Conservation* 125: 427-439.

Esque T. C. & Schwalbe C. R. (2002) Alien annual grasses and their relationship to fire and biotic change in Sonoran Desert scrub. *In: Invasive Exotic Species in the Sonoran Region* (ed. B. Tellman). University of Arizona Press, Tucson, AZ.

Ewel J. J., O'Dowd D. J., Bergelson J., Daehler C. C., D'Antonio C. M., Gomez L. D., Gordon D. R., Hobbs R. J., Holt A., Hopper K. R., Hughes C. E., LaHart M., Leakey R. R. B., Lee W. G., Loope L. L., Lorence D. H., Louda S. M., Lugo A. E., McEvoy P. B., Richardson D. M. & Vitousek P. M. 1999. Deliberate introductions of species: Research needs. *Bioscience* 49: 619-630.

Falge J., Frantz E. & Ambuske R. 2004. NYS Department of Transportation response to E.O. 13112 invasive plant species. *In*: Proceedings of the 2003 International Conference on Ecology and Transportation (eds. C. L. Irwin, P. Garrett & K. P. McDermott) pp. 489-504. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Fenn M. E., Baron J. S., Allen E. B., Rueth H. M., Nydick K. R., Geiser L., Bowman W. D., Sickman J. O., Meixner T. & Johnson D. W. 2003. Ecological effects of nitrogen deposition in the Western United States. *Bioscience* 53: 404-420.

Finnoff D., Shogren J. F., Leung B. & Lodge D. 2007. Take a risk: Preferring prevention over control of biological invaders. *Ecological Economics* 62: 216-222.

Finnoff D. & Tschirhart J. 2005. Identifying, preventing and controlling invasive plant species using their physiological traits. *Ecological Economics* 52: 397-416.

Fitter A. H. & Peat H. J. 1994. The Ecological Flora Database. *The Journal of Ecology* 82: 415-425.

Foster J. & Sandberg L. A. 2004. Friends or foe? Invasive species and public green space in Toronto. *The Geographical Review* 94: 178-199.

Gelbard J. L. & Belnap J. 2003. Roads as conduits for exotic plant invasions in a semiarid landscape. *Conservation Biology* 17: 420-432.

Gelbard J. L. & Harrison S. 2005. Invasibility of roadless grasslands: an experimental study of yellow starthistle. *Ecological Applications* 15: 1570-1580.

Gobster P. H. 2000. Restoring nature: Human actions, interactions and reactions. *In: Restoring Nature: Perspectives from the Social Sciences and Humanities* (eds. P. H. Gobster & R. B. Hull) pp. 1-19. Island Press.

Gobster P. H. & Hull R. B. 2000. *Restoring Nature: Perspectives from the Social Sciences and Humanities.* Island Press, Washington, D. C.

Gordon D. R. 1998. Effects of invasive, non-indigenous plant species on ecosystem processes: lessons from Florida. *Ecological Applications* 8: 975-989.

Gordon D. R., Onderdonk D. A., Fox A. M. & Stocker R. K. 2008a. Consistent accuracy of the Australian weed risk assessment system across varied geographies. *Diversity and Distributions* 14: 234-242.

Gordon D. R., Onderdonk D. A., Fox A. M. & Stocker R. K. 2008b. Consistent accuracy of the Australian weed risk assessment system across varied geographies. *Diversity and Distributions* 14: 234-242.

Gordon D. R., Onderdonk D. A., Fox A. M., Stocker R. K. & Gantz C. 2008c. Predicting invasive plants in Florida using the Australian weed risk assessment. *Invasive Plant Science and Management* 1: 178-195.

Grotkopp E. & Rejmanek M. 2007. High seedling relative growth rate and specific leaf area are traits of invasive species: Phylogenetically independent contrasts of woody angiosperms. *American Journal of Botany* 94: 526-532.

Groves R. H. 2006. Are some weeds sleeping? Some concepts and reasons. *Euphytica* 148: 111-120.

Harper-Lore B. L. 2001. Incorporating invasive plant analysis into NEPA. *In*: 2001 International Conference on Ecology and Transportation (eds. C. L. Irwin, P. Garrett & K. P. McDermott) pp. 317-319. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC.

Harris J. & Deane P. 2005. The ethics of social engagement: learning to live and living to learn. *In: Social Learning in Environmental Management Towards a Sustainable Future* (eds. M. Keen, V. A. Brown & R. Dyball) pp. 191-206, Earthscan. Sterling, VA.

Heywood V. H. 1989. Patterns, extents and modes of invasions by terrestrial plants. *In: Biological Invasions: A Global Perspective* (eds. J. A. Drake, H. A. Mooney, F. D. Di Castri, R. H. Groves, E. L. Kruger, M. Rejmanek & M. Williamson) pp. 31-55. Wiley and Sons, New York.

Higgins S. I. & Richardson D. M. 1999. Predicting plant migration rates in a changing world: The role of long-distance dispersal. *American Naturalist* 153: 464-475.

Hobbs R. J. 2007. Setting effective and realistic restoration goals: Key directions for research. *Restoration Ecology* 15: 354-357.

Hobbs R. J. & Harris J. A. 2001. Restoration ecology: Repairing the earth's ecosystems in the new millennium. *Restoration Ecology* 9: 239-246.

Holloran P., Mackenzie A., Farrell S. & Johnson D. W. 2004. *The Weed Workers' Handbook: A Guide to Techniques for Removing Bay Area Invasive Plants*. The Watershed Council and California Invasive Plant Council. Berkeley, CA.

Holmes P. M., Richardson D. M., Esler K. J., Witkowski E. T. F. & Fourie S. 2005. A decision-making framework for restoring riparian zones degraded by invasive alien plants in South Africa. *South African Journal of Science* 101: 553-564.

Holt J. S. & Boose A. B. 2000. Potential for spread of *Abutilon theophrasti* in California. *Weed Science* 48: 43-52.

Hufbauer R. A. & Sforza R. 2008. Multiple introductions of two invasive *Centaurea* taxa inferred from cpDNA haplotypes. *Diversity and Distributions* 14: 252-261.

Jeschke J. M. & Strayer D. L. 2008. Usefulness of bioclimatic models for studying climate change and invasive species. *Year in Ecology and Conservation Biology 2008* 1134: 1-24.

Jodoin Y., Lavoie C., Villeneuve P., Theriault M., Beaulieu J. & Belzile F. 2008. Highways as corridors and habitats for the invasive common reed *Phragmites australis* in Quebec, Canada. *Journal of Applied Ecology* 45: 459-466.

Keen M., Brown V. A. & Dyball R. 2005. Social learning: a new approach to environmental management. *In: Social Learning in Environmental Management: Towards a Sustainable Future* (eds. M. Keen, V. A. Brown & R. Dyball) pp. 3-21, Earthscan. Sterling, VA.

Kerns B. K. & Ager A. 2007. Risk assessment for biodiversity conservation planning in Pacific Northwest forests. *Forest Ecology and Management* 246: 38-44.

Klein J. 2006. Pseudo-replication, no replication, and a complete lack of control: in praise of dirty data for weed managers. *In*: Proceedings of Cal-IPC Annual Symposium pp. 44-49. Cal-IPC, Rohnert Park, CA.

Klinger R. K. 2007. Review of *American Perceptions of Immigrant and Invasive Species: Strangers on the Land. Madrono* 54: 363-365.

Kowarik I. 2003. Human agency in biological invasions: Secondary releases foster naturalisation and population expansion of alien plant species. *Biological Invasions* 5: 293-312.

Kriticos D. J., Sutherst R. W., Brown J. R., Adkins S. W. & Maywald G. F. 2003a. Climate change and biotic invasions: A case history of a tropical woody vine. *Biological Invasions* 5: 147-165.

Kriticos D. J., Sutherst R. W., Brown J. R., Adkins S. W. & Maywald G. F. 2003b. Climate change and the potential distribution of an invasive alien plant: *Acacia nilotica* ssp. *indica* in Australia. *Journal of Applied Ecology* 40: 111-124.

Lackey R. T. 2001. Values, policy and ecosystem health. *Bioscience* 51: 437-443.

Lambdon P. W., Lloret F. & Hulme P. E. 2008. How do introduction characteristics influence the invasion success of Mediterranean alien plants? *Perspectives in Plant Ecology, Evolution and Systematics* 10: 143-159.

Lambrinos J. G. 2002. The variable invasive success of *Cortaderia* species in a complex landscape. *Ecology*: 518-529.

Larson B. 2005. The war on roses: Demilitarizing invasion biology. *Frontiers in Ecology and the Environment* 3: 495-500.

Leung B., Finnoff D., Shogren J. F. & Lodge D. 2005. Managing invasive species: Rules of thumb for rapid assessment. *Ecological Economics* 55: 24-36.

Levine J. M. 2003. A patch modeling approach to the community-level consequences of directional dispersal. *Ecology* 84: 1215-1224.

Levine J. M. & D'Antonio C. M. 2003. Forecasting biological invasions, with increasing international trade. *Conservation Biology* 17: 322-326.

Levine J. M., Vila M., D'Antonio C. M., Dukes J. S., Grigulis K. & Lavorel S. 2003. Mechanisms underlying the impacts of exotic plant invasions. *Proceedings of the Royal Society Biological Sciences Series B* 270: 775-781.

Livingston M. & Osteen C. 2008. Integrating invasive species prevention and control policies. USDA Economic Research Service. Economic Brief Number 11.

Lodge D. M. & Shrader-Frechette K. 2003. Nonindigenous species: Ecological explanation, environmental ethics, and public policy. *Conservation Biology* 17: 31-37.

Lodge D. M., Williams S. M., MacIsaac H. J., Hayes K. R., Leung B., Reichard S., Mack R. N., Moyle P. B., Smith M., Andow D. A., Carlton J. T. & McMichael A. 2006. Biological invasions: Recommendations for U.S. policy and management. *Ecological Applications* 16: 2035-2054.

Lonsdale W. M. 1994. Inviting trouble: Introduced pasture species in northern Australia. *Australian Journal of Ecology* 19: 345-354.

Mack R. N. 1985. *Invading Plants: Their Potential Contribution to Population Biology.* Academic Press, Inc., London.

Mack R. N. 1996. Predicting the identity and fate of plant invaders: emergent and emerging approaches. *Biological Conservation* 78: 107-121.

Mack R. N. 2005. Predicting the identity of plant invaders: future contributions from horticulture. *HortScience* 40: 1168-1174.

Mack R. N., Simberloff D., Lonsdale W. M., Evans H., Clout M. & Bazzaz F. A. 2000. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications* 10: 689-710.

Margolis M., Shogren J. F. & Fischer C. 2005. How trade politics affect invasive species control. *Ecological Economics* 52: 305-313.

Martinez-Ghersa M. A. & Ghersa C. M. 2006. The relationship of propagule pressure to invasion potential in plants. *Euphytica* 148: 87-96.

Marty J. T. 2005. Effects of cattle grazing on diversity in ephemeral wetlands. *Conservation Biology* 19: 1626-1632.

McCaffrey J. P., Campbell C. L. & Andres L. A. (1995) St. Johnswort. *In: Biological Control in the Western United States: Accomplishments and Benefits of Regional Research Project W-84, 1964-1989* (eds. J. R. Nechols, L. A. Andres, J. W. Beardsley, R. D. Goeden & C. G. Jackson) pp. 281-285. University of California, Division of Agriculture and Natural Resources. Publication No. 3361., Oakland.

McNeely J. A. 2006. As the world gets smaller, the chances of invasion grow. *Euphytica* 148: 5-15.

Meimberg H., Hammond J. I., Jorgensen C. M., Park T. W., Gerlach J. D., Rice K. J. & McKay J. K. 2006. Molecular evidence for an extreme genetic bottleneck during introduction of an invading grass to California. *Biological Invasions* 8: 1355-1366.

Millar C. I., Stephenson N. L. & Stephens S. L. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications* 17: 2145-2151.

Miller J. R. & Hobbs R. J. 2007. Habitat restoration -- Do we know what we are doing? *Restoration Ecology* 15: 382-390.

Moody M. E. & Mack R. N. 1988. Controlling the spread of plant invasions: the importance of nascent foci. *Journal of Applied Ecology* 25: 1009-1021.

National Invasive Species Council. 2007. 2008-2012 National Invasive Species Management Plan Draft for Public Comment, 32 pp, Washington, D.C.

Nelson G. C., Bennett E., Berhe A. A., Cassman K., DeFries R., Dietz T., Dobermann A., Dobson A., Janetos A., Levy M., Marco D., Nakicenovic N., O'Neill B., Norgaard R., Petschel-Held G., Ojima D., Pingali P., Watson R. & Zurek M. 2006. Anthropogenic drivers of ecosystem change: an overview. *Ecology and Society* 11: Article 29.

Norgaard K. M. 2007. The politics of invasive weed management: gender, race, and risk perception in rural California. *Rural Sociology* 72: 450-477.

Okada M., Ahmad R. & Jasieniuk M. 2007. Microsatellite variation points to local landscape plantings as sources of invasive pampas grass (*Cortaderia selloana*) in California. *Molecular Ecology* 16: 4956-4971.

Parendes L. A. & Jones J. A. 2000. Role of light availability and dispersal in exotic plant invasion along roads and streams in the H.J. Andrews Experimental Forest, Oregon. *Conservation Biology* 14: 64-75.

Pattison R. R. & Mack R. N. 2008. Potential distribution of the invasive tree *Triadica sebifera* (Euphorbiaceae) in the United States: evaluating CLIMEX predictions with field trials. *Global Change Biology* 14: 1-14.

Perrings C. 2005. Mitigation and adaptation strategies for the control of biological invasions. *Ecological Economics* 52: 315-325.

Peterson A. T. 2001. Predicting species' geographic distributions based on ecological niche modeling. *The Condor* 103: 599-605.

Peterson A. T., Papes M. & Kluza D. A. 2003. Predicting the potential invasive distributions of four alien plants in North America. *Weed Science* 51: 863-868.

Peterson A. T. & Vieglais D. A. 2001. Predicting species invasions using ecological niche modeling: New approaches from bioinformatics attack a pressing problem. *Bioscience* 51: 363-371.

Pheloung P. C., Williams P. A. & Halloy S. R. 1999. A weed risk assessment model for use as a biosecurity tool evaluating plant introductions. *Journal of Environmental Management* 57: 239-251.

Phillips S. J., Anderson R. P. & Schapire R. E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modeling* 190: 231-259.

Pickart A. J. & Sawyer J. O. 1998. *Ecology and Restoration of Northern California Coastal Dunes*. California Native Plant Society, Sacramento, CA.

Pimentel D., Lach L., Zuniga R. & Morrison D. 2000. Environmental and economic costs of nonindigenous species in the United States. *Bioscience* 50: 53-65.

Pimentel D., Zuniga R. & Morrison D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52: 273-288.

Polley H. W., Johnson H. B. & Tischler C. R. 2003. Woody invasion of grasslands: evidence that CO2 enrichment indirectly promotes establishment of *Prosopis glandulosa*. *Plant Ecology* 164: 85-94.

Pysek P. & Richardson D. M. 2006. The biogeography of naturalization in alien plants. *Journal of Biogeography* 33: 2040-2050.

Pysek P., Richardson D. M. & Jarosik V. 2006. Who cites who in the invasion zoo: insights from an analysis of the most highly cited papers in invasion ecology. *Preslia (Prague)* 78: 437-468.

Radosevich S. R., Holt J. S. & Ghersa C. M. 2007. *Ecology of Weeds and Invasive Plants: Relationship to Agriculture and Natural Resource Management.* John Wiley and Sons, Hoboken, NJ.

Randall J. M. 2008. Learning to live with invasives we cannot control. *In*: Cal-IPC 2008 Symposium (ed. Cal-IPC).

Raven P. H. & Yeates D. K. 2007. Australian biodiversity: Threats for the present, opportunities for the future. *Australian Journal of Entomology* 46: 177-187.

Reichard S. 1997. Prevention of invasive plant introductions on national and local levels. *In: Assessment and Management of Plant Invasions* (eds. J. O. Luken & J. W. Theiret) pp. 215-227. Springer-Verlag, New York.

Reichard S. & White P. 2001. Horticulture as a pathway of invasive plant introductions in the United States. *Bioscience* 51: 103-113.

Reichard S. H. 2004. Conflicting values and common goals: Codes of conduct to reduce the threat of invasive species. *Weed Technology* 18: 1503-1507.

Rejmanek M. & Pitcairn M. J. 2002. When is eradication of exotic pest plants a realistic goal? *In*: *Turning the Tide: The Eradication of Invasive Species* (eds. C. R. Veitch & M. N. Clout) pp. 249-253. IUCN SSC Invasive Species Specialist Group, Cambridge, UK.

Rejmanek M., Richardson D. M., Higgins S. I., Pitcairn M. J. & Grotkopp E. 2005a. Ecology of invasive plants: State of the art. *In: Invasive Alien Species: A New Synthesis* (ed. H. A. Mooney) pp. 104-161. Island Press, Washington, D.C.

Rejmanek M., Richardson D. M. & Pysek P. 2005b. Plant invasions and invasibility of plant communities. *In: Plant Ecology* (ed. E. van der Maarel) pp. 332-354. Blackwell.

Rejmanek M., Thomsen C. D. & Peters I. D. 1991. Invasive vascular plants of California. *In: Biogeography of Mediterranean Invasions* (eds. R. H. Groves & F. Di Castri) pp. 81-101. Cambridge University Press.

Rice K. J. & Mack R. N. 1991a. Ecological genetics of *Bromus tectorum* I. A hierarchical analysis of phenotypic variation. *Oecologia* 88: 77-83.

Rice K. J. & Mack R. N. 1991b. Ecological genetics of *Bromus tectorum* II. Intraspecific variation in phenotypic plasticity. *Oecologia* 88: 84-90.

Rice K. J. & Mack R. N. 1991c. Ecological genetics of *Bromus tectorum*. III. The demography of reciprocally sown populations. *Oecologia* 88: 91-101.

Richardson D. M. 2004. Plant invasion ecology -- dispatches from the front line. *Diversity and Distributions* 10: 315-319.

Richardson D. M. & Kluge R. L. 2008. Seed banks of invasive Australian Acacia species in South Africa: Role in invasiveness and options for management. *Perspectives in Plant Ecology, Evolution and Systematics* 10: 161-177.

Richardson D. M., Pysek P., Rejmanek M., Barbour M. G., Panetta F. D. & West C. J. 2000. Naturalization and invasion of alien plants: concepts and definitions. *Diversity and Distributions* 6: 93-107.

Robbins P. 2004a. Comparing invasive networks: cultural and political biographies of invasive species. *In*: *The Geographical Review* pp. 139(118).

Robbins P. 2004b. Culture and politics of invasive species. *The Geographical Review* 94: iii-v.

Robbins W. W., Bellue M. K. & Ball W. S. 1951. *Weeds of California*. State of California Printing Division, Document Section, Sacramento, CA.

Roche B. F., Jr., Roche C. T. & Chapman R. C. 1994. Impacts of grassland habitat on yellow starthistle (*Centaurea solstitialis* L.) invasion. *Northwest Science* 68: 86-96.

Rogers C. E. & McCarty J. P. 2000. Climate change and ecosystems of the Mid-Atlantic region. *Climate Research* 14: 235-244.

Sanchez-Flores E. 2007. GARP modeling of natural and human factors affecting the potential distribution of the invasives *Schismus arabicus* and *Brassica tournefortii* in 'El Pinacate y Gran Desierto de Altar' Biosphere Reserve. *Ecological Modelling* 204: 457-474.

Saphores J.-D. M. & Shogren J. F. 2005. Managing exotic pests under uncertainty: optimal control actions and bioeconomic investigations. *Ecological Economics* 52: 327-339.

Schroeder H. W. 2000. The restoration experience: volunteers' motives, values and concepts of nature. *In: Restoring Nature: Perspectives from the Social sciences* *and Humanities* (eds. P. H. Gobster & R. B. Hull) pp. 247-264. Island Press, Washington, D.C.

Seastedt T. R., Hobbs R. J. & Suding K. N. 2008. Management of novel ecosystems: Are novel approaches required? *Frontiers in Ecology and the Environment* 6:547-553

Sheppard A. W., Hill R., DeClerck-Floate R. A., McCIay A., Olckers T., Quimby Jr. P. C. & Zimmermann H. G. 2003. A global review of risk-benefit-cost analysis for the introduction of classical biological control agents against weeds: a crisis in the making? *Biocontrol News and Information* 24: 91N-108N.

Sheppard A. W., van Klinken R. D. & Heard T. A. 2005. Scientific advances in the analysis of direct risks of weed biological control agents to nontarget plants. *Biological Control* 35: 215-226.

Shogren J. F. & Tschirhart J. 2005. Integrating ecology and economics to address bioinvasions. *Ecological Economics* 52: 267-271.

Simberloff D. 2003. Confronting introduced species: a form of xenophobia? *Biological Invasions* 5: 179-192.

Skurka Darin G. M. 2008. Prioritizing weed populations for eradication at a regional level. Masters Thesis. University of California, Davis, Plant Science Department.

Smith S. D., Huxman T. E., Zitzer S. F., Charlet T. N., Housman D. C., Coleman J. S., Fenstermaker L. K., Seemann J. R. & Nowak R. S. 2000. Elevated CO2 increases productivity and invasive species success in an arid ecosystem. *Nature* 408: 79-82.

Standish R. J. 2002. Experimenting with methods to control *Tradescantia fluminensis*, an invasive weed of native forest remnants in New Zealand. *New Zealand Journal of Ecology* 26: 161-170.

Standish R. J., Robertson A. W. & Williams P. A. 2001. The impact of an invasive weed *Tradescantia fluminensis* on native forest regeneration. *Journal of Applied Ecology* 38: 1253-1263.

Stocklmayer S., Gore M. & Bryant C. 2005. Science communication for scientists: reshaping a culture. *In: Social learning in environmental management towards a sustainable future* (eds. M. Keen, V. A. Brown & R. Dyball) pp. 3-21. Earthscan, Sterling, VA.

Stohlgren T. J., Otsuki Y., Villa C. A., Lee M. & Belnap J. 2001. Patterns of plant invasions: a case example in native species hotspots and rare habitats. *Biological Invasions* V3: 37-50.

Strain B. R. & Smith S. D. 1985. Response of Great-Basin plants to atmospheric CO_2 enrichment. *American Journal of Botany* 72: 866-866.

Strauss S. Y., Webb C. O. & Salamin N. 2006. Exotic taxa less related to native species are more invasive. *Proceedings of the National Academy of Sciences of the United States of America* 103: 5841-5845.

Strayer D. L., Eviner V. T., Jeschke J. M. & Pace M. L. 2006. Understanding the long-term effects of species invasions. *Trends in Ecology & Evolution* 21: 645-651.

Suding K. N. & Gross K. L. 2004. Modifying the positive correlation between native and exotic species richness: The influence of fire and seed addition. Ecological Society of America Annual Meeting Abstracts 89.

Sutherst R. W. 2003. Prediction of species geographical ranges. *Journal of Biogeography* 30: 805-816.

Sutherst R. W., Maywald G. F., Yonow T. & Stevens P. M. 1999. CLIMEX Program. Predicting the effects of climate on plants and animals. CISRO Publishing, Collingwood, Victoria.

Theoharides K. A. & Dukes J. S. 2007. Plant invasion across space and time: Factors affecting nonindigenous species success during four stages of invasion. *New Phytologist* 176: 256-273.

Trombulak S. C. & Frissell C. A. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14: 18-30.

Trowbridge W. B. 2007. The role of stochasticity and priority effects in floodplain restoration. *Ecological Applications* 17: 1312-1324.

Underwood E. C., Klinger R. & Moore P. E. 2004. Predicting patterns of non-native plant invasions in Yosemite National Park, California, USA. *Diversity & Distributions* 10: 447-459.

Vining J., Tyler E. & Byoung-Suk K. 2000. Public values, opinions, and emotions in restoration controversies. *In: Restoring Nature: Perspectives from the Social Sciences and Humanities* (eds. P. H. Gobster & R. B. Hull) pp. i-321. Island Press.

Vitousek P. M., D'Antonio C. M., Loope L. L., Rejmanek M. & Westbrooks R. 1997. Introduced species: a significant component of human-caused global change. *New Zealand Journal of Ecology* 21: 1-16.

Walkerden G. (2005) Felt knowing: a foundation for local government practice. *In: Social Learning in Environmental Management Towards a Sustainable Future* (eds. M. Keen, V. A. Brown & R. Dyball) pp. 170-187. Earthscan, Sterling, VA.

Walther G. R., Post E., Convey P., Menzel A., Parmesan C., Beebee T. J. C., Fromentin J. M., Hoegh-Guldberg O. & Bairlein F. 2002. Ecological responses to recent climate change. *Nature* 416: 389-395.

Weiss S. B. 1999. Cars, cows, and checkerspot butterflies: nitrogen deposition and management of nutrient-poor grasslands for a threatened species. *Conservation Biology* 13: 1746-1786.

Weiss S. B. 2006. Impacts of nitrogen deposition on California ecosystems and biodiversity. California Energy Commission, PIER Energy-Related Environmental Research. CEC-500-2005-165.

Westbrooks R. G. & Eplee R. E. 1996. Regulatory exclusion of harmful non-indigenous plant from the United States by USDA APHIS PPQ. *Castanea* 61: 305-312.

Whitson T. D., Burrill L. C., Dewey S. A., Cudney D. W., Nelson B. E., Lee R. D. & Parker R. 1992. *Weeds of the West*. Western Society of Weed Science, Jackson, WY.

Williams S. L. & Grosholz E. D. 2008. The invasive species challenge in estuarine and coastal environments: Marrying management and science. *Estuaries and Coasts* 31: 3-20.

Williamson J. & Harrison S. 2002. Biotic and abiotic limits to the spread of exotic revegetation species. *Ecological Applications* 12: 40-51.

Williamson M. 1989. Mathematical models of invasion. *In: Biological Invasions: A Global Perspective* (eds. J. A. Drake, H. A. Mooney, F. D. Di Castri, R. H. Groves, E. L. Kruger, M. Rejmanek & M. Williamson) pp. 329-350. Wiley and Sons, New York.

Wilson J. R. U., Richardson D. M., Rouget M., Proches S., Amis M. A., Henderson L. & Thuiller W. 2007. Residence time and potential range: crucial considerations in modeling plant invasions. *Diversity and Distributions* 13: 11-22.

Worner S. P. 1988. Ecoclimatic assessment of potential establishment of exotic pests. *Journal of Economic Entomology* 81: 973-983.

Young T. P., Petersen D. A. & Clary J. J. 2005. The ecology of restoration: historical links, emerging issues and unexplored realms. *Ecology Letters* 8: 662-673.

Zavaleta E. S. 2000. Valuing ecosystem services lost to *Tamarix* invasion in the United States. *In: Invasive Species in a Changing World* (eds. H. A. Mooney & R. J. Hobbs) pp. 262-299. Island Press, Covelo, CA.

Zavaleta E. S., Hobbs R. J. & Mooney H. A. 2001. Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology & Evolution* 16: 454-459.