What Managers Want From Invasive Species Research Versus What They Get

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Abstract
We compared the published research on exotic invasive plants with research needs identified by practitioners who manage wildland invasions in California. We filtered the 2007–2011 contents of 20 journals to find 347 relevant articles, then classified them in four areas: topical relevance, spatial/temporal scale, management usefulness, and accessibility and timeliness. We found basic research to be heavily overrepresented compared to applied research, but authors of basic research papers typically gave at least some consideration to management implications of the work. The taxonomic coverage of the database was uneven, with four invaders accounting for nearly half the published work, and several high-priority species being absent. Small temporal and spatial scales, lack of information on management costs, and a long lag time before publication also hinder the usefulness of invasions research to managers. However, articles were widely available for free download, suggesting that access to research should not be among managers’ concerns.

Keywords
Actionable science; applied; conservation; knowing-doing gap; research-implementation gap; review; restoration; stakeholder; survey; usable science.

Introduction
There are plenty of purely ecological reasons to study invasive species. Biological invasions shed light on large-scale ecological and evolutionary processes that are difficult to manipulate experimentally (Sax et al. 2007). Much of our current understanding of phenomena such as speciation (Levin 2003), community assembly (Shea & Chesson 2002), and impacts of species on ecosystem processes (Vitousek 1990) has come from exploiting the inadvertent experiments brought about by the spread of exotic species.

However, underlying many research efforts in the field of invasion biology is the assumption that the scientific insights they yield will be useful to controlling or eradicating problematic invaders. This is not necessarily true. In many conservation fields, scientific research does not always translate into on-the-ground conservation action, a phenomenon known as the knowing-doing gap (Cabin et al. 2010; Esler et al. 2010; Bayliss et al. 2012). The knowing-doing gap has been attributed to a wide variety of factors (Shanley & López 2009; Sunderland et al. 2009; Cook et al. 2013), but generally, it may result from shortcomings in the research itself, or flaws in the way research is used by its intended audience.

To understand the first possibility, we analyzed scientific articles of potential relevance to managing plant invasions in California that appeared from 2007 to 2011. We then compared our results to a 2012 survey of California managers that asked them about their scientific needs and their use of research (Matzek et al. 2014). That survey documented the existence of a local knowing-doing gap, as respondents relied little on published research in making management decisions. Managers in the survey believed that their priorities were not well represented in invasion biologists’ research agendas; but they primarily blamed lack of time and library access, rather than lack of relevance, for the minimal contribution of peer-reviewed science to their work.

In the present article, we use two findings from the 2012 survey as a basis for comparison with our literature database. First, respondents identified a set of priorities for basic and applied biophysical research on plant
invasions, as well as on interdisciplinary social science topics. Second, the survey revealed areas of managers’ discontent with invasions research, including: research performed at scales too small for management relevance; unfeasibly costly treatments; a focus on well-studied invaders to the exclusion of others; and barriers to timely access to findings.

Accordingly, we asked these questions in analyzing our California-focused database of invasive plant literature:

- How relevant to managers are the topics studied?
- At what spatial and temporal scales does invasive plant research occur?
- How usable are the findings to managers?
- How timely and accessible are the results?

Methods

To create the bibliographic database, we searched for relevant articles in 20 journals, previously identified (Matzek et al. 2014) as having published the most articles on invasive and weedy plants during the period 2007–2011, based on keyword searches in Web of Science (for details of methods, see Supplementary Information). To identify relevant articles for this study, we searched the journal contents for articles on invasive plants, read their abstracts, and then selected any articles with relevance to California managers, as indicated by California field sites, institutional affiliations, or high-impact invaders. The full text of each of the 347 selected articles was then read by at least two of the authors of this article, and classified according to the variables in Table 1. Besides content, we also evaluated papers for their time to publication and accessibility online. Results from the literature database were then compared to the findings of the 2012 managers’ survey conducted earlier (Matzek et al. 2014). Response frequencies were compared between the literature database and the survey using chi-square tests, and the mean lag time of publication analyzed with ANOVA.

Results

Our findings follow four main lines of inquiry: 1) topical relevance, i.e., the matchup between the literature and the stated preferences of California managers with respect to the balance between basic and applied science, specific topics studied, and the breadth of taxonomic coverage; 2) appropriateness of scale, i.e., the spatial and areal extent of experimental studies; 3) usability, i.e., the frequency of researchers’ attempts to make management recommendations in basic science papers, or address budget considerations in applied papers; and 4) accessibility and timeliness, i.e., the rapidity of publication and the online availability of the eventual results.

Topical relevance

The percentage of articles classed as basic, applied, and interdisciplinary research was 70.3%, 27.4%, and 2.3%, respectively. This represented a proportion of basic research more than twice as high as that desired by managers who responded to an open-ended survey question about their research needs in the 2012 survey reported in Matzek et al. (2014), i.e., 30.1% basic, 48.1% applied, and 21.7% interdisciplinary. The result is statistically significant (overall $\chi^2 = 129.70$, df = 2, $P < 0.0001$).

In the basic research category, most categories of topics were underrepresented compared to manager needs (Figure 1), but a few were overrepresented, including plant–soil interactions and questions of invasibility or invasion resistance (overall $\chi^2 = 43.29$, df = 8, $P < 0.0001$). There was also a substantial “other” category that represented topics addressed in the literature but not identified by managers, consisting largely of papers about impacts of native species on invaders (e.g., herbivores and pollinators), or articles about invader genetics.

Mismatches in the applied research category (Figure 2) included the overrepresentation of papers about biological control and of papers about treatments involving resource manipulation, including fire, grazing, irrigation, and nutrient addition or subtraction (overall $\chi^2 = 21.35$, df = 6, $P < 0.01$). Here, the “other” category was more diverse and no distinct trends were noted.

The taxonomic distribution in the literature database was highly concentrated around a few species, with nearly half of the papers that treat a particular species (44%) devoted to just four invaders: cheatgrass (Bromus tectorum), 15%; spotted knapweed (Centaurea maculosa/stoebe), 11%; yellow starthistle (Centaurea solstitialis), 10%; saltcedar (Tamarix spp.), 8%. When the 2012 survey asked managers to identify their singlemost problematic or troublesome invader, the results were: cheatgrass (1%), spotted knapweed 2%, saltcedar 4%, and yellow starthistle 15%. The invasive grass Arundo donax was mentioned 15% of the time by managers but only appeared in the database 2% of the time. Five of the 41 highest-impact invaders in California wildlands (Cal-IPC 2006) were not represented in the database at all, though their names were used as search terms. Additionally, 19 invaders mentioned by managers as their most troublesome plant did not turn up in our database, and eight of these did not appear in any invasive species study cited in Web of Science during the study period; conversely, only one invasive species occurring in California appeared in the literature database but not on the managers’ or Cal-IPC’s list of priorities (see Supplementary Information).
**Table 1  Categories for classification of literature variables**

| Category                          | Criteria for classification |
|----------------------------------|----------------------------|
| California relevance             | Species = includes a high-impact CA invader |
|                                  | Field site = research performed at CA field site |
|                                  | Institutional = author affiliated with CA institution |
| Approach                          | Field experiment (observational) |
|                                  | Field experiment (manipulative) |
|                                  | Greenhouse/lab experiment |
|                                  | Meta-analysis or review |
|                                  | Theory |
|                                  | Opinion |
| Area (Data papers only)          | Pots/Greenhouse/Lab |
|                                  | Single habitat, single site* |
|                                  | Single habitat, multiple sites* |
|                                  | Multiple habitats |
| Time (Dated observations only)   | 1, 2–3, 4–5, >5 years |
| Primary emphasis                 | Basic = aimed at understanding invasion phenomena |
|                                  | Applied = aimed at solving practical invasion problem |
|                                  | Interdisciplinary = encompasses social and policy issues |
| Specific emphasis (basic)        | Seedbank duration/longevity |
|                                  | Impacts of invaders on native species |
|                                  | Soil interactions that promote/depress invaders |
|                                  | Range and distribution of invasive species |
|                                  | Response of invaders to global change |
|                                  | Succession after invasion or after restoration |
|                                  | Invasibility/Invasion resistance |
|                                  | Dispersal mechanisms and potential for spread |
|                                  | General life history of invaders |
|                                  | Other |
| Specific emphasis (applied)      | Herbicide effectiveness |
|                                  | Biological control/integrated pest management |
|                                  | Effectiveness of resource manipulation (water, fire, and nutrients) |
|                                  | Negative impacts of management efforts |
|                                  | Early detection tools |
|                                  | Timing of treatments |
|                                  | Feasibility of abandoning or forgoing management |
|                                  | Other |
| Specific emphasis (interdisciplinary) | Outreach/education to public |
|                                  | Funding |
|                                  | Policies to prevent invader spread/introduction |
|                                  | Tools for communication and coordination |
|                                  | Regulatory constraints |
|                                  | Other |
| Usability (basic science papers) | Explicit = specific measures based on results in this paper |
|                                  | Mentioned = notes that similar work can influence management |
|                                  | No mention = management implications unmentioned |
| Usability (applied science papers)| Detailed costs = cost of treatment given in dollars or hours |
|                                  | Relative costs = general cost comparison to alternatives |
|                                  | No mention = costs of treatment unmentioned |

**Appropriate scales**

We characterized the spatial extent of all experimental studies, on the assumption that experiments conducted under realistic field conditions, in a wider variety of habitats, provided more useful data to managers. About 60% of the papers concerned only a single vegetation type, and most of these were sampled at only one site (Figure 3A). Multihabitat papers constituted 17% of the database, and about 22% of the experimental work took place in the greenhouse or lab.
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Figure 1 Mismatch between researcher and stakeholder priorities for specific topics in basic research. Bars to the left of the midline show the underrepresentation of topics in the literature compared to what managers want. “Other” refers to all basic research topics in the literature that did not fall into manager-identified priority categories. Sample sizes are $N = 122$ for manager-identified priorities and $N = 243$ for basic research papers.

Figure 2 Mismatch between researcher and stakeholder priorities for specific topics in applied research. Bars to the left of the midline show the underrepresentation of topics in the literature compared to what managers want. “Other” refers to all applied research topics in the literature that did not fall into manager-identified priority categories. Sample sizes are $N = 195$ for manager-identified priorities and $N = 94$ for basic research papers.

The temporal extent of experimental studies was characterized in any paper that mentioned dated observations. Figure 3(B) shows a declining frequency of papers as the time frame increases, with nearly half (45%) the dated studies involving a year or less of data, and another third (34%) lasting 2 or 3 years, the typical span of Ph.D. fieldwork.

Usability

We defined usability differently for basic and applied research (Table 1), on the assumption that the management implications of applied papers would be implicit, but would need to be made explicit for basic papers (but see Simonetti 2011). Among the basic research papers (Figure 4A), more than half mentioned management implications, including more than a third (36.5%) that made specific recommendations for practitioners. Conversely, the applied papers (Figure 4B) failed to meet the other measure of usefulness, with only 2% of papers giving detailed cost estimates, 15% making relative cost comparisons, and the remainder making no mention of costs at all.

Accessibility and timeliness

The lag time between the end of fieldwork and the publication of the final research results was estimated at 3.7±0.1 years. There was no significant difference ($F = 1.178$, df = 3,253, $P = 0.319$) in publication lag time among the different experimental time frames (≤1 year, 2–3 years, 4–5 year, or >5 years). Papers were very accessible through Google Scholar (Figure 5), with 63% available in some form online without cost, and the remaining 37% behind a paywall.

Discussion

Our previous study of the knowing-doing gap in invasion biology (Matzek et al. 2014) addressed the issue from the managers’ side: Are managers reading the literature? Do they have the expertise to understand it? Are they relaying information to other practitioners? Here, we address the issue from the researchers’ side: Are researchers doing the right kinds of research? Are they working at appropriate scales? Do they place their results in a usable context? Do they make their findings rapidly accessible to managers?

Generally, we found wide gaps between California managers’ priorities for research and what is actually published, and we further revealed that published studies frequently fail tests of relevance, as indicated by scale-appropriateness, usability, timeliness, and accessibility. Our study adds weight to criticisms that researchers are not doing enough to advance effective conservation and natural resource management (Cabin et al. 2010; McKinley et al. 2012; Cook et al. 2013). A common theme in such critiques is that managers need more applied science, but researchers are more rewarded for publishing basic research (Esler et al. 2010; Bayliss et al. 2012; Cook et al. 2013). Previous investigation of the invasions literature has shown that applied and management topics receive fewer citations than basic topics (Pysek et al. 2006; Esler et al. 2010), which may deter researchers from applied research.

So, how large looms the divide between basic and applied research in our study? Although basic research was more heavily represented than managers would prefer,
a few caveats are notable. First, managers expressed a desire for interdisciplinary (social science) research topics that were unlikely to show up in our database of ecologically focused journals, so both basic and applied research were bound to appear more frequently in the database than in the managers’ survey. Second, 12 of our journals emphasize basic biological sciences, not management or conservation per se. Journals excluded from the database because they are smaller or less frequent (and therefore publish fewer invasions papers overall) may be a source of applied invasions research that we are not tapping. Third, scientists are fairly conscientious about making explicit management recommendations from basic research findings, doing so at approximately the same rate as in papers that deal directly with alien plant impacts in protected areas (Hulme et al. 2013b). Finally, managers clearly articulate the value of basic research to their work (Matzek et al. 2014), especially management responses to global change and assessing the risk of invasive species spread.

Scientists have other goals for their research besides serving managers’ needs, and it is unreasonable to expect that research topics in the literature should match up exactly with managers’ priorities. However, the mismatch analyses are useful to indicate general trends. One conclusion we draw is that managers lack basic life
history and ecological information on many invaders. These data are crucial to evaluating which invaders are the best candidates for eradication and which ones may be suitable only for containment. A trend emerging from the applied topics analysis is that practitioners are uneasy about some management techniques—e.g., they are mistimed, have negative consequences, or are not effective. Research aimed at testing alternative treatments, or exploring if negative consequences of existing management treatments merit concern, would be helpful.

The over- and underrepresentation of species is a more troubling finding. Certainly, some invaders merit more attention because of their wider distribution or heavier economic impacts, but the phenomenon may also result from “bet-hedging” by scientists who prefer to work on well-known species (Hulme et al. 2013a). It is possible that the taxonomic imbalance is due to our having considered the literature published just prior to the 2012 survey, as there may be a lag between when managers become concerned about an invader and when researchers can get funding to study it. Another possible artifact was the importance placed on California’s 41 most-impactful wildland invaders in keyword searches. For instance, cheatgrass has high impacts, but its spatial extent in California is small, so most of our managers never encounter it. We also considered that including papers whose only California relevance was an affiliation with a California institution drove the database’s taxonomic bias toward species that are less important to our managers. However, when we reanalyzed the species distribution with those papers (14% of the database) removed, the effect was negligible. A similar taxonomic bias in the study of invasions has been noted in the literature previously (Pysek et al. 2008; Kettenring & Reinhart Adams 2011; Hulme et al. 2013a). This bias affects not just managers who need research information on neglected invaders, but also hinders the development of a synthesis in invasion ecology (Pysek et al. 2008).

The spatial scope of research in our database was generally low, an issue of longstanding concern in ecology (Kareiva & Andersen 1988). In manipulative experiments, small scales are common (and understandable) because they permit greater control over experimental variables and decrease costs. A drawback is that such approaches may not be conducted under realistic field conditions, and may not be scalable to management of whole landscapes (Wagner et al. 2008). Restoration projects tend to occur at ecosystem and landscape scales (Aronson et al. 2010). However, in the invasion literature, attempts to eliminate or control the spread of plant invaders are generally applied at scales smaller than 30 m², and sampled for effects at <1 m² plot sizes (Kettenring & Reinhart Adams 2011).

Likewise, short time scales are a bugbear of ecological research. Reviewing literature from 1977 to 1987, Tilman & Likens (1989) found that 86% of field studies lasted 3 years or less, and 40% lasted only one season. That our results two decades later closely mirror these percentages suggests that the short duration of field experiments is due to structural features of academic science—namely, the 3–7 year duration of most grant awards, Ph.D. theses, and tenure clocks—and may resist researchers’ best intentions.

Lack of reporting of costs is a major obstacle to making research on control methods useful to managers. Costs are rarely mentioned in the ecological restoration literature (Holl & Howarth 2000; Robbins & Daniels 2012). Two publications that estimate the cost of invasive species’ presence in the United States come up blank in the category of “costs of control” for many invaders, and where costs are estimated, they may range over several orders of magnitude (Pimentel et al. 2000, 2005). There are certainly reasons why research costs may not accurately reflect management costs, especially at small experimental scales, but an estimate of the capital costs and person-hours required to perform a treatment, combined with data on the treatment’s effectiveness, is a minimum requirement for a truly useful paper on invasive species control.

We found managers’ complaints about inaccessible research (Pullin & Knight 2005) to be unfounded, as nearly 2/3 of the articles could be freely downloaded. However, articles were slow to appear. Some of the blame for the glacial pace of research dissemination has been laid at the
feet of slow-moving journals (Kareiva et al. 2002) and the rest at the feet of slow-moving authors (O’Donnell et al. 2010). Here, it would seem that both researchers and managers would want research to be published as swiftly as possible. We expect improvement in this area as more journals offer open-access and more funding agencies require open-access publishing as a grantee condition.

We aimed our study at one geographical region in order to do a fine-grained analysis of specific mismatches between managers’ needs and scientists’ efforts, possibly limiting the generalizability of the results. However, California has both an exceptionally biodiverse pool of native plants and invaders (4,200 native, 1,800 exotic), and an exceptionally diverse assemblage of land managers, ranging from tribal governments to state agencies to private organizations. We think this renders the results applicable outside the state.

What ways forward can we suggest as a result of our findings? Rather than propose solutions that would require wholesale changes to the academic reward system, or a shift toward applied research by funding agencies whose current emphasis is basic research, we focus here on specific actions available to any individual researcher.

One is to consult with stakeholders when formulating research questions. There is a wide literature documenting formats for priority-setting and consensus-based decision-making (Reyers et al. 2010; Shaw et al. 2010; Liu et al., 2011), in which researchers both provide information and get input on future research needs. Incorporating stakeholder needs from the outset can prevent undesirable outcomes (Gonzalo-Turpin et al. 2008).

Another concrete step is to reach out to boundary organizations, which help join science to decision-making. Boundary organizations exist in many environmental spheres; for invasive plants, several U.S. states, including California, have exotic pest plant councils that fulfill this role.

To expand the scale of research, scientists should seek out managers inclined toward experimentation. Though resource managers often lack funding for formal research and monitoring, many embrace an “adaptive management” approach reliant on data-gathering (DeSimone 2013), and they frequently tackle applied problems at large scales for long periods. With a minimal investment of additional effort, scientists may help managers convert their existing practices into experiments with appropriate controls.

Finally, academic researchers should consider assigning students at the undergraduate or master’s level to research that lacks the novelty or theoretical basis required of a Ph.D. project, but is useful to managers. This work could be funded through supplementary awards or internal funding aimed at engaging undergraduates in independent research.

Acknowledgments

Paige Vannelli assisted with the article database. Comments from the editor and five anonymous reviewers greatly improved the final manuscript.

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