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Comments

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Closing the Knowing–Doing Gap in Invasive Plant Management: Accessibility and Interdisciplinarity of Scientific Research

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Ecosystem management; interdisciplinary; invasive species; managers; practitioners; research–implementation gap; restoration.

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Abstract

Like many conservation disciplines, invasion biology may suffer from a knowing–doing gap, where scientific research fails to inform management actions. We surveyed California resource managers to evaluate engagement with scientific research and to identify research priorities. We examined managers' access to information, judgment of the usefulness of existing research, ability to generate scientific information, and priorities for future research. We found that practitioners rely on their own experience, and largely do not read the peer-reviewed literature, which they regard as only moderately useful. Less than half of managers who do research carry out experiments conforming to the norms of hypothesis testing, and their results are not broadly disseminated. Managers' research needs are not restricted to applied science, or even basic ecology, but include social science questions. Scientists studying invasions can make their research more useful by crossing disciplinary boundaries, sourcing research questions from practitioners, and reporting results in accessible venues.

Introduction

Invasion biology is a field in which it is reasonable to expect that advances in knowledge will help solve an environmental problem. However, in some conservation-related disciplines, there is a gap between research and practice, so that scientific information accumulates, but is not incorporated into management actions. This “knowing–doing gap,” sometimes called a “research–implementation gap” (Knight *et al.* 2008), has been identified in a number of conservation-related fields, including invasion biology (Hulme 2003; Higgs 2005; Sunderland *et al.* 2009; Cook *et al.* 2010; Esler *et al.* 2010), and its perception dates back to the founding of conservation biology (Soulé 1986).

When a knowing–doing gap exists, it might be blamed on either the knowers or the doers—that is, scientists might be producing research that is inapplicable to management, or managers might be unable or unwilling to incorporate new research into practice. Observers have

proposed a number of reasons for the gap, including a “culture clash” between scientists and managers (Roux *et al.* 2006; Cabin 2007; Gibbons *et al.* 2008); scientists' lack of interdisciplinarity or inability to connect science with societal needs (McNie 2007); poor scientific literacy or insufficient expertise on the part of managers and practitioners (Sunderland *et al.* 2009); lack of stakeholder or practitioner involvement in the design of research agendas (Knight *et al.* 2008; Shaw *et al.* 2010); managers' inability to access scientific literature (Pullin & Knight 2005); an academic system that does not reward scientists' participation in policy or practice (Shanley & López 2009; Arlettaz *et al.* 2010); and mismatches in scale, budget, or approach between research experiments and management efforts (Hulme 2003; D'Antonio *et al.* 2004; Fazey *et al.* 2005; Cabin 2007; Kuebbing *et al.* 2013).

Invasive species are frequently classed among the major drivers of biodiversity loss around the globe (Wilcove *et al.* 1998; Molnar *et al.* 2008; McGeoch *et al.* 2010; Pyšek & Richardson 2010). Meanwhile, the invasion literature

has been growing at a dizzying rate, with several hundred new papers published each year (Lowry *et al.* 2013), and at least four new peer-reviewed journals launched since 2008 (*NeoBiota*, *Management of Biological Invasions*, *Invasive Plant Science and Management*, and *BioInvasions Records*). We wanted to know, do conservation practitioners seeking to control invasive plant species use this burgeoning literature to inform their actions? We focused on four components of managers' engagement with science. First was access to research: where do managers go for scientific information, and why? Second was suitability of research: do managers find the existing literature useful and their priorities represented within it? Third was involvement in research: do managers do their own experiments, and can they rely on their own results to inform their practice? Fourth was research needs: what questions do managers need answered to be more effective at controlling invaders?

We surveyed 207 California-based land managers and conservation practitioners. We focused on California for several reasons. The state is a biodiversity hotspot (Myers *et al.* 2000), with more than 4,200 native plant species and at least 1,800 exotics, of which about 200 are considered to have negative impacts in wildlands (Cal-IPC 2006). More than 42% of California's land area is in public ownership (NRCM 2000), and invasive species on these lands are managed by a diverse suite of federal, state, local, and tribal government agencies and nonprofit organizations. Their work has been supported by a network of cooperative weed management areas, a statewide invasive plant council, and the country's second-largest public university system, with its associated outreach and extension advisers. To survey a broad, varied group of managers tackling a large number of plant invaders in a range of habitats with a wide array of scientific resources at their disposal, we could hardly pick a more suitable study area.

Methods

Survey population

Our survey population was land managers and restoration professionals working in California, whose job involves some decision making about plant invasions (hereafter, "managers"). In consultation with the California Invasive Plant Council (Cal-IPC), we generated a list of 403 organizations in California that manage invasive species, including state and federal agencies, land trusts, research stations, tribal groups, utilities, and restoration contractors. Within those organizations, 1–3 individuals whose job titles suggested decision-making power were contacted as potential survey participants, for a total sur-

vey population of 504 managers. By e-mail, managers were asked to fill out an online survey and were offered a \$US10 gift card at a large online retailer, whether they answered the survey or not. Returned surveys were considered complete if they answered at least 17 questions, including all of the first 11; this criterion eliminated 10 returned surveys. We received 214 surveys that were complete (42%), but of these, 7 had to be eliminated because participants responded that they did no decision making about invasive species management at their workplaces. Of the 207 final validated survey responses, 20% were federal, 11% state, 25% municipal/county, 18% private for-profit, 25% private nonprofit, and 1% tribal. No significant difference was found between this distribution of respondents and the distribution of managers in the contacted database ($\chi^2 = 2.12$, $df = 5$, $P = 0.8323$), indicating no systematic response bias by workplace.

Questionnaire and data analysis

We asked a mix of open-ended and closed-ended questions, including yes/no, Likert scale, check-all-that-apply, and ranked-response options. For our questions on the sources of information preferred by managers, we selected 20 relevant peer-reviewed journals by analyzing which journals had published the most articles on plant invasions from 2007–2011 (see questionnaire in Supporting Information for the list). We also generated a list of potential alternative sources of information used by managers by conducting a pilot study, in which we administered a questionnaire from a booth at the October 2011 Cal-IPC symposium. For open-ended questions on research needs, we classified managers' responses into 25 subcategories by topic area, then further characterized these as basic science, applied science, or interdisciplinary research (see below).

For check-all-that-apply questions, the sequence of response options was randomized to avoid order effects. When answering ranked-response questions, respondents made two decisions: whether or not a variable applied, and where it should rank among others deemed applicable. To analyze these statistically, we numbered respondents' rankings as 1 through N (where 1 is the most important variable and N is the number of options), and assigned a rank of $N + 1$ to any variable that a respondent did not choose as applicable. Rankings for each response type were then distinguished using the Kruskal–Wallis test and the Steel–Dwass post hoc test on all pairs of responses. We used chi-square goodness-of-fit tests to analyze some response patterns according to personal characteristics of the managers, with a post hoc test that compared standardized residuals of the distribution to a Z distribution, using a significance level (α)

Bonferroni-corrected for multiple comparisons (Franke et al. 2012). We analyzed managers' ratings of the 20 most relevant invasive species journals by performing ANOVA on the mean frequencies with which managers placed the journals in one of five categories (never consulted; never relevant; rarely relevant; sometimes relevant; often relevant); differences among the categorical response frequencies were distinguished by Tukey's HSD.

Sample size varies throughout the survey because respondents occasionally skipped questions and some questions were presented to a subset of respondents based on their previous answers. We always report the valid percent, that is, the percentage of responses out of the total answering that question. The full set of survey questions, which includes topic areas not analyzed in this article but intended for other uses, can be found in the Supporting Information.

Results

Managers in our survey were highly educated and experienced. Nearly half (48%) had earned master's or doctoral degrees, and the managers' mean level of experience in the field of invasive plant management was 12.3 ± 0.6 years. Thirty-one percent of those surveyed said they did all of the decision making at their organization with regard to invasive plant management, whereas 69% said they shared decision-making power. The sample leaned slightly toward the public sector, with 57% of the managers employed by local, state, federal, or tribal governments, and 43% at private nonprofit and for-profit organizations.

Managers' access to research

Peer-reviewed journals ranked lowest among sources of information used by managers ($H = 137.7$, $df = 4$, $P < 0.0001$), while "informal conversations with other managers" and "my own experiments or monitoring" were ranked highest. Written material synthesized in books, newsletters, or Web sites were the third-most important source of scientific information for managers, and conference/symposium attendance ranked a distant fourth, but still significantly higher than peer-reviewed literature.

More than one-third of managers (34%) reported that they did not use peer-reviewed journals at all to get scientific information about plant invasions. These managers were statistically more likely (overall $\chi^2 = 41.4$, $df = 3$, $P < 0.0001$) to have bachelor's degrees ($Z = 4.57$, $P < 0.0001$) and less likely to have master's ($Z = -3.75$, $P = 0.0002$) or doctoral degrees ($Z = -2.54$, $P = 0.011$). They also tended to work for local governmental agencies such as water districts (overall $\chi^2 = 21.1$, $df = 5$, $P < 0.001$;

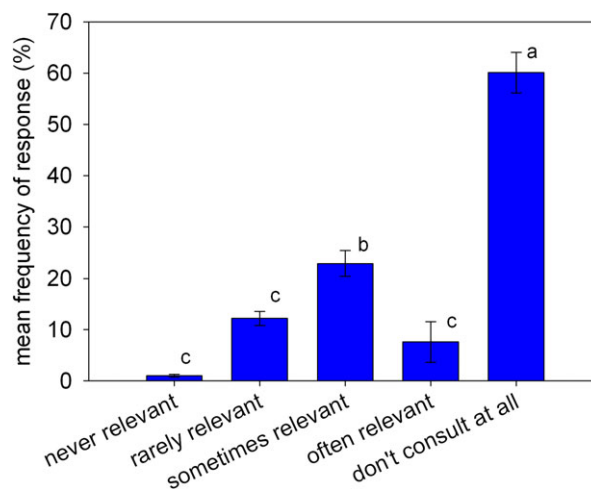


Figure 1 Relevance of peer-reviewed journals as rated by land managers and conservation practitioners who work with plant invasions. Managers individually rated each of 20 journals that publish invasive species research, and one-way ANOVA was used to distinguish the frequency of the categorical responses. Data shown here represent the mean rating for all 20 journals; error bars are ± 1 SE. Percentages do not add up to 100% because sample sizes varied from journal to journal and valid percent was used for the calculations. Different lower-case letters indicate significant differences by Tukey's HSD at $\alpha = 0.05$.

post hoc $Z = 2.75$, $P < 0.003$) rather than federal, state, or private sector agencies. The principal reasons cited for not consulting the invasion literature were "not enough time to search for articles and read them" (66%) and "no library access to those kinds of articles" (50%); only 13% said they did not find them useful or relevant, and a mere 3% said they did not have the scientific expertise necessary to read the literature.

Suitability of research

Managers who said they did use the peer-reviewed literature to guide their decision making (66% of the sample) were then asked to rate the usefulness of the 20 journals that most frequently publish invasive species research, by saying whether they consulted the journal, and if so, whether they "often, sometimes, rarely, or never" found articles relevant to management there. Managers rated individual journals "often relevant" only 7.6% of the time, on average, and "sometimes relevant" only 22.9% of the time. By far the most common response by managers was "I don't consult this journal at all," with the average journal receiving this rating from more than 60% of the managers (Figure 1). The mean response frequencies for "rarely" and "never" finding relevant articles were 12.2% and 1.0%, respectively.

By contrast, written sources that were not peer-reviewed journals were consistently rated as much

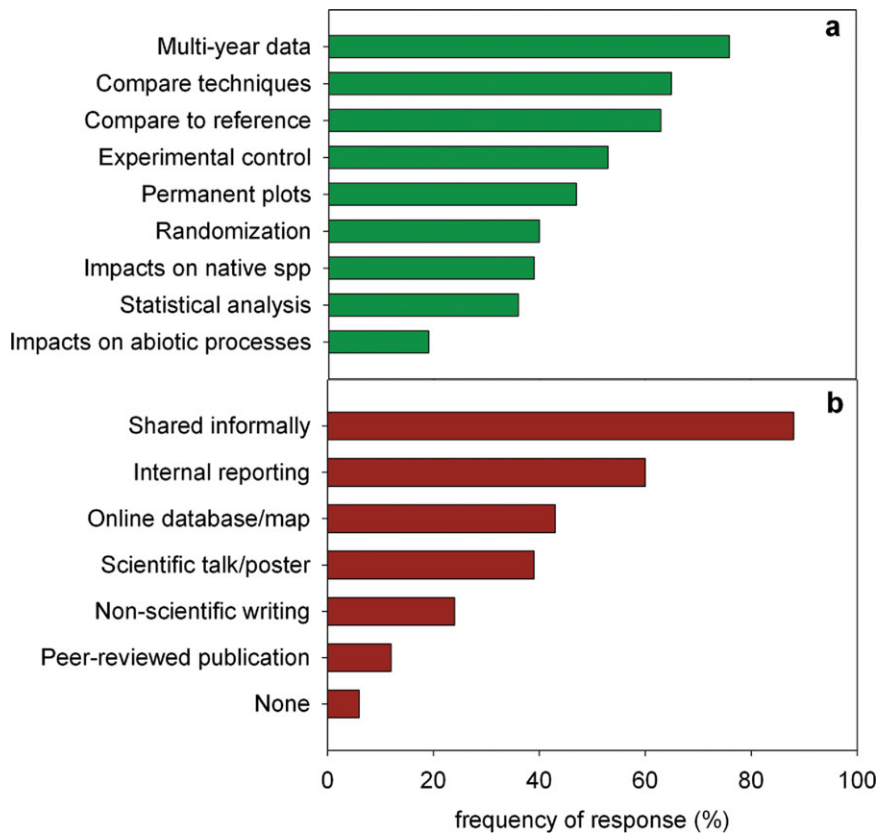


Figure 2 Components of managers' scientific work (a) and method of dissemination of results from managers' experiments and monitoring (b). Managers were asked, "Which of the following have been a component of (your experimental and monitoring) work in the past 5 years?" and "Which of the following have you used to communicate the results from your experiments or monitoring in the past 5 years?" and could check all answers that applied.

more relevant to management. Web sites maintained by university and government agencies as clearinghouses of plant information (e.g., plants.usda.gov, calflora.net) were rated "often relevant" by 52% of managers. Books that synthesize regional invasive plant information were next most useful, rated "often relevant" by 39% of managers, followed by newsletters from conservation and management agencies (28%) and "best management practices" guides (20%).

Managers' involvement in research

The vast majority of managers, 88%, said they used their own experiments or monitoring to guide their decision-making and management practice. We questioned those managers further, asking them to indicate all the categories of research scope and quality that applied to their experiment and monitoring work in the previous 5 years (Figure 2). Most managers collected data for more than one season (76%), compared two or more management techniques to each other (65%),

and compared restored sites to a reference site (63%). However, managers' research efforts less often bore the hallmarks of formal science and hypothesis testing: use of an experimental control (53%), randomization (40%), and statistical analysis (36%).

We also asked managers how they had disseminated the results of their own research in the previous 5-year period. These findings echoed the managers' responses about where they sought information, as most reported sharing data with other managers informally (88%), internally (60%), or via online tools (43%) or symposium talks (39%), while only 12% reported contributing to an article for publication in the peer-reviewed literature (Figure 2).

Manager-identified research needs

Only 24% of managers agreed with the statement that "managers' priorities are well-represented in research agendas." To understand managers' priorities for invasion research, we made this open-ended query: "What

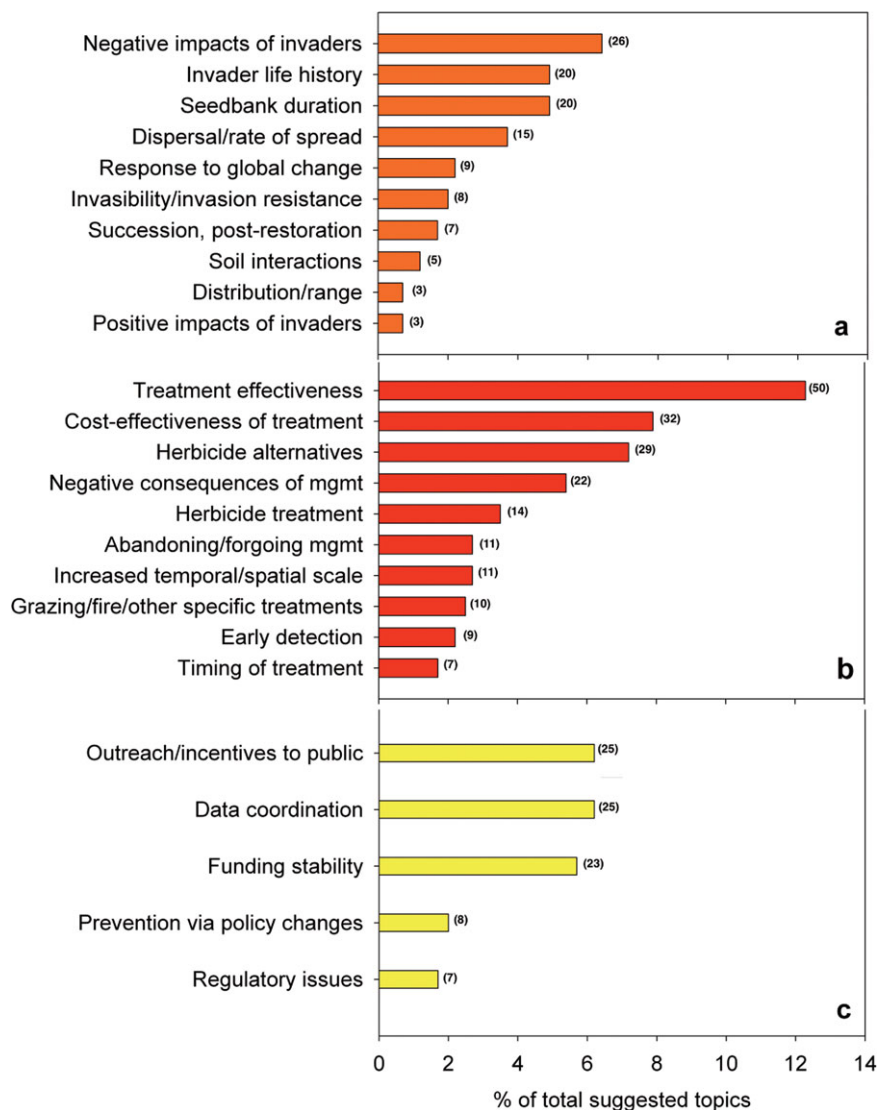


Figure 3 Managers' suggested topics in response to the prompt, "What research questions do you most need answered, in order to be effective at managing plant invasions?" Numbers in parentheses indicate the quantity of individual suggestions made in each category. Open-ended responses were classified after the fact into the categories shown and then divided into (a) basic science, (b) applied science, or (c) interdisciplinary research. Basic, applied, and interdisciplinary topics accounted for 30.1%, 48.1%, and 21.7%, respectively, of the 405 suggested topics.

questions do you most need answered, in order to be effective at managing plant invasions?" Respondents were encouraged to pose any number of scientific questions that they thought researchers should address to generate information useful to management. These responses were then categorized after the fact into topical subcategories (e.g., "invaders' response to global change,") and then further classified as basic or applied science. We defined basic science as research aimed at understanding invasive organisms and their ecology (e.g., studying the longevity of an invader's seedbank) and applied science as research

aimed directly at preventing or reducing invaders' impact in the environment (e.g., testing whether mowing is effective at reducing an invader's seedbank). However, we found that a substantial portion (~22%) of managers' responses defied this easy categorization. Such responses concerned managers' needs for solutions to problems of communication and coordination; conflicting agency mandates; outreach to the public; inconsistent funding; and policymaking. As examples of typical questions in this genre, managers asked, "What are the sociological barriers to cooperation between land managers and

private land owners in conducting invasive species management . . . ?” and “How can (government agencies) control the spread of nonnative invasives through plant nurseries?” We called this category “interdisciplinary research,” and show the breakdown of subcategories of responses into the three categories (Figure 3).

Discussion

Here we document that managers perceive a gap between their need for scientific information to manage plant invasions effectively and the research output of scientists studying invasions. We attribute this partly to managers’ disengagement with scientific research, and partly to the scope and relevance of the research itself.

Our results show that managers rely heavily on their own observations and those of their colleagues at other management agencies, rather than scientific research in the peer-reviewed literature. Similarly, a survey of conservation planners in Australia and the United Kingdom revealed a strong reliance on experience-based information such as expert opinions, rather than evidence-based information derived from experiments or quantitative analysis (Pullin & Knight 2005). River restoration practitioners in the United States cited their own past experience as the most important source of information used in project design, while considerably less than 1% made that claim about the peer-reviewed literature (Bernhardt *et al.* 2007). When our managers seek help from the invasion literature, they prefer research results that have been distilled or summarized for a resource manager readership rather than scientific journals, which they find only moderately relevant. More than a third of managers never read peer-reviewed journals, principally because they do not have library access or sufficient time. Other researchers have also noted that time and library access are strong barriers to conservation practitioners’ engagement with current research (Pullin & Knight 2005; Renz *et al.* 2009; Robison *et al.* 2010). A study of invasive species researchers, practitioners, policymakers, and other stakeholders in Great Britain similarly found a strong reliance on field experience, expert opinion, and synthesized sources of literature such as literature reviews, as well as a preference for information that was freely accessible online (Bayliss *et al.* 2012).

We conclude that invasive species researchers who wish to ensure that managers are seeing their work should seek out new avenues for disseminating their results. Presenting research papers at symposia and workshops attended by managers are an obvious choice for direct communication; more indirectly, scientists could communicate with extension agents, or contribute to a conservation-focused newsletter. Even within the peer-

reviewed literature, the choice of publishing venue may matter to managers’ access: choosing an open-access option, or a journal that requires authors to provide a lay summary for interested nonspecialists, can help broaden a paper’s reach. Another strategy is to convene workshops in which scientists, practitioners, and/or policymakers are expressly asked to exchange information or set priorities together (Gibbons *et al.* 2008; Robison *et al.* 2010; Shaw *et al.* 2010; Liu *et al.* 2011). Any opportunity to cross into each other’s spheres can potentially improve interchanges between researchers and practitioners and understand their sometimes conflicting needs and motivations (Gibbons *et al.* 2008). An advantage of this approach is that, unlike shifts in publishing venue on the part of academic scientists, it addresses managers’ lack of time for reviewing the literature. Committing resources to those agencies that synthesize research studies for management audiences, via newsletter or list-serve, would also help managers more efficiently allocate time for keeping up with the latest research. We therefore see a clear role for third-party management agencies, such as the statewide exotic pest plant councils in the United States, to help close the knowing–doing gap from the management end. Finally, the use of citizen science or participatory research approaches can help bring scientific research closer to its end users (Shanley & López 2009; McKinley *et al.* 2012).

Our results also raise the question of whether the scientific research on plant invasions is relevant to wildland management and restoration. A recent systematic review of the invasion literature found that studies concerning the causes of invasion—a topic of questionable interest to managers who deal with existing invasions—outnumbered studies on the impacts of invaders nearly 2 to 1, while fewer than 10% of the total experimental studies dealt with management issues or invader risk assessment (Lowry *et al.* 2013). Another study found that nearly three-quarters of the South African invasion literature was focused on basic “knowing” research, rather than applied “doing” research, though local conservation professionals preferred a more even balance (60:40) among basic and applied topics (Esler *et al.* 2010). In our survey, about half of the research topics suggested by managers concerned strictly applied topics such as herbicide use, but managers also articulated a strong need for basic invasive species ecology, including species interactions and impacts, life history, and dispersal, all of which would be valuable to assessing risk. This suggests that even those scientists who are most intrigued by how invasions fit into ecological theory can generate information of use to management.

More importantly, managers cannot divorce their research needs from the social and political context in

which they work, and therefore require interdisciplinary research. There have been frequent calls in recent years for the social sciences to be better integrated into ecological restoration and invasive species management, and for restoration and management priorities to include local, social, and economic values, as well as biological values (Thresher & Kuris 2004; Bernhardt *et al.* 2007; Hobbs 2007; Miller & Hobbs 2007; Robison *et al.* 2010; McKinley *et al.* 2012). When South African managers were asked to pose research questions to invasion biologists at a symposium, they spanned a wide variety of disciplines, touching on sociological, political, and regulatory issues in addition to invasive species biology and applied ecology (Shaw *et al.* 2010). However, invasive species researchers and managers in the Midwestern United States gave a relatively low ranking to social/political factors when asked about research needs (Renz *et al.* 2009). The discrepancy between the groups may owe less to national origin and more to the way managers' opinions were elicited; our results for California managers, like those of the South African managers, came from allowing respondents to give free-form answers, rather than ranking specific categories of research.

Finally, we asked the managers who said that research agendas did *not* reflect their needs to volunteer suggestions for improvement (data not shown). The most frequent response was that researchers should focus more on applied science topics, but managers' comments also touched on (1) lack of consultation with managers when field experiments are designed; (2) frustration with proposed experimental treatments that are too expensive or feasible only at small scales; and (3) a perception that researchers are "out of touch" with the realities of management, lending credence to the idea of a culture clash between managers and scientists (Roux *et al.* 2006; Cabin 2007). The good news is that the survey indicates that there is substantial room for researchers of all stripes—from ecological theorists to sociologists—to make a more substantive contribution to management of invasive species. We conclude, as others have (Bernhardt *et al.* 2007; Sutherland *et al.* 2009; Shaw *et al.* 2010), that partnering with managers at the outset of a research effort will yield more useful, interdisciplinary, and collaborative research—through which managers and scientists can cooperate to close the knowing-doing gap.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Survey Questions

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