How broad are our broader impacts? An analysis of the National Science Foundation's Ecosystems Studies Program and the Broader Impacts requirement

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The National Science Foundation (NSF) has tried to narrow the gap between science and society with its Broader Impacts requirement. We analyzed the proposed broader impacts of proposals funded by NSF's Ecosystems Studies Program (ie the activities that provide benefits to society through teaching, broadening participation, enhancing infrastructure, and disseminating research. We obtained all of the abstracts of funded proposals from NSF's website and characterized the scope of the proposed broader impacts activities in 296 proposals (2000–2010). Only 65% of abstracts included a broader impacts statement and, of those, 57 (19%) included just one of the five NSF Broader Impacts criteria. The most frequent criterion addressed was teaching and training (37%), followed by broad dissemination (22%), infrastructure enhancement (18%), benefits to society (13%), and underrepresented groups (11%). Most Principal Investigators who proposed outreach did so for audiences who are very close to academics, and most targeted small (61%) to medium-sized (32%) audiences. Although some progress has been made, much work remains for ecologists to participate more substantially in these activities. Interactions with social scientists may facilitate this work. The NSF must create new mechanisms that will make grantees accountable for broader impacts activities, and develop pathways that provide positive feedback for those ecologists carrying out effective broader impacts activities.

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Although highly supportive of science and technology, nearly 80% of Americans lack knowledge of the scientific process and less than 15% follow science and technology news closely (NSB 2010). Increasing urbanization, greater reliance on virtual rather than actual experiences, and fewer encounters with nature among the younger generations have contributed to a situation where people do not recognize that they are part of nature, rather than being separate from it (Kollmuss and Agyeman 2002; Uriarte *et al.* 2007). These gaps between science and society – and between people and nature – have led to a call from high-level scientists for greater scientist-initiated public engagement (Bell *et al.* 2009; Foote *et al.* 2009). The President's Advisor to Science, John Holdren, urged scientists to allocate10% of their professional time to work "in ways that increase the benefits of science for the human condition" (AAAS Presidential Address, 16 February 2007). The America COMPETES Act (Public Law 110-69, 2007), which authorizes the National Science Foundation (NSF), requires reports of such activities to be submitted to the NSF Director (Holbrook and Frodeman 2007).

These requirements reinforce NSF's long-term goal of involving grantees in broadening the impacts of science beyond academia. On October 1, 1997, the National Science Board introduced two criteria to assess proposals: (1) Intellectual Merit (also referred to as "Criterion 1") and (2) the Broader Impact Criterion (BIC, "Criterion 2"). The BIC was viewed as a means of increasing researcher participation in extending science beyond the scholarly community because it is applied to all grants, and because Principal Investigators (PIs) are attentive to ways that will make their grants more competitive (NSF 2007). The five components of BIC (paraphrased here) are:

- advancing discovery and understanding while promoting teaching, training, and learning;
- broadening participation of underrepresented groups;
- enhancing the infrastructure for research and education;
- disseminating research results broadly to enhance scientific and technological understanding; and
- creating benefits to society.

Initially, many PIs and reviewers ignored the BIC or gave it little attention in their proposals and reviews. Some did embrace the new criterion, but many others felt it was "confusing, burdensome, inappropriate, counterproductive" (Chodos 2007), or even that it was in conflict with

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the Intellectual Merit criterion. By 2002, proposer and reviewer attention to BIC was so minimal that the NSF issued Important Notice No. 127, which advised PIs that it would return without review proposals that did not address both of these criteria (NSF 2002). Some NSF entities that provide oversight and advice to NSF policies and protocols (eg Committees of Visitors and Advisory Committees) reported that, in general, few scientists venture beyond the standard communication pathways when transmitting their results to their students and to the public (www.nsf.gov/pubs/2004/nsf04216/nsf04216.pdf). Other reports confirm that little evidence of reward or punishment exists for fulfilling or not fulfilling the BIC (Mervis 2001; NSF 2004; Bhattacharya 2006; Poliakoff and Webb 2007). Attention to BIC tends to occur when a proposal is being reviewed, rather than when the work is complete and is being reported. There is inconsistent follow-up on PIs' accomplishments in these activities. The results of scientific work are available to other scientists via published literature, but, in contrast, only the PI and the relevant NSF Program Officers have access to reports on BIC activities (Holbrook and Frodeman 2005).

The generally minimal value placed on BIC within the reward system recognized by scholars is due to scientists' and science administrators' belief that: (1) public outreach lies well outside the central mission and activities of academic scientists; (2) public audiences are not interested in or are incapable of understanding science; and (3) scientists are too introverted, too specialized, or have not received the necessary training to communicate with non-scientists(Andrews *et al.* 2005; Poliakoff and Webb 2007; Leshner 2003, 2007).

In addition, the NSF review process itself includes some barriers that prevent scientists from complying with the BIC. In general, proposals are of a fixed length and specific format, and must be submitted to a particular program. They are first sent to ad hoc reviewers who are knowledgeable in the field, and are then reviewed by a panel of experts selected by a NSF Program Officer. Results from previous work (both scientific research and its broader impacts) can be reported in two places in the proposal: a short piece on "Results of Prior Support" and a two-page curriculum vitae (CV). More detailed results and impacts are described in the required Progress and Final Reports section, but these are only viewable by Program Officers, not by reviewers. Anyone has access to the title, abstract, the amount requested, and the dates of any proposal on FASTLANE (the interactive system used to conduct NSF business over the Internet). The abstract generally contains 3–5 lines on proposed Broader Impacts.

Products and impacts of Broader Impacts are less tangible and more elusive than those associated with Intellectual Merit. Outcomes of Intellectual Merit include scientific papers, talks, databases, and collections that include scientific citation records as a metric of impact. The two-page CVs and informal sources of information reviewers have access to (such as the "reputation" of the PIs in terms of productivity) may also convey a propensity for achieving Intellectual Merit outcomes. In contrast, at present, the only direct way a PI can report Broader Impacts outcomes (other than in the Progress and Final Reports, which are only available to NSF Program Officers) is to list them in the "Prior Support" section of proposals that include them. Results of these activities are rarely published in the scientific literature. How these activities are weighted in ranking proposals varies widely between Program Officers, panels, and directorates.

Scientists who undergo the NSF review process can be effective at broadening research to non-scientific audiences because of their deep knowledge of the subject matter and the passion they have for their work (Gregory and Miller 1998; Pacific Science Center 2010). In addition, public audiences have the potential to help scientists by providing long-term observations, fresh questions, and unexpected and valuable insights (Falk 2001). Some public outreach training programs do exist (eg American Association for the Advancement of Science's Center for Public Engagement with Science & Technology, Aldo Leopold Leadership Program). Positive associations between scientists and these audiences can also be reflected in political support for governmental representatives who support strong NSF budgets (Crotty 1991).

Although the costs and benefits of broader impact activities (BIAs) have long been debated, there is little quantitative data on what ecosystem scientists actually do to fulfill their Broader Impact requirements. This is especially important to study because NSF is – for those carrying out basic research in the US and to some extent, internationally – the research funding agency that sets standards and influences trends in general research funding.

We examined the composition, goals, and mechanisms of BIAs in one area of NSF-funded research, the Ecosystems Studies Program (Division of Environmental Biology, Biology Directorate). Specifically, we examined: (1) Are BIAs described and explained? (2) Of the five components of the BIC, which and how many are addressed? (3) What type and size of audience is the research intended for? (4) What modes of communication are proposed and how specific are they? And (5) how distant from academia are the audiences and venues involved in BIAs? Answers to these questions within the field of ecosystems science may lead to enhancement of broader impacts in this and other academic fields.

Methods

We used the NSF Award Search function to identify awards under the "program" term of: Ecosystem Science Cluster, Ecosystem Studies, and Ecosystems Studies (www.nsf.gov/awardsearch/; 20 December 2010). This provides access to titles, PIs' names and contact details, level of funding, start and end date, and abstract. Because of inconsistencies in the number of awards made prior to 2000, we chose the timeframe of 2000–2010, and down-

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loaded a total of 559 (243 active, 316 expired) award abstracts (Figure 1). We focused on researchers whose goal was primary research, so we filtered the following types of awards: primarily educational (eg Strategies for Ecology Education, Diversity and Sustainability [SEEDS]); monitoring and facilities (eg infrastructure for Long-term Ecological Research and Land-Margin Ecosystems Research sites); and communications (eg conferences, workshops). Projects with multiple PIs listed were counted as a single project. Our final (filtered) tally was 296 total awards (126 active, 170 expired). Funding levels ranged from between US$79 000 to US$3.4 million. We categorized each of the abstracts with respect to the following criteria:

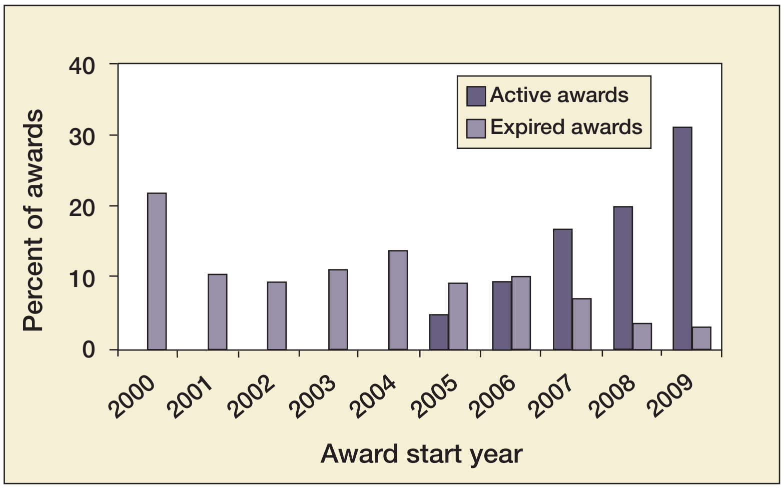

Figure 1. *Distribution of the percentage of active and expired grant awards from the NSF Ecosystems Studies Program that were used in the analyses reported in this study. The total number of awards was 296; 126 were active and 170 were inactive.*

(1) *Presence of BICs and number of BIC components in the proposal:* awards were classified according to whether they included the BIC and, if so, how many of the five components were involved.

(2) *Type and size of intended audiences:* we sorted the audiences described by the PIs into seven categories: students (K–12, undergraduate, graduate); "the public"; managers; academics; and policy makers. Audience types were not regarded as mutually exclusive categories, as some researchers conducted activities that were intended for more than one audience. We note that audience size does not necessarily reflect total impact (ie a superficial effect on a large audience may have less impact than a deep and lasting effect on a small audience).

It was difficult to classify the size and composition of the intended audience from the small amount of information presented in the abstracts, but we placed them into sizes of audience according to the activities being described. Activities that rely on personal interaction, such as presentations or classroom proceedings, were considered as "small audiences". Activities involving K–12 children, community involvement, and curriculum development were assumed to be "medium-sized audiences". Activities involving websites popular with the public (as opposed to those oriented mainly toward scientists) and popular media were assumed to have "large audiences".

(3) *Mode of communication and specificity of audience:* we characterized the modes of communication into nine non-exclusive categories: educational activity; curriculum development; community involvement; internet; conferences; popular press; academic texts; video/television; and radio. For specificity of BIAs (how specialized or generalized the audience was) we created a three-point scale: low (vague intended-audience statements [eg "the public"]); medium (a particular audience type is categorized, but no particular group or venue is described [eg "at-risk children"]), or high (audience specifically identified [eg website address, specific organizational partner]).

(4) we created a five-point scale for those abstracts with stated BIAs that specifically addressed the first and fourth BIC components (teaching and dissemination). This served as a rough measure of how far BIAs reached beyond classrooms, labs, and academic institutions.

1 – no broader teaching or outreach described, but other BIA components are included;

2 – undergraduate and graduate students only (eg mentoring, teaching, lab work) or partnerships among one or more academic institutions;

3 – specific mention of academic text (journal or book) publication or conference/workshop involvement or making datasets available to the public, including via the internet;

4 – K–12 students, summer camps, educational activities, curriculum development; or internet (if clearly directed toward a public audience); and

5 – popular press, media, radio, television.

Results

(1) *Inclusion and number of BICs*

Overall, only 65% of abstracts included BICs. The proportion of proposals that included BICs was larger (85%) in active grants than expired grants (50%). Of the proposals that had BICs, 57 (19%) included just one criterion. Only three awards (1%) included all five NSF criteria. A larger proportion of active grants met multiple NSF criteria (Figure 2). For those grants that proposed BIAs, the most frequent criterion was teaching, training, and learning (37%), followed by broad dissemination (21%), enhancement of infrastructure (18%), benefits to society (13%), and underrepresented groups (11%) (Figure 3).

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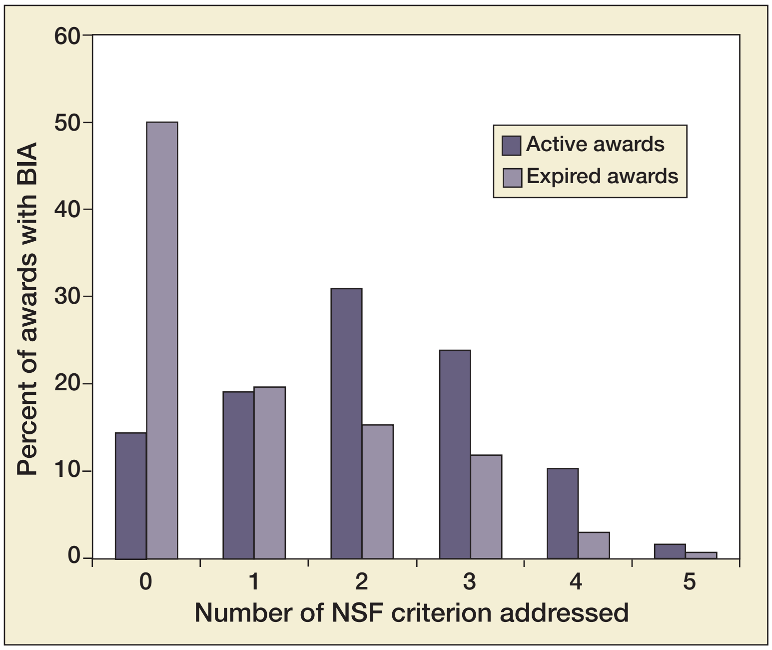

Figure 2. *Distribution of the percentage of total active and expired awards that were categorized as meeting 0 to 5 of the NSF Broader Impacts criteria.*

Note that these figures take into account the inclusion of multiple activities within a single grant, so that the sum of all activities for each grant is 100%),

(2) *Type and size of intended audience*

Students dominated the types of intended audiences: audiences included students (undergraduate, [33%]; graduate [29%]; K–12 [16%]); "the public" (12%); managers (5%); academics (3%); and policy makers (2%). The small number of proposals that mentioned managers or policy makers is intriguing, because managers and policy makers are among the most important audiences in terms of making decisions about use of ecological resources. The largest percentage of activities were educational, and involved scientists personally going to classrooms, as well as supporting the development of museum exhibits.

Overall, most intended audiences (61%) were small, while 32% were medium sized and 7% were large. More detail than was provided in the abstracts would be needed to obtain more definitive results. Active grants had a greater proportion of medium and large audiences than did expired grants, indicating that ecosystem scientists are gaining access to larger audiences nowadays than they did in the past (Figure 3). Inclusion of underrepresented groups constituted only 11% of the BIAs. This proportion differed only slightly between older (expired) grants and newer (active) grants (10% to 11%).

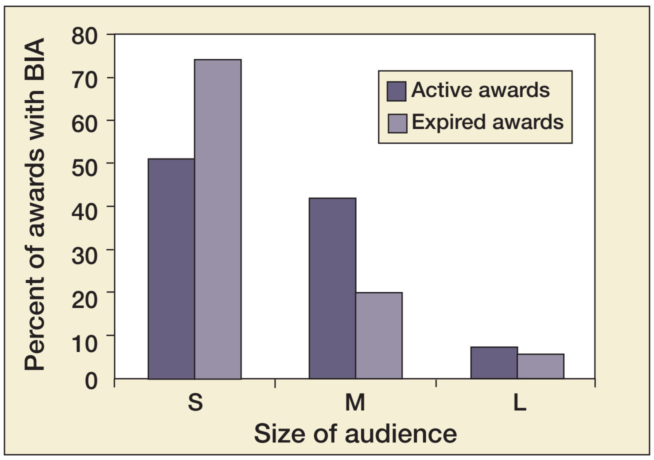

Figure 3. *Distribution of the percentage of active and expired awards that proposed Broader Impacts that were categorized as having small, medium, or large audiences.*

(3) *Mode and specificity of dissemination*

The mode of dissemination varied widely. Most were educational activities or curriculum development (30% and 18%, respectively), followed by community involvement (15%), internet (13%), conferences (11%), popular press (5%), academic texts (5%), video/television (2%), and radio (1%).

The PIs provided varying levels of specificity in their proposed activities, with the majority (58%) of grants articulating broader impacts categorized in the "medium" level of specificity and only 16% in the "high" level. Active grants had a higher overall level of specificity than did expired awards, indicating a trend toward greater specificity in recent projects (Figure 4).

(4) *Distance from academia*

Of the PIs who addressed the BIC in their proposals (65% of total), slightly over 20% proposed communication or activities that involved a specific academic publication, conference/workshop involvement, or internet, or making datasets available to the public. Slightly more than 40% of PIs had outreach targets of K–12 students, summer camps, museums, and other informal science education institutions; curriculum development; public audiences on the internet; or community member involvement, including citizen-science projects. Only 3% indicated that their outreach would be via television and radio. Active proposals included proportionately more activities that were more distant from academia than those of expired grants, suggesting that ecosystem scientists are now targeting BIAs further outside academia than they did in the past.

Discussion

Although this was an exhaustive study of BIAs, taken from over a decade of abstracts from proposals submitted to NSF's Ecosystem Studies Program, our results are derived only from what PIs proposed, not what was actually carried out. It may be that some PIs had an exaggerated sense of

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what they would accomplish; others may have underestimated the amount of BIAs because some PI's may not have included broader impacts within their abstracts or may not have foreseen BIAs that arose during the course of the research. Thus, the confidentiality of fully funded proposals and non-funded proposals limits our ability to address the possibility that the abstracts themselves might not always reflect the depth or breadth of the proposed BIAs. Being limited to proposal abstracts, and not having access to annual or final reports (or other sources of information about what was actually done in terms of BIAs) limits them to making conclusions only about intentions.

We were also not able to look at the BIAs of those proposals that were rejected, because full proposals are confidential. It would be useful to quantify whether the inclusion of strong BIAs substantially affects proposal success – ie are proposals that include BIAs suggesting more PI commitment funded more often than proposals that do not include such statements? Do funded proposals differ from rejected proposals in the quality of the BIAs described? Answers to these questions could give an indication of the value placed on BIA's by reviewers (eg NSF's post-panel process), although it could also be the result of a non-causal correlation (ie good Criterion 1 proposals tend to have good Criterion 2 components).

Given those limitations, our most striking result was that, despite the requirement of including BIAs in the activities and abstracts of every NSF proposal, 35% had no stated BIAs in their abstracts. Because we categorized proposals as active versus expired, we were able to acquire some evidence of trends over time. Active (more recent) awards had a much higher proportion (85.7%) than expired awards (50%). In terms of audiences, there was a striking predominance of teaching, training and learning, and benefits-to-society NSF criterion (30% of total awards), indicating that students are the main targets for outreach activities, with very few PIs aiming to reach policy makers, managers, or the public. Thus, for ecosystem ecologists, the broader impacts initiatives that NSF currently acknowledges and rewards are mainly focused on activities that scientists traditionally conduct anyway – that is, ecological research that trains students graduate students in the field and labs, and teaches undergraduate students about the research in the college or university curriculum.

One noticeable trend was that engagement with underrepresented groups hardly increased at all when comparing expired (10% of total) and active (11% of total) awards. In terms of audiences, there was a difference between expired and active proposals in terms of size of audience and distance from academia (see Methods, category 4). We also noted the small number of proposal abstracts that mentioned managers (12%) and/or makers (2%); this is a cause for concern, since managers and policy makers are major players in decisions about natural resources and environmental issues. In contrast, PIs were being more specific about the BIAs they proposed. For example, rather than simply stating "we will present results to an agricultural resource group at the end of our project", a PI proposed to "present our results at the regional chapter of the Oklahoma 4-H Club conference, to engage agricultural youth in our project".

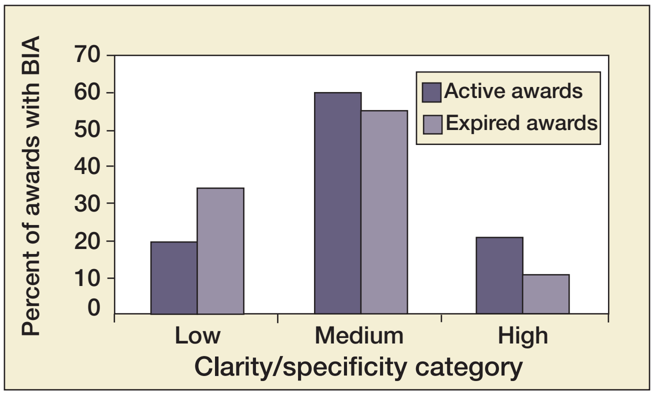

Figure 4. *Distribution of the percentage of active and expired awards that proposed Broader Impacts that were categorized as having low, medium, or high clarity and specificity in terms of audience.*

Because we only had access to abstracts, we were unable to document the actual outcomes of BIAs. For example, it was not possible to determine whether a scientist who collaborated with museum professionals to create a large (but impersonal) exhibit would have a greater or smaller impact than a scientist who had direct contact with a smaller number of participants in a hands-on field event. The creation of electronic resources such as websites also raises questions in terms of impacts, because the effects of such activities on learning ecological content, taking action, or changing attitudes of visitors to these sites cannot be measured. Documenting and assessing the relative impacts of all these activities requires that scientists have access to effective evaluation instruments; these should shape the design of BIAs in the future.

Based on this study, we suggest that the "best" BIC might include one or more of the following: (1) reach

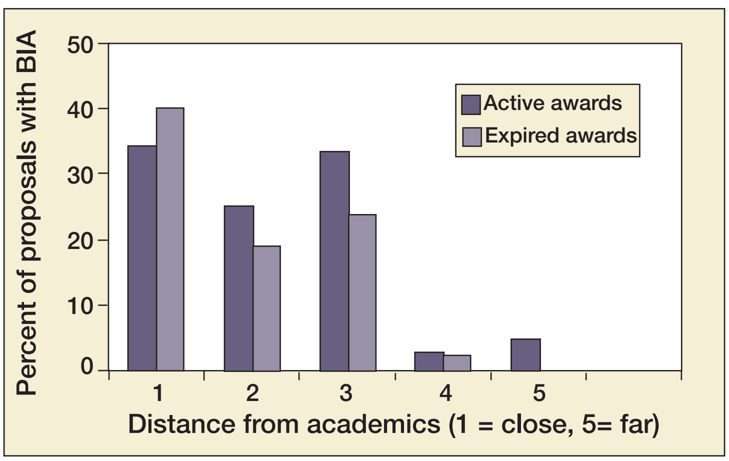

Figure 5. *Distribution of the percent of active and expired awards that proposed Broader Impacts that were categorized being very close (1) to very distant (5) from academia (See Methods, category 4).*

much broader audiences than just students; (2) be very specific with respect to audience; (3) be genuinely collaborative with social scientists, outreach specialists, and users of content; (4) involve the public in real science; and (5) explicitly engage underrepresented groups.

Our results highlight the need for natural scientists to collaborate with social scientists, a growing trend within ecosystem ecology, and one that can provide field scientists with better ways to understand connections between knowledge production and use (Frodeman and Parker 2009; Baurer and Jensen 2011). For example, several Integrative Graduate Education and Research Traineeship (IGERT) program initiatives now train graduate science students to view their science within the context of a variety of public concerns (www.nsf.gov/funding/pgm_summ.jsp?pims_id=12759). In addition to this type of training effort, ecologists should work with media and journalism professionals to produce materials that will appeal to non-scientists. Creating and presenting workshops on outreach methods that are specific to ecologists should be a high priority for professional organizations, such as the Ecological Society of America; happily, more such training is being offered each year. For instance, the nascent Research Ambassador Program, sponsored by the NSF, has recruited and trained a group of "Research Ambassadors" in the field of ecosystem ecology, and there are plans to expand this work in the future (www.researchambassador.com).

There are many challenges and possible solutions involved in measuring actual impacts of research, and we have mentioned only a few here. Assessing the impacts of BIAs and allowing these to be reflected in the review of subsequent proposals will require sustainable mechanisms that do not currently exist. Some kind of framework for oversight, direction, and encouragement on the part of reviewers and NSF program officers must be developed. Examining annual and final reports is one way to address at least what types of activities have carried out, and is a good first step. We recommend that the NSF either carry out such analyses themselves, or provide access to others who could do so. Although easily recommended, it will be difficult to find the needed resources to carry out these recommendations when the agency is already stretched to carry out its current activities.

A key concept that emerged from this examination of broader impacts for ecosystem ecology is that outreach is currently perceived more positively in academic circles than it has in the past – as something directed by science administrators to broaden the impacts of academic work. However, such activities are still secondary to the primary work of ecosystem science. Although explicit pathways are few, examples of successful outreach are increasing in scope and number, and so the directive for scientists to communicate with non-scientists – with the resulting potential for communication in the opposite direction – is moving outreach into a more prominent position within the scientific enterprise.

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