Frontiers in Ecology and the Environment

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

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Front Ecol Environ 2013; doi:10.1890/110106

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

Nalini M Nadkarni[*†] and Amy E Stasch

The National Science Foundation (NSF) has tried to narrow the gap between science and society with its Broader Impacts criterion. We analyzed the proposed Broader Impacts (ie the activities that benefit society through teaching, broadening participation, enhancing infrastructure, and disseminating research) of proposals funded by NSF's Ecosystem Studies Program. We obtained abstracts from 296 funded proposals from NSF's website and characterized the scope of the proposed Broader Impacts (2000–2009). Only 65% of abstracts included a Broader Impacts statement and, of those, 57 (19%) included just one of five NSF broader impacts activities (BIAs). The most frequent component was teaching and training (37%), followed by broad dissemination (22%), infrastructure enhancement (18%), benefits to society (13%), and underrepresented groups (11%). Most proposed audiences were small (61%) to medium-sized (32%) and were closely associated with academics. NSF as a whole, and Program Officers in the Ecosystem Studies Program in particular, are generally reinforcing the importance of BIAs, but improvements are required within the academic culture. NSF needs to create new mechanisms that make grantees accountable for BIAs and provide positive feedback for those efforts.

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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, rather than being separate from, nature (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 US President's Advisor to Science, John Holdren, urged scientists to allocate 10% of their professional time to work "in ways that increase the benefits of science for the human condition" (American Association for the Advancement of Science [AAAS] Presidential Address, 16 February 2007). The America COMPETES Act (Public Law 110-69, H.R. 110-289), the authorizing Act for the National Science Foundation (NSF), calls for NSF to invest in innovation through research and development, and to improve the competitiveness of the United States. The Act requires reports of Broader Impacts 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 1 October 1997, the National Science Board (NSB) – the NSF's governing board – introduced two criteria to assess proposals: (1) the Intellectual Merit criterion (IMC, also referred to as "Criterion 1") and (2) the Broader Impacts 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 grant applications more competitive (NSF 2007). The five components of the 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.

The Evergreen State College, Olympia, WA [*]*(nalini.nadkarni@utah.edu);* [†]*current address: Department of Biology, University of Utah, Salt Lake City, UT*

Some did embrace the BIC, but many others felt it was "confusing, burdensome, inappropriate, [and] counterproductive" (Chodos 2007), or even that it was in conflict with the IMC. By 2002, proposer and reviewer attention to the 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 the IMC and BIC (NSF 2002). Some NSF entities that provide oversight and advice on 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 there is little evidence of rewards for fulfilling or penalties for disregarding the BIC (Mervis 2001; NSF 2004; Bhattacharya 2006; Poliakoff and Webb 2007). Attention to the 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 broader impacts activities (BIAs; Holbrook and Frodeman 2005).

The generally minimal value placed on the 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 neither interested in nor capable of understanding science; and (3) scientists are too introverted, are too specialized, or lack the necessary training to communicate with nonscientists (Leshner 2003, 2007; Andrews *et al.* 2005; Poliakoff and Webb 2007).

In addition, the NSF review process 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. 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 abstracts generally contain 3–5 lines on proposed broader impacts.

Products and impacts of the BIC are less tangible and more elusive than those associated with the IMC, the outcomes of which include scientific papers, talks, databases, and collections that contain scientific citation records as a metric of impact. The curricula vitae and informal sources of information that reviewers have access to (such as the "reputation" of the PIs in terms of productivity) also relate to IMC outcomes. In contrast, at present, the only direct way a PI can report BIC outcomes is to list them in the "Prior Support" section of proposals. 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.

However, scientists who undergo the NSF review process can be effective at broadening research to nonscientific audiences because of their extensive knowledge of the subject matter and their passion 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 AAAS'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 impacts activities (BIAs) have long been debated, there is little quantitative data on what ecosystem scientists actually do to fulfill their BIC requirements. This is especially important to study because the 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 in one area of NSF-funded research: the Ecosystem Studies Program (Division of Environmental Biology, Directorate of Biological Sciences). Specifically, we asked: (1) Are BIAs described and explained? (2) Of the five components of the BIC, how many and which 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 ecosystem 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 2009). This function 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 2000–2009, and downloaded a total of 559 (243 active, 316 expired) award abstracts (Figure 1). We focused on researchers whose goal was primary research and filtered the following types of awards: primarily educational (eg Strategies for Ecology Education, Diversity and Sustainability), 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 were counted as a single project. Our final (filtered) tally was 296 total awards (126 active, 170 expired). Funding levels ranged from US$79 000 to US$3.4 million. We categorized each of the abstracts with respect to the following criteria:

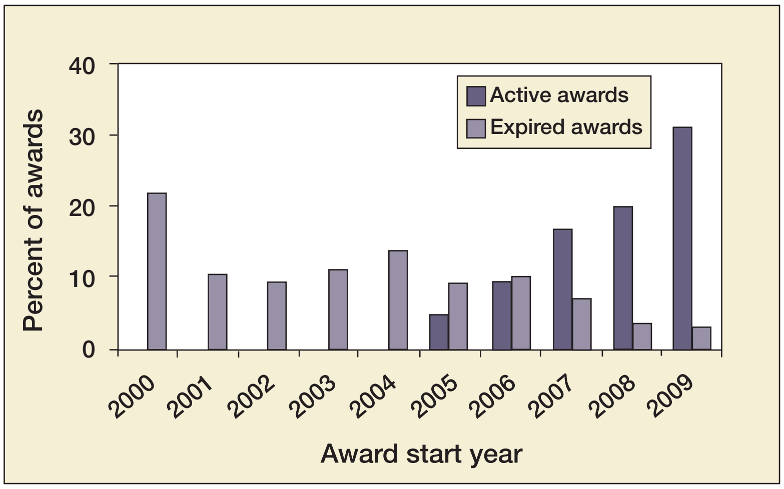

Figure 1. *Distribution of the percentage of active and expired grant awards from the NSF Ecosystem Studies Program that were used in the analyses reported in this study. The total number of awards was 296; 126 were active and 170 were expired.*

(1) *Presence of BIAs and number of BIA 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 limited information presented in the abstracts, but we organized abstracts by audience size 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) *Association with academia:* 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 with 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 BIC components*

Overall, only 65% of reviewed abstracts included BICs. The proportion of proposals that included BIAs was larger in active grants (85%) than expired grants (50%). Of the proposals that had BIAs, 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

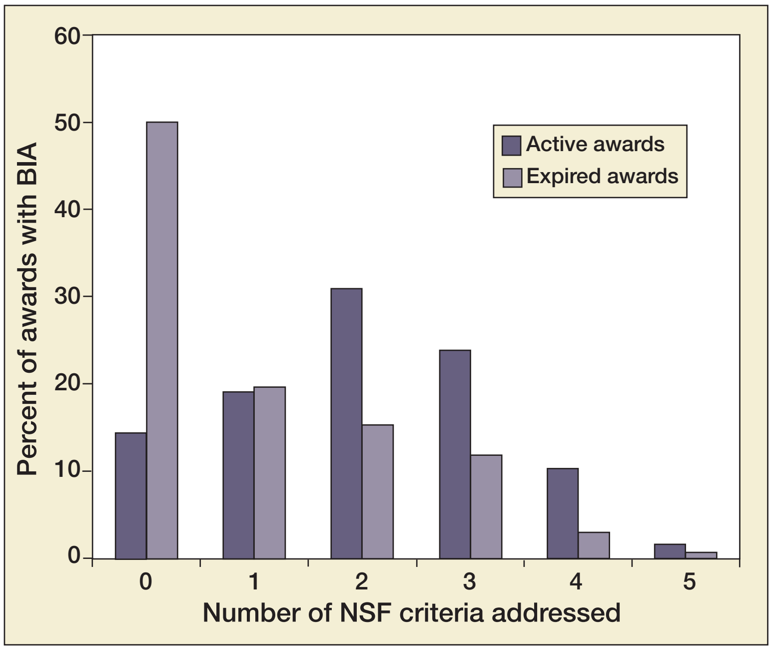

Figure 2. Distribution of the percentage of total active and expired awards that were categorized as meeting 0 to 5 of the NSF Broader Impacts criteria.

(13%), and underrepresented groups (11%) (Figure 3). 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 was unexpected, 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 was 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 now than 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% and 11%, respectively).

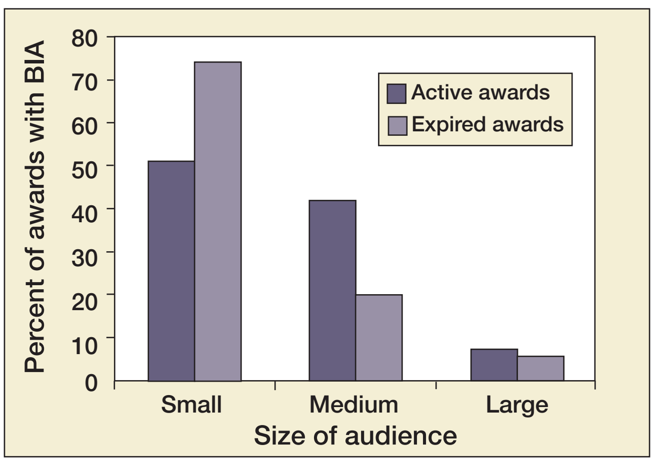

Figure 3. Distribution of the percentage of active and expired awards that proposed Broader Impacts that were categorized as having small, medium, or large audiences.

(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), a little over 20% proposed communication or activities that involved a specific academic publication, conference/workshop involvement, or the internet, or making datasets available to the public. Just over 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 conducted via television and radio. The abstracts of active proposals put forward proportionately more activities that were more closely associated with academia than those of expired grants, suggesting that ecosystem scientists are now targeting BIAs farther from 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. Perhaps some PIs had an exaggerated sense of what they would accomplish; others may have underestimated the amount of BIAs because they may have excluded broader impacts from 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 might not always reflect the depth or breadth of the proposed BIAs. Being restricted 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) thereby limits conclusions to be based only on intentions.

We were also unable to consider 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 – that is, are proposals that include BIAs suggesting more PI commitment funded more often than proposals that exclude 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 BIAs by reviewers (eg NSF's post-panel process), although this could be subject to 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% did not state 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 marked predominance of teaching, training and learning, and benefits-to-society NSF criterion (30% of total awards), indicating that students were 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 graduate students in field and laboratory work, and teaching undergraduate students about the research in a college or university curriculum.

Notably, engagement with underrepresented groups hardly increased at all when comparing expired (10% of total) and active (11% of total) awards. With regard to audiences, there was a difference between expired and active proposals in terms of audience size and distance from academia (Figure 5; see Methods, category 4). We also noted few proposal abstracts that mentioned managers (12%) and/or policy makers (2%); this is a cause for concern, since managers and policy makers are critical players in decisions about natural resources and environmental issues. In contrast, PIs were 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", one PI proposed to "present our results at the regional chapter of the Oklahoma 4-H Club conference, to engage agricultural youth in our project".

Because we had access only to abstracts, we were unable to document the actual outcomes of BIAs. For instance, 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 fewer 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 of these activities requires that scientists have access to effective evaluation instruments, which should shape the future design of BIAs.

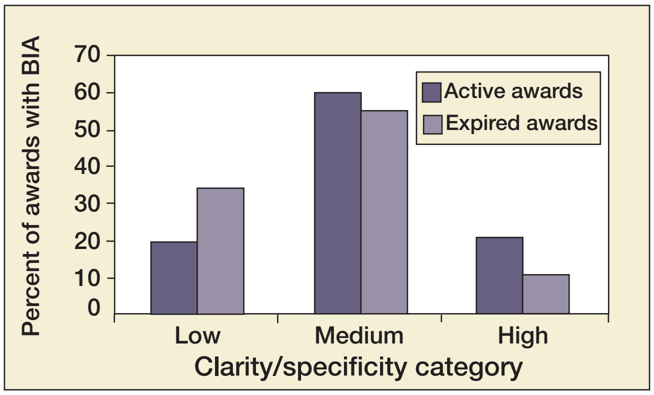

Figure 4. *Distribution of the percentage of active and expired awards that proposed Broader Impacts that were categorized as having low, medium, or high clarity and specificity in terms of audience.*

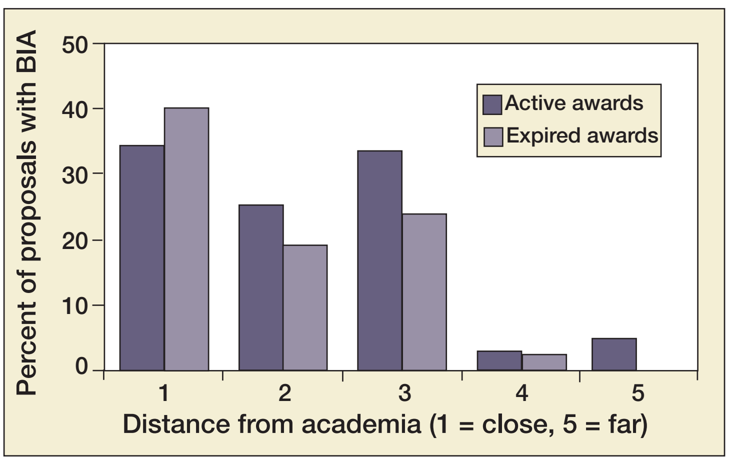

Figure 5. *Distribution of the percent of active and expired awards that proposed Broader Impacts that were categorized as being very close (1) to very distant (5) from academia (see Methods, category 4).*

On the basis of this study, we suggest that the "best" BIA might include one or more of the following aims: (1) reach much broader audiences than students alone; (2) be very specific with respect to target 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 lead to a call for natural scientists to further collaborate with social scientists, a growing trend within ecosystem ecology 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 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; fortunately, 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 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 the question of what types of activities have been carried out, and is a good first step. We recommend that the NSF either conduct such analyses themselves or provide access to others who could do so; however, it will be difficult to obtain the needed resources to implement these recommendations when the agency is already stretched financially.

Our examination of broader impacts for ecosystem ecology revealed 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 – but that such activities are still secondary to the primary work of an 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 potential for communication in the opposite direction as well – is moving outreach into a more prominent position within the scientific enterprise.

Another positive sign is that, in the past 2 years, NSF has devoted more attention to the broader impacts of the research it supports. In 2011, the NSB created a Task Force to examine its merit review criteria by analyzing reports from Committees of Visitors and querying Program Officers, PIs, and reviewers in an effort to understand their perspectives on the current criteria (www.nsf.gov/nsb/publications/2011/01_19_mrtf.jsp). The ensuing report reinforced that the two review criteria – IMC and BIC – continue to be congruent with NSF's core principles. An important result from the standpoint of broader impacts is NSF's statement that "both criteria are to be given full consideration during the review and decision-making processes" (www.nsf.gov/pubs/policydocs/pappguide/nsf13001/gpg_3.jsp).

NSF also made specific logistical changes that reinforce the attention paid to BIAs in proposals. The Project Description and Project Summary sections must contain a separate subsection on broader impacts that describes activities that "contribute to the achievement of societally relevant outcome". These include broader participation by underrepresented groups; improved Science, Technology, Engineering, and Mathematics education and enhanced public engagement; improved human well-being; creation of a more competitive workforce; increased partnerships with industry; enhanced research and educational infrastructure; and fostered economic competitiveness and improved national security (www.nsf.gov/pubs/policydocs/pappguide/nsf13001/gpg_2.jsp#IIC2di). There are also specific questions about BIAs that reviewers should address when evaluating proposals.

However, two principles might undermine this orientation. The report states that: (1) NSF projects, in aggregate, should contribute more broadly to achieving societal goals, and (2) the effectiveness of these activities may best be assessed at a higher, more aggregated level than at the individual project. This language lends some ambiguity to the responsibility that PIs have to perform their own BIAs; it might let PIs "off the hook" by allowing them to rely on the aggregate broader impacts of their departments, campus science education centers, or whole universities.

Another notable change recommended by the Task Force was the deletion of examples illustrating activities likely to demonstrate the BIC. This was done to remove the perceived perception that this list was prescriptive rather than illustrative of possible scenarios for each component. However, its absence as a guide may make it more difficult for PIs to formulate their BIAs or model successful BIAs of others. In addition to these general changes, in 2012, NSF staff at the Division of Environmental Biology carried out an internal study to learn more about what PIs described in their full proposals and final reports for the programs within the Division (P Firth pers comm). Using the same framework and methods described here, NSF personnel are documenting the BIAs that PIs have reported as accomplished; their results will be reported in a future publication. The willingness of NSF Program Officers to address the problem outlined in this paper – that a substantial proportion of PIs either fail to perform BIAs or carry out BIAs that do not venture far from academia – is a positive sign, and one that may lead to greater participation of researchers in the important work of bringing ecosystem ecology to society.

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