Ecological Science and Sustainability for a Crowded Planet

21st Century Vision and Action Plan for the Ecological Society of America

Report from the Ecological Visions Committee* to the Governing Board of the Ecological Society of America

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Executive Summary

Environmental issues will define the 21st Century, as will a world with a large human population and ecosystems that are increasingly shaped by human intervention. The science of ecology can and should play a greatly expanded role in ensuring a future in which natural systems and the humans they include coexist on a more sustainable planet. Ecological science can use its extensive knowledge of natural systems to develop a greater understanding of how to manage, restore, and create the ecosystems that can deliver the key ecological services that sustain life on our planet. To accomplish this, ecologists will have to forge partnerships at scales and in forms they have not traditionally used. These alliances must implement action plans within three visionary areas: enhance the extent to which decisions are ecologically informed; advance innovative ecological research directed at the sustainability of an over-populated planet; and stimulate cultural changes within the science itself that build a forward-looking and international ecology.

New partnerships and large-scale, cross-cutting activities will be key to incorporating ecological solutions in sustainability. We recommend a four-pronged research initiative, to be built on new and existing programs, to enhance research project development, facilitate large-scale experiments and data collection, and link science to solutions. We emphasize the need to improve interactions among researchers, managers, and decision makers. Building public understanding of the links between ecosystem services and human well-being is essential. We urge the development of a major public information campaign to bring issues and raise awareness of ecological sustainability before the general public.

Specific recommendations for each visionary area will support rapid progress. Standardization of data collection, data documentation, and data sharing is long overdue and should be kick-started through a data registry, easy access to metadata, and graduate and professional training of ecologists in ecoinformatics. A rapid response team that draws on ecological expertise in responding to legislative and executive branch proposals would result in a larger role for ecological knowledge and ecological scientists in the legislative and policy processes that impact sustainability. We must develop resources that will help ecologists and collaborators from other sciences work together more effectively. A meeting of key leaders in research, management, and business should be convened to produce a plan to create reward systems for ecological researchers and educators, as well as to foster collaborations. We need more global access to ecological knowledge. This effort could be started through routine translation of key ecological articles from non-English to English and vice versa. In addition, strategies to ease the exchange of students, managers and practitioners among institutions in various countries should be implemented.

The three visionary areas and the recommendations to achieve them will provide a framework for advancing ecological research and ensuring it plays a key role in public and private discourse. The most critical vision area is the first: building an informed public. The results of simultaneously addressing our recommendations for the three visionary areas will be an ecological science marked by strong regional and global partnerships that will be instrumental in the move toward a more sustainable future for ecosystems and the humans they support.

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History and Approach of the Ecological Visions Committee

The desire to develop a sustainable future and the science to accomplish this is widespread, and has been an explicit goal of the Ecological Society of America (ESA) for over a decade. The Sustainable Biosphere Initiative (Box 1) was produced by the ESA in an effort to highlight the key role of basic ecological research and articulate ecological research priorities related to global change, biological diversity, and strategies for sustainable ecological systems. Considerable effort has been and continues to be devoted to the first two priorities, yet we still have only a rudimentary understanding of what is needed for sustainable ecological systems, even though such systems are required for a vast array of vital ecosystem services (Kates et al. 2001, Cash et al. 2003). We find ourselves in the earliest stages of understanding sustainability.

In 2002, the Governing Board of the ESA charged a commitee with preparing an action plan that would accelerate our progress in addressing the major environmental challenges of our time and increase the contribution of ecological science in the coming decades. The SBI motivated the committee's work, but our charge was to develop an action plan for the Society and for the future of ecological science in general. We were *not* asked to identify the most critical research questions nor to prioritize a list of research topics. This has already been very effectively accomplished by many highly esteemed groups and our committee agrees with their general assessment (Box 2). In initiating our work as a committee, we fully embraced the views expressed by the ESA Governing Board in 2003 under the leadership of President Pamela Matson:

> ...to make progress in solving the major environmental challenges and ensure that ecological science contributes to a more sustainable world, a bold and specific action plan is needed….

After significant input from our membership and many individuals and organizations outside ESA, we chose to focus our action plan on three areas: *building an informed public; advancing innovative, anticipatory research; and stimulating cultural changes that foster a forward-looking and international ecology*. The actions we recommend will require commitment and hard work, including collaboration and new partnerships among the ESA and other societies,

Box 1

The Sustainable Biosphere Initiative

ESA created the Sustainable Biosphere Initiative (SBI) as "a call to arms for all ecologists," and also to "serve as a means to communicate with individuals in other disciplines with whom ecologists must join forces to address our common predicament." It called for acquiring ecological knowledge, communicating that knowledge to citizens, and incorporating that knowledge into policy and management decisions. (Lubchenco et al. 1991). The Initiative has influenced and informed much of ESA's efforts since 1991.

Box 2

Critical Environmental Issues for Prioritizing Ecological Research*

The science of ecosystem services
Biodiversity, species composition, and ecosystem functioning
Ecological aspects of biogeochemical cycles
Ecological implications of climate change
Ecology and evolution of infectious diseases
Invasive species
Land use and habitat alteration
Freshwater resources and coastal environments

* This list was compiled by the ESA Ecological Visions committee after reviewing numerous reports (see http://www.esa.org/ecovisions/ev_projects/ref_documents.php). Issues are not listed in order of priority and reflect committee views and particularly input from two reports: NRC (2003), NSF-ERE (2003).

organizations, agencies, and the business sector. Furthermore, these partnerships should be international in scope and in focus.

Our recommended actions cover a large range: from big-scale, long-term, high-budget projects to smaller tasks that could be undertaken immediately with few additional resources. We did not shy away from the larger, more ambitious activities; we believe they represent the scale at which we as a community must think and act in order to achieve sustainability science. We envision the ESA playing a significant role in all of the actions we propose. That role may range from facilitator or champion of activities that require multiple partners and significant resources to sole implementer of actions that can be accomplished within existing ESA structures.

The recommended actions represent the conclusions we reached after many hours of work as a committee. We received extensive input from numerous groups (government, non-governmental organizations [NGOs], the business sector), individuals, and many members of our Society, including the Governing Board itself. The input varied from one-on-one discussions to group meetings among the committee members (Appendix 2), breakfast briefings in Washington, DC with agency, NGO, and industry representatives (Appendix 3), presentations from federal agency and NGO representatives (Appendix 2), as well as email correspondence and input from a web survey of the ESA membership (Appendix 4).

The Need for an Action Plan

As we enter the 21^{st} Century, wide recognition exists that humans have altered virtually all of Earth's ecological systems. Few places remain that rightly could be called pristine. People and their institutions need wood, so even the most remote rain forests have been logged to the point of exhaustion (Kremen et al. 2000). The need for energy and transportation has led to increases in atmospheric carbon dioxide,methane, and nitrous oxides (NRC 2000, IPCC 2001). Earth's supply of water has remained finite, but the usable amount has declined; almost all freshwater bodies are degraded or water is being siphoned off at rates that are leading to total depletion in some regions (Gleick 2003), threatening fierce cross-border disputes. We are profoundly degrading the health of Earth's ecosystems.

The impacts that humans make on the environment are clearly at odds with the fact that humans depend on a diverse array of natural services that can be provided only by healthy ecosystems (Daily 1997). The challenge is to preserve these vital services as the world's human population soars and as nations and their inhabitants quite naturally seek to improve their standard of living. The issues are not just overpopulation but over-exploitation of natural resources, particularly by peoples of the developed world such as the United States.

Human population size reached 6 billion in the spring of 2004, according to the United Nations. growth projections suggest that even if the growth rate does taper off , as expected , the momentum of previous population growth means that by the end of the century, the world's ecosystems will have to support 8–11 billion people (Lutz et al. 2001). However, from the perspective of ecological sustainability, it is difficult to see any future scenario that would support this many people at today's rates of resource consumption (Dobkowski and Wallimann 2002). Even given the current population level, the ability of global ecosystems to sustain humans is quickly being eroded and exceeded in many places. Meanwhile, Earth's ability to produce goods and services is being degraded further. Thus, regardless of the ultimate human population size, new thinking and new solutions are needed now to ensure a planet that can sustain a burgeoning human population.

Box 3

Sustainability

"Sustainable," from the Latin sustinere, means to keep in existence. The term "sustainable development" came into general use with the 1980 publication of the World Conservation Strategy by the International Union for the Conservation of Nature. The term gained wide currency eight years later with the release of Our Common Future by the World Commission on Environment and Development, better known as the Bruntland Commission. There have been many variations on the definition of the word.

This report adopts the definition used by the National Research Council: "meeting human needs while conserving the Earth's life support systems and reducing hunger and poverty" (NRC 1999).

Ecologists traditionally have paid great attention to Earth's least disturbed areas—the rain forests, islands, wildernesses. Their research has produced immensely significant insights into complex ecological interactions. This valuable work has uniquely positioned researchers to create an ecology of the future: a science that reshapes the view of key ecological questions and a science that explicitly recognizes and incorporates the dominant influence of humans. It is time for ecology and ecologists to enter a new and critically important phase, one that requires crucial changes in thoughts and actions.

We believe that ecologists (and environmental scientists generally, as well as decision makers) must accept the inevitability of a planet with a vastly increased population and over-exploited resources. All must incorporate into their thinking, planning and research the irrepressible tendency of humans to modify their world. That tendency may decline as Earth's precarious position becomes better understood by its inhabitants. But until that happens, our thinking must reflect today's reality.

The ecology of the future must become more responsive to, and respectful of, the huge human footprint. Ecological knowledge can and must play a central role in helping achieve a world in which human populations exist within sustainable ecological systems. This is not a utopian view, but a realistic one. It need not invite despair. It does require that sound, problem-driven environmental science and forecasting become critical components of decision making. And it requires an acknowledgement that a more sustainable future will involve some combination of conserved, restored, and invented ecological solutions.

Thus, we argue for a more forward-looking and international ecological science focused on how natural systems and the large human populations they support can coexist on a more sustainable planet. We call this *Ecological Science and Sustainability for a Crowded Planet.* It is based on the views that: 1) the rich history of basic ecological research provides us with a strong foundation for moving forward in sustainability science; and 2) the central role that ecological science must play in the future of our planet places a unique responsibility on ecologists to develop and implement plans of action. The central goal must be to chart an understanding of how ecosystems help sustain humans and the ecological services they value and how we can balance conservation, restoration, and designed solutions to ensure that nature's services continue into the future.

The need for an action plan stems in part from the fact that thus far ecological science has not been characterized by regional and global partnerships for advancing research that can influence issues of sustainability. Nor has it been particularly effective in informing decisions that affect our environment. We need to bolster research, but perhaps more importantly, we need to communicate our science much more effectively than we have in the past. Major changes in ecological science have already laid the foundation for these changes, since many ecologists who once concentrated their research on systems with "minimal" human influence are now focusing on how humans interface with nature (Povilitis 2001, Turner et al. 2003) and are now considering the relevance of their work for policy. The community must, however, go one step further.

Unparalleled interactions with physical and social scientists, as well as the public, policy, and corporate sectors, are required, as are major new initiatives across the three frontier action areas that are described below. Indeed, regional and global partnerships will be required to implement many of the actions that we recommend. The ESA cannot and should not attempt by itself to implement those actions that need input, perspectives, and resources from diverse groups around the world. However, because of its international political influence and its disproportionate consumption of non-renewable natural resources *and* disproportionate release of globally-transmitted pollutants (UNEP 1999), the US and its ecologists have a particular responsibility to initiate such partnerships.

Many current efforts at the international level are already ongoing but they should be enhanced and should play a significant role in these partnerships. For example, the Millennium Ecosystem Assessment (MA) is an international work program launched by UN Secretary General Kofi Annan in June 2001. Its goal is to provide scientific information on the consequences of ecosystem change to decision makers and the public (MA 2003). Similarly, the Resilience Alliance (2004) has an international program to assist in the development of theory and solutions for managing social-ecological systems.

Partnerships between researchers and government agencies are also important, as agencies have the resources to help implement new research programs and to understand from their perspective the critical problems that we need to respond to or anticipate. For example, in implementation of the Endangered Species Act, US government agencies set specific ecological information requirements, and, in the process, very effectively framed gaps in current knowledge (Levy 2003). Multinational initiatives such as the Pan-European Biological and Landscape Diversity program represent innovative partnerships between governmental and non-governmental groups that also bridge science, policy, and economics in order to protect biodiversity. These programs and many others are ripe for more science and more participation on the part of the ecological scientific community.

We now turn to the three visionary themes with associated actions—informing decisions with ecological knowledge, advancing innovative and anticipatory research, and stimulating cultural change. Without progress in all three areas, we will not achieve the goals of bolstering ecological science and sustainability for our crowded planet.

VISION 1:

INFORM DECISIONS WITH ECOLOGICAL KNOWLEDGE[1]

Vision Statement: *The science of ecology is poised to provide the scientific insights crucial to the sustainable management of our planet and its resources. To meet this challenge, ecological knowledge must underpin the decisions that affect ecological sustainability and this integration must occur at all levels of society worldwide.*

Rationale

Ecologists and current ecological knowledge presently play only marginal roles in many, if not most, of the daily decisions that affect ecological sustainability (NRC 2001, Walters 1998). Such decisions include the choices individual citizens make about how they use resources, from whether or not to recycle a soda can, to which car to purchase, to how to dispose of manure from their chicken farms. Those decisions also include people's perceptions of the the actions of agencies entrusted with environmental stewardship. Decisions about land and natural resource management, ecological restoration, technology development, and the regulation of environmental hazards are made by government agencies operating at the local, state, provincial, national, and international levels.

The translation of ecological knowledge into a form that is accurate and serviceable for policy, management, or education purposes is often delayed. This lag between advances in ecological science and integration of these advances into decision making occurs for several reasons (Bradshaw and Borchers 2000). Ecological science does not always answer the questions that matter to user groups because the research community does not understand such needs or recognize them as priorities. One consequence is that the decision makers may not view ecology as relevant (Cash et al. 2003); therefore, ecologists do not always have a "seat at the table" in contexts in which they could make fundamental contributions. The situation can be changed, but it will require new ways of identifying scientific priorities and new ways of communicating ecological knowledge, both within our own countries *and* across international borders. It is no longer enough to just do the science; the new knowledge must be conveyed in a way that allows policy makers to translate the science into actions (Cash et al. 2003), as well as convinces those policy makers that action is important. And the knowledge must be globalized so that access to worldwide ecological information is easy to obtain.

Relatively few people or institutions routinely translate ecological information and concepts into knowledge that is directly applicable to real-world decisions—or, conversely, identify science questions based on user needs. Understanding and appreciation of the significance of these functions is generally low among the general public and decision makers (Cash et al. 2003). In the vacuum that is left, an increasing number of organizations, ranging from environmental nonprofits to industry lobbyists, are aggressively marketing mission-driven messages and information about the environment. Many users and members of the public now gather information from a variety of

[1] As noted by the International Council for Science (ICSU), "inform" implies three interacting processes: "Ecological knowledge helps to 'inform' decision-making at all levels, decisions are 'informed' by the best ecological knowledge available, and future research can be 'informed' by needs and concerns of decision makers." (ICSU 2002). "Knowledge" can be considered information that changes behavior either by motivating or changing capacity for action (see Allen 1999). Information dissemination may have impact on awareness, but not necessarily behavior or action (Allen 1999). Therefore, communication, education, and capacity-building are required to effect change in integration of ecological knowledge into decisionmaking at all levels.

sources, ranging from peer-reviewed journal articles, to materials that present self-serving interests, to news accounts, to both well-documented and unattributed Web pages. As a result, decision makers, managers, educators, and the public may have difficulty discriminating among the differing objectives and scientific reliability of these sources.

Institutions such as the ESA have a critical role to play in ensuring that science-based information about ecological sustainability is accessible to decision makers at all levels and that this information is framed globally. Environmental policies set by the US that do not consider environmental impacts across international borders are not adequate. **We recommend a two-part strategy, which we describe as action areas, to greatly accelerate the integration of ecological knowledge and ecologists into decision making, management, and educational processes that affect ecological sustainability.** Each action area targets a different, but equally important, part of the problem.

existing processes affecting ecological sustainability have yielded mixed success in integrating current ecological science. For example, these processes do not always pull in the appropriate experts: for various reasons, ecologists do not participate in many sustainability issues that have significant ecological components. Moreover, those scientists who *are* involved may have limited opportunity to offer their ideas or may not understand the policy or management context fully enough to provide useful advice.

The problem does not lie solely with the scientists. The users of ecological knowledge often do not understand the full range of information or conceptual insights that ecologists might provide (Alpert and Keller *et al*. 2003). There are several possible reasons for ecology's lack of "a seat" at the decision-making table; other scientific fields may have co-opted ecology's role. Ecology is a relatively new discipline, and it still suffers in some circles from not being recognized as a "real" science. By definition, ecology is (or should be) a multidisciplinary undertaking, and this may frustrate decision makers who seek simple, "magic bullet" answers. And sometimes ecologists fail to assert themselves in policy matters.

Action Areas for Informing Decisions (ID) with Ecological Knowledge

A. Integrate advances in ecological knowledge into policy and management decisions that affect ecological sustainability.

B. Promote a thoughtful public today and educate future generations so that the public can use the best ecological knowledge when making individual choices about sustainability.

Area A: Integrate advances in ecological knowledge into policy and management decisions that affect ecological sustainability.

A growing consensus has emerged worldwide that, as might be expected, better environmental decisions occur when choices are informed by dialogue among scientists, policy makers, and the public (OST and Wellcome Trust 2001, Parsons 2001, Worcester 2002, 2000). Nevertheless,

Over the years, ecologists have created a huge knowledge base, but they do not always advertise its availability or know how to present it to nonscientists in comprehendible form. If ecological knowledge is to be better integrated into public policy and management choices, there must be better communication and collaboration between ecologists and the people who develop the policies and manage the resources.

Recommended Actions:

ID Action 1. *Establish an international network of Centers for the Ecological Implementation of Solutions (CEIS).* (also see AR Action 1 below and Box 5). Building on existing expertise and infrastructure within the ESA and other professional societies, government, and private institutions and programs, CEIS would foster partnerships among researchers, managers, and decision makers to actively develop and disseminate relevant new information to the appropriate audiences. Various developmental methods (e.g., workshops, working groups) and outreach methods (e.g., Web-based materials, white papers) would be used to build support for the centers.

The media should not be overlooked. Not all of its members are responsible or have the time or inclination to determine the relevance of complex ecological information. But some are, and they complain that their editors lack interest in stories that do not promise miracle breakthroughs or can not be told in a few words. Ecologists should cultivate relationships with the more thoughtful reporters and editors.

The centers would play a pivotal role in linking research scientists with managers to ensure a broad understanding of the science that is needed to take us toward a more sustainable future. The centers would address policy and management issues at local to international scales by involving interdisciplinary groups of scientists and managers in solving shared problems.

Such an approach would provide valuable forums for connecting ecological science to its applications in policy and management issues that affect sustainability. Projects hosted by the centers would address issues that range from local to international decision making. Scientists, policy makers, natural resource managers, or corporations could feel free to propose projects. The projects would share one provision: each must involve true collaboration and balanced representation among the users and producers of ecological knowledge.

The centers would provide a "level playing field" that encourages high-quality, two-way exchange of information between decision makers and scientists. *Two-way* exchange is critical, because the goal is to improve integration of the very best ecological knowledge into policy and management *and* to inform the direction of ecological research to address societal needs. In addition, because so many issues of ecological sustainability are inherently interdisciplinary, the centers also would provide a venue in which ecologists could collaborate with economists, engineers, hydrologists, and scientists from many other disciplines in solving shared problems.

The projects hosted by the centers would produce a rich set of "experiments" in linking ecological science to sustainability policy and practice. This presents an enormous opportunity to learn the best way to create such linkages. An assessment activity would be part of all projects hosted by a center. It would analyze methods for encouraging group interactions and communication and would evaluate the projects' impacts on ecological sustainability. What researchers learn from these assessments would be documented in a body of scholarly literature on the institutional arrangements and processes that work best in joining ecological science to its applications (e.g., Bennett et al. 2003, Cash et al. 2003, Castillo 2000).

The centers would function with a small permanent staff and facility to support projects, to conduct project assessment activities, and to ensure continuity across projects in selected areas of special interest. For example, over a given period of time, a center might host a set of projects on specific issues such as forest management, sustainable agriculture, or wetlands restoration. Ongoing participation by a dedicated staff member at a center would ensure that insights could be gleaned from comparisons across projects.

Functions anticipated for the centers include:

- Convening working groups, symposia, and analytical projects that will improve the integration of ecological knowledge into real-world policy or management issues at international, national, regional, or local scales.
- Convening projects specifically to evaluate the implications of new discoveries or conceptual advances in the ecological sciences for policy or management issues. These projects would communicate results more broadly across potential user communities, and thus reach a wider audience.
- Developing a special focus on effectively integrating ecological knowledge into land-use planning decisions made at the county level. Those decisions have profound effects on the environment and its sustainability, but this important area is particularly poorly addressed at present**.**

ID Action 2. *Build on programs that serve as "honest brokers" of information and use rapid response teams to assist decision makers.* The ESA could initiate partnerships to develop a program, based in Washington, DC, that would draw on expertise from the field of ecology to score legislative and executive branch proposals for their impact on ecological sustainability, and to identify experts who would expeditiously provide input and testimony on pending legislation or regulations. If successful, this venture would result, over time, in legislative and policy proposals that are better informed by ecological knowledge and an increased involvement by ecological scientists in legislative and policy processes.

The work will require a skilled and scientifically literate staff of science policy analysts who have permanent networking relationships with decision makers in Washington. These analysts also would be well-connected to the membership of the ESA and other societies in order to identify appropriate experts as needs arise. The staff would also work with experts to ensure they are effective in communicating their scientific knowledge through testimony, in writing, and other public participation opportunities. Their work would include:

- Developing and implementing an Informed by Ecological Knowledge (IEK) scoring system. The results would function as independent and objective report cards for pending legislation. The intent would be to assess and emphasize the quality of ecological science underpinning the legislation. They explicitly would not take advocacy positions.
- Serving as the contact point and source for scientifically credible and trusted advisors drawn from the membership of the ESA and other professional societies. Decision makers in Washington would know they could call on the team to rapidly provide high-quality, independent, and—above all—objective ecological input and testimony for emerging legislative, policy, and management issues. (In this sense, the team would function similarly to the US Congressional Research Service or the now-closed Office of Technology Assessment, and would act as a rapid response team that provides input on time-sensitive issues).

This program could serve as model for similar programs in major cities worldwide.

ID Action 3. *Increase the number of ecologists within government agencies who make decisions or influence the decisions of others related to ecological sustainability*. Individuals with strong backgrounds in ecological science will ensure that policy and management decisions are informed by the best available ecological knowledge; or, when the best available ecological knowledge is not sufficient, these individuals will be positioned to push to obtain it—to argue for targeted research or adaptive management approaches or both. Ecologists employed in positions that require frequent interaction with the public will have opportunities to educate the public on issues of ecological sustainability. Ultimately this should occur on a worldwide basis. To begin to increase the employment rate of ecologists in agencies and the legislative branch in the US, the ESA could undertake the following:

- Develop a postdoctoral program, such as the AAAS Science, Technology and Policy Fellows, and the National Sea Grant or John A. Knauss Marine Policy Fellowships, designed specifically to place promising early-career ecologists on Congressional staffs and in federal agencies.
- Collaborate with workforce planners in federal and state agencies in building ecological capacity and knowledge. Particularly important places for capacity building include agency functions that interact with the public (e.g., NRC's field service representatives, Bureau of Land Management agents, county agricultural extension agents) and that conduct research that should, but presently does not, often have an ecological component. Possible approaches include persuading managers of the importance of ecological knowledge within agency mission statements and helping agencies develop postion descriptions and advertise openings across the ESA membership.

Area B: Foster a thoughtful public today and educate generations of tomorrow so that the best ecological knowledge informs individual choices about sustainability.

In the near term, accomplishing this goal will require a full-scale public information effort. The campaign would seek to increase awareness about ecological sustainability and explain the sustainability issues affecting the quality of people's lives and those of future generations. There is no question that the public is aware of threats to sustainability, especially when "sustainability" is related to the well-being of the public's children and grandchildren. But there is ample evidence of public uncertainty—perhaps fuelled by the "environmentalists versus developers" tone of much of the discussion—over how sustainability might best be achieved. Through this information campaign, members of the public will become more aware of ways in which their decisions and actions make a difference, and they will better understand the science that should inform their choices. They also will learn that concerns about sustainability include much more than the charismatic "mega-issues" such as climate change and species extinction.

Over the longer term, a full-scale public education program will be essential to ensure lasting changes in the public's understanding of the link between ecology and sustainability. The next fifty years will be a period of great change in ecosystems worldwide, and future generations must be prepared to make sound and scientifically informed choices that influence the environment at all levels—local, landscape, regional, and global. Education will be critical if future generations are to have the necessary knowledge, attitudes, and skills to do so (Castillo et al. 2002, Jenkins 2003). There is considerable evidence that the public, especially younger persons, will welcome such education.

Ensuring that ecology education provides a foundation for informed decision making will require improved literacy about ecological sustainability among teachers and integration of ecological sustainability into the standards and curricula mandated by countries, states, and provinces (Berkowitz 1997, NCSE 2003, Slingsby and Barker 1998). Busy educators at all levels also need increased access to ecological knowledge in useful formats, as well as to the latest advances in ecology education theory and practice.

Recommended actions:

ID Action 4. *Develop a major public information campaign to bring issues of ecological sustainability before the general public.* The campaign will be of sufficient scope and breadth that it will significantly raise awareness about ecological sustainability among most segments of society. Additional targeted campaigns will seek to increase understanding among attentive and influential segments of society.

The ESA, in collaboration with funding and other partners, can help create a campaign that delivers a science-based perspective on ecological sustainability and that avoids advocacy of specific policy positions. Parts of the campaign could be structured around a set of high profile issues of broad public concern and help audiences understand the scientific basis for solving problems of ecological sustainability. Other groups have already begun education campaigns, and ESA should not reinvent the wheel—ESA should partner with such groups, help leverage resources, and bring the membership of these groups into the process.

Broad-scale dissemination of information to the public demands a quantum leap past conventional print, broadcast, and Web-based media. National awareness of what ecological sustainability is and how each citizen is connected to his or her ecosystem will require a coordinated and prolonged campaign of Internet, television, radio, and print media—one on the scale of the US antismoking campaign.

For example, the ESA, working with other partners, could hire professionals in mass media communications to design and implement the campaign. Strategies could include public service announcements in radio, network TV ads, and posters on billboards and in public transport systems ("This is an ecosystem" [a series of posters depicting a variety of systems, from drops of rainwater to satellite images of the Amazon basin]; "Have you seen your ecosystem lately?"), and more comprehensive materials for those who would like to learn more. Specialized campaigns should also target groups that have the ability to effect significant changes in public policy or industry—for example, members of Congress, national industry associations, and environmental lobbyists and similar audiences in state capitals.

ID Action 5. *Work with diverse public, nonprofit, and religious organizations to better integrate ecological knowledge into their relevant outreach and public education campaigns.* Many religious groups have responded to emerging environmental concerns by linking values to an ethos of environmental stewardship. The ESA can encourage the integration of contemporary and rigorous ecological knowledge into this movement by providing speakers on ecological issues of local and national significance and developing appropriate information products. For example, the ESA could prepare targeted information packages by working with multi-faith organizations and scholars that are addressing the link between ecological sustainability and religion, such as the National

Religious Partnership for the Environment (http://www.nrpe.org/mission.html), and the Harvard University Center for the Study of World Religions (http://www.hds.harvard.edu/cswr).

Numerous other government and private organizations are delivering messages to the public that directly or indirectly address ecological sustainability. Some already support the dissemination of peer-reviewed science (e.g., US federal and state agencies). These and many other organizations, including environmental and sustainability NGOs, would benefit from broader involvement of ecologists in helping to build scientifically accurate messages; however, they may not be aware of the enormous resources the 8,000 members of the ESA represent. The ESA could facilitate the involvement of ecologists by building working relationships between the ESA Governing Board and such organizations (through memoranda of understanding, for example) and then "matchmaking" between each organization's needs and expertise from across the ESA. The matchmaking could take place either actively on a case-by-case basis or by creating a Web-based resource built upon the existing Ecological Information Network (EIN 2004).

ID Action 6. ***Establish internationally-coordinated ecology education programs.*** The goal of these programs is to ensure that systemic changes occur in ecology education to make better and more effective use of concepts and discoveries in sustainability science. The programs could be modeled after the National Academy of Engineering's Center for the Advancement of Scholarship on Engineering Education (CASEE) (NAE 2002). The ESA would need to work with other ecology and education professional societies, education research institutions, and funding partners to establish local, national, and international programs.

Advances in ecology education research will also be essential to enable this systemic change. There must be better connections between ecologists and educators through education research, teacher education, science education policy development, and professional development. Relatively little support exists for any of these activities today, specifically for ecology education. Innovative programs could remedy this gap by connecting ecological knowledge with the best information from education research to advance K-12, undergraduate, and non-formal education (D'Avanzo 2003, Keys and Bryan 2001, Walczyk and Ramsey 2003). Programs must provide ecologists with access to best practices in teaching and learning, advances in educational research, and expertise from the education sector to help develop curriculum-based and developmentally-appropriate education or outreach programs (e.g., McKeown 2003).

ESA-related actions anticipated for education programs include the following:

ID 6a. Develop and deliver professional development programs for K-12 educators related to ecological sustainability. This might include an annual international Ecology Education meeting[1], bringing together a hundred leading science education specialists and ecologists. Each meeting could focus on developing ecological sustainability education programs and curricula of state, provincial, or national significance. The meetings also might promote ecologist-educator partnership programs such as SYEFEST (Schoolyard Ecology for Elementary School Teachers) at all levels of K-12 education.

ID 6b. Expand the TIEE (Teaching Issues and Experiments in Ecology 2004) FIRST (Faculty Institutes Reforming Science Teaching 2004), or similar undergraduate faculty support and enhancement programs for ecology education—with a special focus on ecological sustainability. Appropriate education research could be assisted by partnerships between the ESA and major education professional societies or education research centers to assess and disseminate information about such capacity building programs.

ID 6c. Analyze and participate in curriculum standards and textbook development for ecology in K-12 and undergraduate education. Government mandated national, state, and provincial standards, or programs of study, undergo review every five to ten years, and the reviews frequently attract partisans of various causes (the evolution-creationism debate is a prominent example). These reviews provide opportunities for scientists to make the case for, and explain the facts of, ecological sustainability (Blank and Brewer 2003). The ESA Education Office staff could track changes and opportunities for ecologists to participate in education policy reform.

ID 6d. Increase diversity among ecology educators nationally and internationally. Educators are usually the closest that most K-12 students come to working with anyone having scientific knowledge (Slingsby 2001). We need accessible role models to meet the needs of diverse student populations at the primary, secondary, and undergraduate education levels. The ESA could expand and apply the highly successful SEEDS program to recruit minority ecology undergraduate and graduate students to pursue careers in K-12 education—particularly in the area of ecological sustainability.

ID 6e. Establish a Web-based e-library that provides up-to-date access to advances in research and education on ecological sustainability. The library would be available to educators, curriculum developers, and the public, both within the US and internationally. The *ERIC Digests* provides a potential model for presenting best-practices and education research summaries for use by educators at all levels.

ID Action 7. *Work with the United Nations to declare an "International Decade of Ecology Education" as part of the Decade of Education for Sustainable Development (2005-2015).* International ecology education reform will require international actions. Such a declaration will raise awareness in the US and beyond about the significance of ecological knowledge in enabling sustainable ecosystems. It also is likely to result in policy outcomes, such as declarations that address government incorporation of ecological knowledge into decision making, education, and literacy. Actions to accompany this declaration could include the following:

ID 7a. Organize and implement a series of Ecology Education Conferences, bringing together professional science and education societies to identify advances, gaps, and frontiers in education related to ecological sustainability. The scope and sequence for the series could include: an all-society Ecology Education symposium at the 2005 ESA/International Association for Ecology (INTECOL) meeting, a 2010 National Ecology Education Conference for science and education professional societies, and a 2015 International Ecology Education Conference.

ID 7b. Publish and widely disseminate proceedings from the education conferences. Only four major books have been published by professional ecological societies, institutes, or ecologists since 1966 that directly address the status of ecology education in undergraduate education (Lambert 1966), environmental education (Bakshi and Naveh 1980, Hale 1993), and urban ecosystems (Berkowitz et al. 2003). The proceedings would promote scholarship in ecology education and provide educators at all levels with periodic syntheses of advances in education practice.

[1] The meetings could be modeled after the Woodrow Wilson National Fellowship Leadership Program for Teachers.

Summary - Informing Decisions

The most important thing we can do to move ecology toward assuming the critical role it must play in addressing our current and future environmental challenges is to get the right information into the right hands at the right time and in the right form. It is also one of our most difficult tasks. But it needs to be done if ecological science is to make its badly-needed contribution to sustainability. For this to happen, we must take the responsibility to ensure that our science is relevant and that it is used in all levels of decision making. The strategy we propose will promote a foundation for progress that will move ecology beyond the marginal role it currently plays to full partnership in decisions regarding ecological sustainability.

In our vision of the future, ecological knowledge is a standard and necessary factor in decision making in all aspects of society. If we are successful, ecological scientists will be called upon to assist in policy decisions at the local, national and global levels. Industry will see ecological science as a friend, rather than opponent—and as a key ingredient in making economically and socially good business decisions. Natural resource managers and research scientists will work together to develop more informative and useful research programs. We will see the fruits of ecological education in a global human population that better understands our dependence on ecological services and that respects and appreciates biological diversity. We believe this vision is obtainable, but this future depends on the actions we take now. The vast array of existing information, important advances in research, technological innovations, and exciting new collaborations that are called for in other parts of this report will provide ammunition but will not move us forward unless we have the structure in place to take us from data, to outreach, to application.

VISION 2:

ADVANCE INNOVATIVE AND ANTICIPATORY RESEARCH

Vision Statement: *Broadly innovative and effective ecological research in the 21st Century will require proactive research in which ecologists anticipate problems and needs, develop creative and sometimes high-risk ideas, employ novel methods, and are willing to work at unprecedented scales and levels of coordination. Within this decade, steps must be taken to develop, implement, synthesize, and apply new conceptual approaches, analytical methods, and technological tools. The aim here is to quantify, explain, and predict ecological phenomena critical to the sustainability of the biosphere.*

Rationale

Ecological research questions extend across a spectrum that ranges from increasingly rich and sophisticated molecular-level analyses of both living and nonliving components of the world's ecosystems to integrated views of the entire globe (e.g., Thompson et al. 2001). The enterprise of ecological research already spans Earth and is reaching into our solar system. It ranges from remote outposts on land and sea, to the familiar patchwork landscape of more developed areas, to the heart of our most populated cities. Despite this, ecological understanding still often lags behind the scale and rapid pace of changes that occur on the planet (Vitousek 1994, Lubchenco 1998, NRC 2001). The extent of human-induced environmental change is making the science of ecology increasingly critical to the future of life on Earth (Lubchenco 1998, NRC 1999, 2001, NEON 2000, NSF 2000, NSF-ERE 2003). We must *anticipate* the scientific needs, not simply react to and report on them.

For ecology to meet the challenges of the future, we must develop anticipatory and novel conceptual, analytical, and interdisciplinary frameworks. Progress in understanding ecosystems—how they function, how they relate to one another, and how they can be restored or created to provide essential services—requires the development of new, imaginative tools and improved accessibility and ease of use of technologies. Comprehensive ecological understanding demands integration and synthesis of multiple sources of information. Widely accessible, integrated devices to capture information in ecology and allied disciplines are needed, even those whose links to ecological sustainability are not immediately apparent. The interdisciplinary nature of the research we need means that new models of collaboration must be built both at the national and international levels.

The research we undertake must be ultimately motivated by the need to build a better understanding of how ecosystem services are provided and can be sustained. Basic research is critical; solution-driven research is its partner. To accomplish this will require not just highly innovative thinking that *anticipates* future needs and problems; it also will require significant changes in the way ecological information is collected, synthesized, and communicated, and it requires new research tools, approaches and infrastructure.

Action Areas for Advancing Innovative and Anticipatory Research (AR)

A. Enhance the intellectual and technical infrastructure for ecology.

B. Create new incentives to recognize and encourage anticipatory and innovative research.

C. Promote the standardization of data collection, data documentation, and data sharing.

<u>Area A.</u> Build the intellectual and technical infrastructure for ecology.

Ecological understanding rests on knowledge that is gained from multiple avenues, including experimentation, theory and modeling, comparative observations, long-term study, and synthesis (Carpenter 1998). The environmental research community has generally responded to problems that are *here and now* (e.g., biodiversity loss, the spread of nonnative species, the initial signs of global climate change). We also need a focus on the future, even though by definition the future is largely unknown. We need a new body of knowledge, radically new research agendas, and new ways of ensuring that ecology is a component of the important decisions facing society in the future. We need additional funding resources to support research, but we also must foster intellectual and interpersonal support within our discipline for experimenting with new conceptual frameworks and for developing new analytical methods.

New frameworks mean envisioning the knowledge and research that we need to realize a future world in which socio-ecological systems are sustainable. Forward-looking, anticipatory research goes beyond what we know is technically feasible *now* to what *could be* feasible if we only knew or had some piece of information, a new tool, or some analytical solution (Box 4). The intellectual infrastructure we need to accomplish anticipatory research is not just idea-driven but also includes a suite of widely available tools for the seamless integration of data, theory, concepts, and models. In some cases, this framework (e.g., software, algorithms) is reasonably well–developed, yet progress in collecting and evaluating new data is limited by technical or financial barriers. For example, the quantitative approaches to design and interpretation of results from studies of variance in both space and time simply do not exist, yet such variance can be a major factor in determining key ecological responses (Rusack et al. 2002, Burrows et al. 2002, Fraterrigo et al. in review).

Experimental tests of new ideas will in many cases require replicating large-scale manipulative experiments. Efficient computational algorithms will be needed to store, analyze, and view the volumes of data that may be generated. Interdisciplinary frameworks that incorporate such complicated interactions as multivariate causality, nonlinear feedback, and individual-based decision making are sure to be at the leading edge of future research that explicitly incorporates humans in the system. Thus, we will need the infrastructure (e.g., NEON, LTER, ocean observatories) to conduct large-scale experiments, but we also will need significant increases in training, collaborations, and infrastructure to assist in the rapid and thorough development of a theoretical and analytical framework—one that can optimize subsequent efforts in data collection and synthesis (Clark et al. 2001, Hastings and Palmer 2003, Palmer et al. 2003).

Advancements in research technology, notably the development of automated sensor systems for *in situ* and remote measurement of ecological phenomena, should become fundamental to future ecological science. In some areas, such as remote sensing, scientists are making good use now of technologies that address the complex scales of modern ecology, and ecologists have also helped drive the research and development of new tools. After the first satellites were launched for weather prediction in 1960 (Hastings and Emery 1992), scientists, including ecologists, eagerly began using them to gather ecologically relevant information about the surface of the Earth, from landscape structure to fluxes of key elements (e.g., Botkin et al. 1984, NRC 1986, NASA-EOS 2003). Almost magically, we were able to view and assess our planet from a totally new perspective—and, furthermore, to measure its change over time.

Nonetheless, we still do not see Earth with the clarity and resolution we need. Similarly, our resolution of the ecosystems below land and water surfaces, and our ability to collect species and genetic data at the necessary spatial and temporal scales, still fall well short of the detail we need to answer many key ecological questions (e.g., Soulé and Orians 2001). Furthermore, we have yet to realize the full potential for applications of new molecular techniques to ecological research. As the new techniques have become available, our appetite has grown for even more sophisticated tools.

New technologies, such as satellite platforms, increased computing power, and robust GPS-based tracking devices, to name just a few, can help overcome barriers to progress. Astronomers could not unravel mysteries of our solar system without high-powered telescopes; physicists could not see the structure of an atom without massive accelerators. Ecology needs similar technologies to allow it to face similar grand challenges (NRC 2001), but ones that do not resolve so easily into single flagship instruments. Instead, understanding the extraordinary complexity of life on Earth requires a diverse portfolio of tools and approaches. Designing and implementing such a portfolio will be essential to the success of ecology in helping the human enterprise arrive at a more sustainable future.

Recommended Actions:

AR Action 1. *Fully scope and then promote the four-pronged Ecological Research for Sustainability Initiative. The initiative requires close coordination among two novel programs, an existing center (The National Center for Ecological Analysis and Synthesis [NCEAS]) and a new center. The goal of the initiative is to facilitate: i) research project development, ii) large-scale experiments and data collection, iii) synthesis, and iv) the linkage of science to solutions.* To successfully manage, restore, and create sustainable ecosystems, we need new ways of thinking, along with the ability to generate and test bold ideas without being hampered by institutional arrangements that limit access to information and people. Ecology is vastly complex; no individual or single group of ecologists can acquire optimal expertise in the wide range of disciplines that are encompassed by an ecological science for a crowded planet. Researchers must be able to easily obtain the intellectual and technological tools they need to answer a question without becoming experts in multiple fields. Funds must be available for individuals and groups during the “maturation phase” of their research idea. There are a few federally supported grant programs for idea development (e.g., NSF incubation grants). Many more are needed.

Thus, we recommend establishment of new programs and one new center that build from and

Box 4

Anticipatory Research

Until now, much of ecological science has been based on reaction. We want to know why climate is changing; why species are going extinct; what happens when exotic species invade an ecosystem. To keep pace with today's explosion in environmental discoveries and threats, we also need to engage in *anticipatory research*—to use novel ideas, powerful data acquisition and management tools, and new technology that is developed to prepare for, and perhaps build defenses, against what is coming next.

Case study: Understanding exchanges between large rivers and their floodplains

River-floodplain ecosystems are among the most dynamic, spatially complex, and biologically rich habitats on Earth and a main intersection between environment and society. Their high diversity and productivity result from their position at the terrestrial-aquatic interface and from interactions between physical and biotic processes. Terrestrial and aquatic areas are alternately connected and disconnected as waters inundate and recede from the floodplain, producing a shifting river- and -landscape of habitats that change dramatically in size, duration and arrangement [1]. This variable mosaic of land- and water-based components is a unique property of river-floodplain systems that profoundly affects both the direction and magnitude of critical biotic fluxes, such as organic matter transport and deposition[2]. This movement of organic matter is extremely important to the provision of ecosystem services such as clean water and riparian vegetation suitable for wildlife and recreation. However, little is known about how organic matter is actually exchanged between a river and its floodplain because the interaction between flow and complex features of the habitat make it difficult to measure this exchange.

To ensure adequate water for human consumption and to support natural systems, we need to be able to answer questions such as: Under what conditions and at what scales is the floodplain a source of organic matter to the river, and under what conditions and scales does the floodplain store such matter? Are there thresholds in physical processes, habitat connectivity, or biotic community composition that cause the system to change state, such that the floodplain releases rather than stores carbon? Answering these questions is critical to our abilities to preserve and restore ecosystem services along rivers.

Recently, water researchers have called for new integrative conceptual frameworks and critical empirical data[3]. To develop these frameworks and gather the necessary data will require: a distributed array of *in situ* sensors that can record key functional variables (e.g., rates of denitrification) remotely and at appropriate spatial and temporal scales, perhaps in multiple rivers; event-based remote sensing of the extent and depth of flooding and recession; spatially explicit models that link surface and ground water flows in a landscape that is complex in topography and vegetative communities; analytical methods that incorporate nonlinear dynamics and complex feedbacks; and experimental floods of varying magnitude.

[1] Ward et al. 1999; Malard et al. 1999; Tockner et al. 2000

[2] Bayley 1989, Junk et al. 1989, Bayley 1995

[3] Gurnell et al. 2000, Wiens 2002, Ward et al. 2002, Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) 2004

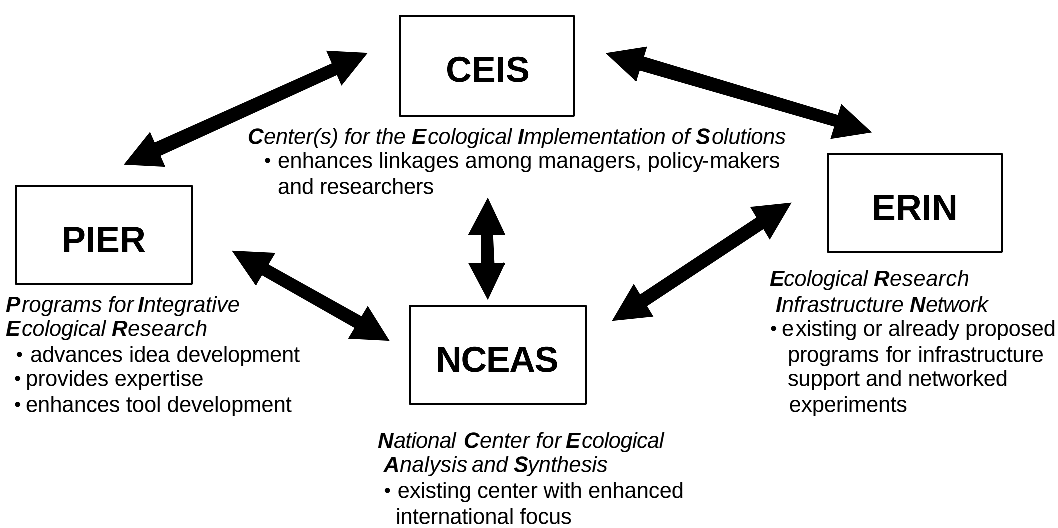
add to existing and planned resources and infrastructure (Box 5). Individually, the initiative's components would greatly enhance research capability by providing both virtual and place-based resources and facilities. **With tightly-linked components, the four-part initiative would provide a powerful integrated system to stimulate the sophisticated, collaborative, and innovative approaches necessary to design and conduct new research, analyze multifaceted data, and interpret complex ecological information to the public.** We are not suggesting that the specific research to be done should be dictated by a committee. Rather, the initiative would provide information, tools, and services to individuals or user groups that may enhance design, implementation, and synthesis of research. Furthermore, the resources from these programs and centers would be open to all users, regardless of the nature and scope of their projects, and would be easily available to them, both on-line (virtual) and in their physical settings.

As a whole, the initiative would facilitate: 1) the development of complex research projects that directly address issues of sustainability or enhance the basic ecological science that must underlie sustainability science; 2) the ability to conduct large scale projects or gather unique data; 3) research synthesis; and 4) the implementation of the research that leads to policy and/or management solutions. We expect that one of the major benefits of this suite of programs and centers would come from changes in the ways ecologists and professionals from many disciplines interact productively.

This array of intellectual and technical infrastructure would build upon a successful existing center (NCEAS) and the proposed (NEON) (NRC 2003) to create a resource that collectively provides

Box 5

Schematic of the four components of the Ecological Research for Sustainability Initiative. Where appropriate, a research project could benefit from all four components or could enter or leave the sequence at any point, depending on needs. This structure creates a highly flexible set of resources for the full spectrum of ecological and implementation research needs.



the building blocks needed for a proactive and responsive future ecology. Furthermore, in an effort to maximize and integrate similar efforts, this initiative would promote collaborations with other such entities (e.g., Consortium of Universities for the Advancement of Hydrologic Science Inc. [CUAHSI]; Collaborative Large-Scale Engineering Analysis Network for Environmental Research [CLEANER]).

The initiative to advance Ecological Research for Sustainability would involve thoughtful coordination of a set of new programs, a new center, and an existing center to:

Enhance access to the latest and best expertise and tools—PIER (Programs for Integrative Ecological Research). Ecologists have a proud history of designing their own tools, whether they are computer programs, statistical packages, or equipment for collecting data—everything from cameras that record nocturnal visits by shy wild animals to adaptations of plastic plumbing fixtures that catch nematodes as they travel through the soil. But as research becomes increasingly complex, ecological science needs the latest, most applicable expertise, facilities, and technology. Presently, such services are either not available or are being met only on an individual basis. The program should be able to offer small grants for idea development that is forward-looking—that is, "anticipatory" research.

Further, this initiative would play a pivotal role in forging research collaborations ("expertise match-making") and would be a clearinghouse for the latest information on technology and methods relevant to ecological science.

The present lack of such a clearinghouse where information and guidance can be obtained is seriously hampering research progress. Many individual scientists have been able to overcome this hurdle, but doing so requires a great deal of time and effort, and will demand even more as researchers probe ever deeper into the complexities of ecological sustainability. A far more efficient arrangement would be for the information center to be operated by experts who can keep up with ever-changing technology and information.

This program would have the specific mission of assisting in the creation of novel ideas and accessing the most applicable, up-to-date expertise, facilities, and technology. We can accomplish this through staff experience in such areas as information management, analytical/modeling/statistical tools, and technology; creation of opportunities for multidisciplinary collaborations to form and to develop the capacity to conduct comprehensive ecological research; and serving as a Web-based clearinghouse for the latest information on technology, tools, and methods relevant to ecological science.

An explicit goal of the program would be to encourage ecologists to undertake ambitious, comprehensive studies that remain investigator-driven and are likely to yield substantial gains in ecological understanding.

Support existing initiatives that address ecological challenges—ERIN and NCEAS. ERIN (the proposed Ecological Research Infrastructure Network) would forge an international network of regional observatories—with field sites, intensive sensor networks, analytical laboratories, and experimental manipulations—to address key ecological challenges. Layered across this *regional* system would be an *international* network of experiments and monitoring infrastructure designed to address the ecological challenges that are fundamental to our goal of moving toward sustainability. We could form the network almost immediately by linking together and adding to existing and proposed research networks (e.g., NEON, LTER, OBFS, CUAHSI, CLEANER) and enhancing their research infrastructure, capabilities, and coordination.

The National Center for Ecological Analysis and Synthesis (NCEAS) already exists in the United States (UC-Santa Barbara) and successfully applies a collaborative and integrative approach to the advancement of ecological understanding as a supporter of synthetic research, development of novel modeling, simulation, and other analytical methods, and technical training. We envision an expanded role internationally and Web-based methods so that it would be an information clearinghouse for synthetic approaches. We strongly endorse continuation of NCEAS, and we support efforts by federal agencies to ensure the coordination of the existing networks.

Another initiative, the Centers for the *Ecological Implementation of Solutions (CEIS)* was described earlier in ID Action 1. We view centers such as these as absolutely essential to ensure that managers and policy makers work much more closely with researchers.

Overall, the Ecological Research for Sustainability Initiative is large in scope but vitally important if we are to move ecological research toward a future in which it effectively informs decisions at regional, national, and international scales. Each of the four components would develop programmatic areas related to its own mission. Some functions would be fulfilled as a virtual facility, while other elements of function would take place on-site. As a whole, this assembly would serve as a large, virtual institute and as a portal to a broad range of information and services that will be essential to past and future ecological knowledge and its application.

To more fully develop details and responsibilities of the Ecological Research for Sustainability Initiative components and the opportunities they can provide, *ESA, with the help of its membership, should secure support to work with the ecological community to gather information, analyze options, and make recommendations regarding the components' characteristics.* While NSF and other agencies might support these workshops and some portion of the institutes themselves, specific efforts should be made to engage other public and private entities that might be interested in this approach.

Area B. Create new incentives to recognize and encourage anticipatory and innovative research.

Ecologists must begin to look inward at ways in which their own institutional and personal culture may help or hinder a broad, maximally innovative approach to advancing ecological understanding. For example, ecologists need to become willing to coordinate their efforts in unprecedented ways: to construct and obtain large-scale, high-resolution datasets needed to address many current challenges in ecology. They also need to reach out to funding agencies with a clear, unified voice in ways that have been successful for other disciplines, and that could drive funding changes that will allow ecological science to address large, complex questions. These changes will require incentives as well as training for ecologists in the managerial hurdles encountered at this large scale.

Ecology must not only recognize, but also reward, the contributions made by innovations in technology, synthesis, informatics, and quantitative approaches. Degrees in physics, chemistry, and engineering are frequently earned based on the creation of new methods or instruments. This pipeline of innovation provides a steady supply of new tools that become broadly useful across the discipline. In contrast, it is a rare student in ecology who earns a degree in this fashion, despite the substantial impact it might have on the field.

Students are also typically not encouraged to pursue degrees that are largely based on synthesis of existing information, yet such synthesis is an absolutely essential and growing branch of ecological science (NSF-ERE 2003). Current training does not prepare young scientists and technicians in ecology to utilize ecoinformatics tools. Furthermore, modern ecology increasingly relies on a substantial level of quantitative and computer literacy; thus students in ecology should have rigorous quantitative training as a core part of their graduate programs. Continuing technical education for ecologists at all career stages is particularly important, given the pace at which available technologies are changing.

Incentives and recognition are powerful motivators in science, and ecology is no exception. We identify here several key incentives that would produce significant strides toward motivating and recognizing the major scientific developments needed for the ecology of the 21st Century.

Recommended Actions:

AR Action 2. *Seek a Nobel or Equivalent Prize in Ecology.* While there are some prominent international awards open to ecological scientists (e.g., *the Blue Planet Prize)*, there is no award of comparable prestige to the Nobel Prize for our discipline. There are international awards for environmental stewardship, but no high-visibility awards targeting the ecological *sciences* are given from within our disciplinary communities. This is somewhat astonishing, given the importance of the science of ecology for the global environment. A Nobel or prize of equal prestige in ecology would be a highly visible and effective way to recognize both the contributions made by the discipline and those made by individual scientists. The impact of such an award could be enormous.

Establishment of a new Nobel Prize would be no small task. The most recent Nobel Prize was established in 1967 for economics with a large donation from the Bank of Sweden. Thus, a new Nobel Prize or similar award would undoubtedly require both substantial endowment funds and collaboration with other countries. Nonetheless, success in this venture would guarantee a quantum leap in the visibility of ecological science to the world. The ESA could initiate and participate in a process of exploration of this idea by establishing a committee of influential and respected ecological scientists and leaders from outside the discipline to look at the feasibility of a Nobel Prize or equally authoritative new award in ecology.

AR Action 3. *Establish an annual award for the best new instrument or new technology.* Ecologists have shown remarkable innovation in borrowing technologies from other arenas. But for the most part the discipline has not exerted a coordinated and direct influence on both private and academic engineering sectors in ways that produce technologies designed specifically to address ecological questions. Active outreach to these sectors—including annual awards for the best new instrument—is essential. The growing need for ecological information with relevance to environmental problems means that profitable markets for such instruments exist. We envision an award given annually by the ESA for the best new instrument or new technology that will lead to a significant increase in ecological understanding.

AR Action 4. *Establish an international contest among collaborative groups to solve an annual ecological challenge.* We envision an "Eco Challenge" along the lines of problem-solving competitions that are conducted in mathematics and engineering. For example, an ecological challenge could be given at the ESA's Annual Meeting, and collaborative groups, perhaps with an emphasis on graduate students, would work to develop solutions. These challenges might require the development of new technologies, analytical approaches, models, and/or experimental designs, and solutions would be evaluated by a review team. At the following year's ESA meeting, all solutions would be displayed to highlight the diversity and creativity of alternative solutions. An award would be given for the best solution. The

Environmental Protection Agency recently announced a "design competition for sustainability" that is open to students. We applaud such efforts.

AR Action 5. *Create a prestigious journal on methods development*. The establishment of a prestigious new journal both recognizes and encourages research in a particular area. A journal devoted to research innovations in ecology would be a way of showcasing important new methods while providing a high-profile outlet for such work. Alternatively, a new section could be added to existing ESA journals in which developments in research technology are published.

Area C. Promote the standardization of data collection, data documentation, and data sharing.

Ecological analyses, and management decisions that rely on them, commonly employ highly diverse data. Unfortunately, much of this information has been accumulated and stored in haphazard and inaccessible forms in the nooks and crannies of research. This may not have been recognized as a big problem before the arrival of the digital age, but now it seems an archaic barrier to progress. Even when made available, environmental data are often highly distributed and profoundly heterogeneous, and few tools exist that can acquire and characterize data and models, and then make them widely accessible in a convenient, integrated way. These barriers to data access limit progress in environmental science, and greatly limit data use by resource managers, economists, political analysts, and other decision makers.

Much of the information that already has been gathered is no longer in useful formats, even for those who collected it. Progress in environmental science may most be limited now not by our lack of information, but by the fact that vast amounts of existing data are simply not accessible.

A revolution in information technology that will ease the generation of ecological knowledge is occurring in response to a growing need to document, store, retrieve, manipulate, analyze, and display data (Estrin et al. 2003). Information technology research is yielding mechanisms for ecologists to document their data using standardized protocols, and store their data in carefully managed, widely accessible archives. These data can then feed into the conceptual frameworks and analytical tools described above. Thus, ecology could greatly profit from the development of technological means, cultural inducements, and training opportunities to effectively represent ecological knowledge. This can be done via a suite of widely available tools for the seamless integration of data, theory, concepts, and models.

To implement this vision, we propose increased effort in technology development and training in ecoinformatics and Ecological CyberInfrastructure (ECI) (Box 6). ECI provides the link between people and the data, hardware, software, and other tools for creating and displaying ecological knowledge. Advancements in ECI require the development of generic tools for data input, access, and analysis. Ecological data should be digitally captured early in the acquisition process, while concurrently generating *metadata* (information about the data itself). Data then must be easily and widely accessible to individuals even in the most remote areas of the world through a set of generic data access tools. The goal is to link the vast body of data resources, whether they are small compilations, or large well-known data sources. The key tools are an efficient,

Box 6

Ecoinformatics and ECI

The International Society for Ecological Informatics offers this definition of ecoinformations:

"Ecological Informatics is defined as interdisciplinary framework promoting the use of advanced computational technology for the elucidation of principles of information processing at and between all levels of complexity of ecosystems—from genes to ecological networks—and aiding transparent decision making in relation to important issues in ecology such as sustainability, biodiversity and global warming." Many other disciplines—medicine, agricultural research, and engineering are only a few—are working toward perfecting their own informatics resources.

Ecological CyberInfrastructure is a close relative to informatics. According to the National Science Foundation, ECI can produce an "integrated high-end system of hardware, software, and services" that will allow scientists to "work on advanced research and education problems that would not otherwise be solvable."

flexible, and standardized way to describe ecological information, and a powerful information searching capability. One important result will be the enormous savings in the ecologist's time—time that could be devoted to more forward-thinking research.

Both undertakings were made possible by modern digital technology. They are vast improvements in the traditional ways of ecological record keeping and recovery. In the not too distant past, ecologists (and other scientists) kept their handwritten records in waterproof field books, filed in dusty boxes or on office shelves. Some still do. Only the author may have known where the information could be found, and after the author's retirement or death, the sometimes valuable data would be lost to science.

Once scientists acquire datasets, they must be able to quickly analyze them, and transport them into appropriate visualization tools that make the data understandable. It will then be possible to rapidly find, download, and analyze disparate datasets to test an idea much in the way we now use abstracts of articles to get a sense of whether a new idea warrants our further consideration. Sophisticated visualization tools, including maps and landscape-based Geographical Information System (GIS) data and virtual imaging, will make communication within and beyond the scientific community easier and more effective, and allow major advances in ecological modeling. Through improved generic data input, access, and analysis tools, standardized metadata, and open access to environmental data, more comprehensive analysis and synthesis of ecological knowledge will be possible. Both the original gatherer of the data and the science world at large will be the beneficiaries—as will, eventually, Earth's health.

Several of the actions we recommend are already being considered by others. This is very encouraging. For example, the NSF's Long Term Ecological Research (LTER) network has made great strides in some of the action areas below.

Recommended actions:

AR Action 6. *Develop a data registry.* The registry would be a simple form that characterizes the core features of a data set, generating a data catalog identifying the data and its owner. The ESA could encourage all authors of articles in the Society's publications and presenters at its meetings to use the registry.

AR Action 7. *Make raw data and metadata easily and freely available.* The ESA could lead this effort, setting a goal that 20 percent of all papers published in its own journals include metadata by 2006. By 2008, all papers should make associated raw data and metadata easily and freely available. The ESA could help lead an effort to actively encourage federal and state agencies, NGOs, research centers and field laboratories and their scientific societies to follow suit.

AR Action 8. *Convince funding agencies and federal agencies to require and support open access to data.*

AR Action 9. *Encourage training in ecoinformatics both during graduate school and in ongoing programs.* The ESA could promote ongoing training through regular training workshops and opportunities at its Annual Meeting.

Summary - Innovative and Anticipatory Research

Ecology is by its very nature an interdisciplinary science, making it impossible for any single ecologist to be well-versed in the details of every relevant discipline, method, or instrument. Yet, it is increasingly obvious that ecologists must come together to help understand, solve, and anticipate the environmental issues facing our world. To do so, ecologists may need to think of themselves as entrepreneurs in a shifting and pressure-driven marketplace, where strategic collaborations and rapid responses are keys to scientific success. Our best chance to succeed in those efforts is to have a broadly inclusive approach to ecological research. This approach must include actively recruiting expertise beyond our discipline, as well as changing our own culture to best foster the innovations we need. We are, in effect, a company facing enormous challenges, but ones that, if met, will have immeasurable rewards. Like any successful company, we must therefore be willing to change our approach and structure rapidly to keep pace with the demands of the modern and future world.

If this action plan is successful, we envision a future ecology with a diverse portfolio of new ideas, theories, methods, and technologies. Ambitious, comprehensive research programs will be under way by 2010, providing society with new knowledge that is made readily available to educators, decision makers, and the public, including those members who are most enthusiastic: young people. All steps required to increase ecological understanding—from data acquisition to analysis, interpretation, synthesis, and application, as well as research that anticipates the future and probes the present and the past—will be significantly enhanced within the coming decade. If successfully implemented, this new depth and breadth of ecological understanding, including its improved communication beyond the discipline, would allow ecologists to play an influential and eminently helpful role in decisions made at all levels that affect the sustainability of the biosphere.

VISION 3:

STIMULATE CULTURAL CHANGES FOR A FORWARD-LOOKING AND INTERNATIONAL ECOLOGY

Vision Statement*: Advancing ecological science for global sustainability requires that ecological science become more international in scope, that ecologists develop advanced expertise in the collaborative process, create new partnerships, and build diversity within the discipline. The culture of ecology must be transformed to influence how we think both individually and institutionally so that we can accomplish these goals and so that reward systems promote rather than hinder collaborations, partnerships, and diversity.*

Rationale

The goal of creating science for a sustainable world that includes an already large and increasing human population requires that human activities and a global perspective be vital components of ecological research. This means more than studying direct human impacts on the environment in one or more particular areas. Rather, the complexity of human economic, social, political, and environmental management activities at regional and global scales must be considered as a critical part of ecological systems, and the goal of ecology should include solving problems, not just describing them. The effort to incorporate human processes into research is under way (McDonnell and Pickett 1993, McMichael et al. 2003) but needs to accelerate. For example, in several sections of the United States, farmers and other citizens are working with scientists to measure human effects on stream ecology.

Our report thus far has stressed ways in which ecological research can be accelerated through better networking, creation of new research initiatives, educational outreach, and improvements in technology and data-sharing. However, the ability of the ecological sciences to deliver the knowledge that will help society understand and address environmental problems requires further changes. Ecology's culture requires new ways of working, better reward systems, and more fruitful interactions with other disciplines and new partners, nationally and internationally, as well as with the public.

In the last decade we have seen greater recognition of the value of collaborative work, greater institutional acceptance of applied research, and diversification of career options in ecology. We need to go even further. We must build, develop and support successful and diverse collaborations involving natural and social scientists as well as decision makers. There must be rewards for leadership and increased diversity in ecology-related fields. Ecologists and institutions must think and act internationally to better address large-scale environmental problems and solutions that will require multinational, as well as collaborative, approaches.

Action Areas for Stimulating Cultural Changes (CC) for the Ecological Sciences

A. Capture, translate and disseminate knowledge on successful collaboration.

B. Broaden diversity within ecology by promoting cross-disciplinary interactions and partnerships, and by increasing gender and ethnic diversity within the discipline.

C. Forge international linkages and globalize access to ecological knowledge.

Area A. Capture, translate and disseminate knowledge on successful collaboration.

In the future, the need will grow to seek out and amalgamate relevant expertise to address emerging and anticipated environmental problems, which undoubtedly will become more complex. Multidisciplinary research will become less a rhetorical ideal and more a reality and necessity. Teams will be built rapidly and often with members who have not collaborated with each other in the past. These teams will need to provide solutions or at least propose scientifically well-informed choices over short periods of time. Given these needs, ecologists must approach the challenges of collaboration in more deliberate and self-reflective ways in order to reduce the risk of unsuccessful collaborations and failed enterprises. While there is already a general intellectual acceptance of collaboration as critical to ecological science, very little work has been done to examine how and where interdisciplinary collaboration occurs, when and why it leads to scientific innovation, and why collaborations sometimes fail. **We need to understand what promotes successful collaborative enterprises and we need to communicate that knowledge within our research communities. The result will be a marked change in ecological science's very culture.**

Problem solving will demand many new forms of collaboration as well as the infrastructure to support them. Funding programs need to recognize and support the increased level of communication and administration necessary to carry out effective team research. (The National Science Foundation's biocomplexity grants reflect this, to cite one of few examples.) We need mechanisms to promote international, cross-disciplinary and cross-institutional collaborations. One way to do this is by providing resources and advice for the special challenges faced by groups made up of scientists and nonscientists with diverse backgrounds and training. These issues demand that, on top of all their other duties, ecologists become more knowledgeable about the collaborative process.

Collaboration training will apply to multiple levels within the community of ecologists, among academic disciplines, and between ecologists and other groups. It will promote dialogue among ecologists working in academia, agencies, and the private sector. Collaboration will foster dialogue between ecologists and other academic disciplines, and between ecologists and management agencies. Collaboration between ecologists and managers is especially important to the practice of adaptive management. Lack of trust and dialogue is often stated as a reason for the failure of promising management approaches (Walters 1998).

Study of interdisciplinary collaborative efforts by social scientists suggests that there are common elements to successful collaboration. The environmental science community should learn from this new body of research in order to facilitate the collaborative efforts necessary to address complex environmental problems. We suggest partnering high profile interdisciplinary groups of scientists with social science researchers and professional facilitators in order to publicize the benefits of collaborative efforts, as well as to learn how to collaborate more effectively. Promoting effective collaborations will require managerial skills and not just individual accomplishment in scientific research. The ESA can take a leadership role in working with other societies to promote training in collaboration and expose ecologists to new research findings from social scientists engaged in studying collaboration.

Recommended Actions:

CC Action 1. ***Create resources that will help ecologists and their collaborators work together more effectively.*** Drawing on the latest social science research and building on the experience of those who have engaged in successful collaborations, we can capture existing knowledge and make it available to the scientific community.

CC 1a. Organize a working group composed of environmental scientists and social scientists to publish a "primer" for successful collaboration. The guide would be used to educate the community at large and serve as an important resource for new collaborations.

CC 1b**.** Develop a leadership program that focuses on issues of collaboration among applied scientists, social scientists, and policy makers. The goal would be to help develop leaders trained in the art of collaboration. This would be analogous to the Aldo Leopold Leadership Program (http://www.leopoldleadership.org) but would be focused on stimulating the success of collaborations.

CC Action 2. ***Stimulate proactive changes in flagship ecological journals and in meeting symposia.*** These changes would reflect the increased emphasis on interdisciplinary solution-driven science, particularly that which is focused on regional and global scale problems of joint interest to ecological researchers and practitioners.

CC Action 3. ***Convene a meeting of key leaders (National Academy or Royal Society level) in research, management, and business to develop a plan for enhancing the reward systems for those who exercise leadership in the environmental sciences and those who foster novel scientific collaborations.*** The reward system for applied and solution-driven ecology should also be evaluated so that these contributions are promoted within academic, government, and private sector institutions.

Area B. Broaden the human and disciplinary dimensions of ecology.

The field of ecology is more than an academic discipline, and its purview extends well beyond national borders. For example, only half of all ESA members are academic ecologists, and although it is a North American organization 16 percent are not U.S. residents and 78 countries are represented within ESA's membership. To perform more effective solution-driven science it is necessary that ecological researchers, managers, practitioners, and businesses work not only collaboratively, but also across borders. An example of this strategy is the European Union of Coastal Conservation (EUCC) (http://www.eucc.npl). The EUCC is an association with members and member organizations in 40 countries, founded in 1989 with the aim of promoting coastal conservation by bringing together scientists, environmentalists, site managers, planners, and policy makers. Currently, it is the largest network of coastal practitioners and experts in Europe. The EUCC sponsors activities that promote coastal conservation while integrating biodiversity conservation with coastal development. It does so by mobilizing experts and stakeholders, providing advice and information, and implementing demonstration projects.

Ehrmann (2003) notes that "a better understanding of the interrelationships between human well-being and the goods and services provided by ecosystems" can have an impact on business sector **decisions. Achieving global sustainability requires that consideration of environmental impacts become as fundamental to the decision-making processes of business as are calculations of return on investment.** In some cases, more forward-thinking businesses are already practicing this; they have learned that Earth's resources are finite and that sustainability is good for business. Trade and industry have been significantly affected by environmental concerns over the past several decades, and ecologists can advance ecological understanding and positive changes in corporate perspectives (Hoffman 1997). This requires fundamental alterations in the relationship between ecologists and the business community. The tendency for ecologists to simply "educate" business about environmental impacts when asked must give way to partnerships in which non-industry and industry ecologists and business representatives learn from each other to further the linked goals of economic and environmental sustainability.

The impact of business practices on the environment is significant. Novel partnerships between the public and private sectors that are informed by ecological knowledge can result in better stewardship of ecosystem services-through, for example, changes in the way wastes are disposed or environmentally persistent chemicals are used (Loucks et al. 1999). The Council for Environmentally Responsible Economies (CERES), a coalition of environmental, investor, and advocacy groups, has produced a report on how 20 of the world's biggest emitters of greenhouse gases are factoring climate change risks and opportunities into their business practices (Cogan 2003). The report features a checklist of specific actions that companies can take to address climate change. Additionally, the Center for Sustainable Systems Studies (O. Loucks, personal communication) is developing a guide to investment that would yield cheaper capital for companies conserving resources and protecting the environment, and more expensive capital for those who do not. Ecologists can play increasingly active roles in such projects through direct involvement or through research motivated by the needs of such ventures.

Ecologists can broaden the dimensions of their discipline in several ways: 1) active engagement between scientific institutions such as the ESA and the business community to enhance the understanding and use of ecological knowledge in decision making in sectors such as manufacturing, agriculture, resource extraction, and land development; 2) recognition of ecological researchers, managers, and practitioners as equal partners; 3) active recruitment of a greater diversity of people and their skills to the study of ecology; and 4) encouragement of broader metrics for evaluating scientists both within and outside academics. Existing disincentives for participating in such collaborations must be lessened and new reward systems developed.

Moreover, ecologists must work with diverse populations and in diverse contexts. Educating people, partnering with diverse communities, and persuading people to accept scientific expertise is a critical component of success in problem solving. Ecologists need to understand the varied perspectives and special problems of various communities. *The ecological community should reflect the diversity that exists in society at large, to ensure that its expertise can be applied and communicated to all sectors of human society. This includes not only ethnic, gender, and international diversity but diversity brought by including perspectives from the business sector, the NGO sector, the management sector, and the academic sector.*

Recommended Actions:

CC Action 4. *Engage with the private sector in four areas:*

CC 4 a. Enhance the value for private sector ecologists of belonging to ESA and participating in ESA activities. We can accomplish this through annual and regional activities that focus on the application and use of ecological knowledge, through plenary speaking invitations to private sector ecologists, and through development of workshops that address private sector problems. Private sector ecologists should help define and develop this action item.

CC 4 b. Recruit private sector ecologists to leadership positions in the ESA, particularly the Governing Board.

CC 4 c. Build cooperative partnerships addressing private sector needs. These would be analogous to past and present partnerships with federal agencies created through the ESA's Public Affairs, Education, and Science Programs Offices (Sustainable Biosphere Initiative) programs.

CC 4 d. Actively seek corporate support for the ESA's activities.

CC Action 5. *Sponsor symposia, workshops and projects that focus on the interface between the work of ecological scientists and ecological practitioners.* These types of activities would strengthen the flow of ideas between ecological scientists and ecological practitioners and provide benefits to both. Participants could share their state-of-the-art knowledge and identify gaps in information required for management.

CC Action 6. *Promote ethnic and gender diversity and equality in the ecological sciences.* Ecological research should expand beyond national borders and ethnic differences because the solutions to environmental problems and sustainability are inherently international and multicultural. Thus, partnerships with sister societies in other countries and programs to recruit underrepresented groups should be promoted. The ESA should not only collect, but also report the demographic statistics of Society membership in order to promote more gender, ethnic, and institutional diversity in ecology. Demographic trends need to be tracked so that ESA staff and officers can be more responsive to the its membership. The ESA should continue ongoing successful efforts to recruit minority students into ecology through the SEEDS (Strategies for Ecology Education, Development and Sustainability) mentoring and other programs.

CC Action 7. *Highlight nonacademic career paths in efforts such as SEEDS and other educational programs.* We will attract students from a greater diversity of backgrounds by pointing out the valuable contributions to ecological sustainability made by those in consulting firms, corporations, NGOs and government agencies and by increasing the visibility of those following other career paths.

Area C. Forge international linkages among ecological scientists and globalize access to ecological knowledge.

The scale of ecological science must match the scale of the most pressing challenges to ecological sustainability, such as climate change, invasive species, depleted fisheries, and water and land use changes (e.g., NRC 1999). Ecological science must be as big and as important as the environmental challenges it seeks to meet. **The predominantly national focus of many professional societies and institutions reinforces an insularity that impedes progress on regional and international scientific problems**. To broaden our discipline, in part, requires a more proactive approach to promote international cooperation among ecological and environmental scientists—in short, an alteration of the culture of ecology. For some scientists, this will bring uncomfortable change. But in the longer run, ecology will benefit greatly as an accepted science and as a solver of global problems. We need to create a multinational science agenda for exchanging knowledge and building collaborative multinational projects in areas that are critical for ecological sustainability.

Recommended Actions:

CC Action 8. ***Globalize access to ecological knowledge.***

CC 8 a. Routinely translate key articles from prominent foreign ecology journals and other sources into English and vice versa. Too often language poses a barrier that hinders access to ecological knowledge. Information relevant to scientists, students, managers, and decision-makers in many countries may only be accessible in one language. Often the published language is English even if the science originated in another country, and in contrast, if it is published in the indigenous language, it is rarely accessible to those outside the country. At the inaugural meeting of the Federation of the Americas at the ESA 2003 Annual Meeting, participants representing six countries identified translation of articles as a priority for action. They recommended translation of the ESA Journal *Frontiers in Ecology and the Environment* as an initial activity.

Global access to ecological knowledge fosters novel and collaborative research and will enhance the quality of ongoing projects. It will also make information accessible to decision makers in those parts of the world where biodiversity and threats to biodiversity are highest, but the capacity to respond to these threats is low.

CC 8 b. Ease the exchange of students, managers, and practitioners among institutions of different countries. Exchange programs involving students, managers and practitioners will have several positive outcomes: a) an update on ecological information and new technologies from other countries; b) a greater appreciation of local knowledge in developing countries by those from the developed countries; and c) international collaborations among students, managers and practitioners.

CC 8 c. Promote efforts to foster international collaborations among ecological societies. These collaborations will have a profound effect on research agendas and education programs by helping to build networks of ecologists from different countries.

CC 8 d. Foster international collaboration by seeking funds for multinational joint research programs among academics and practitioners. These could be similar to ongoing programs between the European Union and Latin America.

CC Action 9. ***Promote an international agenda for global ecological science.*** ESA can hold thematic meetings that focus on sustainability science. They should highlight international or interdisciplinary needs for ecological science that have come out of forums such as the Convention on Biological Diversity and the Intergovernmental Panel on Climate Change. The results of these meetings can be published and made widely available on the Web. An event at the joint meeting of ESA and INTECOL in August 2005 would be a good first start as would the meeting ESA is already planning to hold in Mexico in early 2006.

CC Action 10. ***Bolster an international young ecologists research community.***

CC 10 a. Develop an international Ecological Scholars program. These can be similar in nature to the Rhodes and Gates Scholars program.

CC 10 b. Create programs for exchange of students and postdoctoral researchers to research labs and meetings.

Summary – Cultural Change

The culture of ecology has grown, adapted, and changed throughout its existence. We are now at a juncture in which change must accelerate to meet the challenges we face if ecology is to play a significant role in developing a sustainable future for our planet. Single scientists, working alone in the field and in the laboratory, have given the world much valuable knowledge already. But now, collaboration and inclusion have become the backbones of addressing global environmental issues and achieving sustainability. To meet this challenge, we must consider the range of human economic, social, political, and management activities and undertake collaborations that involve natural and social scientists as well as decision makers from the local to the international level. We must work to globalize access to ecological knowledge and promote international collaborations and an international research agenda that focuses on regional and international problems. Coordinated efforts to train ecologists in effective collaborations and the expansion of the reward system for such activities will result in creative, novel, and productive programs that successfully address global sustainability issues.

We envision an ecological community that is distinguished by mutual respect among different cultures and among members from the worlds of academia, industry, NGOs, education, management, and policy. Collaborations within the international community of ecologists, as well as among other disciplines, will become business as usual and a key component of funding programs and professional success. Membership will mirror the gender and ethnic diversity of the global community and will be informed by the insights and expertise this diversity brings. These changes will have far-reaching benefits and ramifications across institutions, disciplines, and international borders. They will pave the way for ecological science to be an effective partner in the multicommunity, multidisciplinary efforts to reach the global sustainability that now is so essential.

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And our most important thank-you goes to the ESA members who provided invaluable direction and ideas through the questionnaire, the discussion session at ESA's 2003 Annual Meeting in Savannah, and through individual email and personal discussions with members of the committee.

Appendix 1: Acronyms and Abbreviations

AAAS — American Association for the Advancement of Science

AR — anticipatory research

ASLO — American Society of Limnology and Oceanography

AVHRR — advanced very high resolution radiometer

BEN — Biological Education Network

CASEE — Center for the Advancement of Scholarship on Engineering Education

CC — cultural changes

CEIS — Centers for the Ecological Implementation of Solutions

CERC — Center for Environmental Research and Conservation

CERES — Council for Environmentally Responsible Economics

CLEANER — Collaborative Large-scale Engineering Analysis Network for Environmental Research

CUAHSI — Consortium of Universities for the Advancement of Hydrologic Science Incorporated

ECI — Ecological CyberInfrastructure

EIN — Ecological Information Network

EPA — Environmental Protection Agency (US)

ERIC — Educational Resources Information Center

ERIN – Ecological Research Infrastructure Network

ESA — Ecological Society of America

EUCC — European Union of Coastal Conservation

FIRST — Faculty Institutes Reforming Science Training

GIS — Geographical Information System

ICSU — International Council of Scientific Unions

ID — informing decisions

IEK — informed by ecological knowledge

INTECOL — International Ecology Education Conference

IPCC — International Panel on Climate Change

K-12 — kindergarten through 12th grade

LTER — Long Term Ecological Research Network

NAE — National Academy of Engineering (US)

NASA-EOS — National Aeronautics and Space Administration—Earth Observing System (US)

NCEAS — National Center for Ecological Analysis and Synthesis

NCSE — National Council on Science and the Environment

NEON — National Ecological Observatory Network (US)

NGO — non-governmental organization

NIH — National Institutes of Health (US)

NOAA — National Oceanic and Atmospheric Administration (US)

NRC — National Research Council (US)

NSF — National Science Foundation (US)

NSF-ERE — National Science Foundation—Environmental Research and Education (US)

OBFS — Organization of Biological Field Stations

PIER — Programs for Integrative Ecological Research

SBI — Sustainable Biosphere Initiative

SeaWeb/COMPASS — SeaWeb's Communication Partnership for Science and the Sea

SEEDS — Strategies for Ecology Education, Development, and Sustainability

SYEFEST — Schoolyard Ecology for Elementary School Teachers

TIEE — Teaching Issues and Experiments in Ecology

TNC — The Nature Conservancy

UC-Santa Barbara — University of California at Santa Barbara

URL — Uniform Resource Locator

USDA — United States Department of Agriculture

WWF — World Wildlife Federation

Appendix 2: Summary of Committee Meetings

<u>Meeting 1: January 6-8, 2003, Washington, DC</u>

Committee Attendees: Margaret Palmer, Emily Bernhardt, Liz Chornesky, Cliff Duke, Jim Ehlringer, Robb Jacobson, Rhonda Kranz, Mike Mappin, Fiorenza Micheli, Jen Morse, Mike Pace, Mercedes Pascual, Steve Palumbi, Jim Reichman, Bill Schlesinger, Alan Townsend, Monica Turner.

Guests: Becky Allee, NOAA; Ann Bartuska, ESA Past-President, TNC; Scott Collins, NSF (now University of New Mexico); Jerry Elwood, USDE; Jeff Frithsen, EPA; Lara Hansen, WWF; Sue Haseltine, US Geological Survey; Tony Janetos, Heinz Center; Katherine McCarter, ESA Executive Director; Pamela Matson, ESA Past-President, Stanford; Mark Poth, USDA; Silvio Olivieri, Conservation International; Peter Preuss, EPA; Catriona Rogers, EPA; David Rogers, NOAA; Don Scavia, NOAA; Gerald Selzer, National Science Foundation.

Pam Matson and Ann Bartuska opened the meeting with a charge to the Committee to develop a Strategic Action Plan for ESA. The plan will act as a follow-up to the Sustainable Biosphere Initiative Report but with an implementation strategy. The result must go beyond a priority statement. It should do the following: (1) refresh the agenda of ecology; (2) identify impediments to progress in ecology; and 3) suggest mechanisms for overcoming these impediments. One of the goals of this initiative is to support the recent shift in the focus of ESA to more applied ecology and to increase the value of "practical science."

Several presentations were given in the mornings of the first and second days of the meeting. Katherine McCarter and Rhonda Kranz gave an overview of the structure of ESA. This was followed by a discussion of the outcome of the recent NSF Geosciences-funded workshop through ASLO, and their future direction ideas. The Committee heard presentations and had helpful discussions with representatives from six governmental agencies and three NGOs. They provided the Committee with an overview of what their communities would like from the ecological community. Ideas discussed included: providing information to act as ammunition for agency and organizational programs; more active involvement in management issues; help in educating the public with the idea that policymakers will follow the public; putting good scientists into top positions within funding agencies; providing research results more quickly and more widely; sharing data in order to accomplish urgent tasks; being bold and thinking big—asking the critical questions and finding the money; increasing the math skills among ecology graduates; more ecological training for non ecologists; increasing minority recruitment; developing more modeling/forecasting/predictive capacity; developing more collaborations; providing more training; increasing the convergence between scientific initiatives and conservation/ management needs; supporting the increase in monitoring networks.

All Committee members provided their vision for what could be accomplished as a result of the Ecological Visions project. The group aimed at developing a short vision statement that was compelling, easy to understand, inspiring, and just out of our reach. The following draft statement was proposed:

> We are in an era of unprecedented environmental change that demands more from ecologists. The ecology of the future must explain and predict our shared environment. Ecology must also be embedded in education to enhance public decision-making. The field of ecology must be poised to create a responsive and integrated science that harnesses the explosion of ecological knowledge, solves societal problems, and increases fundamental knowledge about

humans *and* the natural world. A revolutionary change is required in the way ecological information is gathered and used in research, education, and public decision making.

The group discussed research priorities, concluding that it was important to use the recommendations from previous reports such as those of NSF and NRC, but that the Committee must go beyond setting priorities to identifying specific actions to be undertaken. Four initiatives were identified as priorities in speeding progress in ecology. Working groups were formed to draft a document on each:

- Information Acquisition By and Access For All
- Necessary Cultural Shifts
- Outreach and Education (to all sectors of society)
- Technological Innovation & Development.

Meeting 2: April 1-3, 2003, NCEAS, Santa Barbara, CA

Committee Attendees: Margaret Palmer, Emily Bernhardt, Scott Collins, Rodolfo Dirzo, Andy Dobson, Cliff Duke, Barry Gold, Robb Jacobson, Sharon Kingsland, Rhonda Kranz, Mike Mappin, Fiorenza Micheli, Jen Morse, Mike Pace, Mercedes Pascual, Jim Reichman, Alan Townsend.

Guests: Gretchen Hofmann, UC-Santa Barbara; John Melack, UC-Santa Barbara; Dar Roberts, UC-Santa Barbara; Mark Schildhauer, National Center for Ecological Analysis and Synthesis; NCEAS Post-doctoral Associates.

The Committee welcomed three new members: Scott Collins (University of New Mexico), Sharon Kingsland (Johns Hopkins University) and Barry Gold (Packard Foundation).

The meeting focused on the "Information Technology" and "Research Innovations" Visions (developed from the information acquisition by and access for all and the technological innovation & development working groups). Presentations were given by a number of scientists from NCEAS and UC-Santa Barbara scientists.

Participants identified internationalization as a fifth Vision.

A decision was made to follow a rapid timetable with publishable forms of the Committee's recommendations to be complete and submitted by the end of December 2003. In addition to the Report to the ESA Governing Board, the Committee will pursue two publications to unveil the Action Plan.

The Committee developed a plan to obtain input from the ESA community at large, as well as federal agency representatives, NGOs, and industry representatives. The plan includes: 1) a series of breakfast briefings in Washington D.C.; 2) a questionnaire to go out to the ESA membership; 3) a report to the ESA Governing Board in May; 4) communication with the ESA Section chairs; 5) collaboration with the ESA Education and Public Affairs office; 6) a lunch meeting with the Latin American Ecological Society presidents at the ESA meeting in Savannah; and 7) an open forum and discussion about the Initiative at the ESA meeting in Savannah.

The members of the working groups were reconstituted and will continue to be fluid throughout the process. Working groups will continue to work on the five Vision area documents.

Meeting 3: August 24-28, 2003, Annapolis, MD

Committee attendees: Margaret Palmer, Emily Bernhardt, Liz Chornesky, Scott Collins, Andy Dobson, Cliff Duke, Barry Gold, Robb Jacobson, Sharon Kingsland, Rhonda Kranz, Mike Mappin, Marisa Martinez, Fiorenza Micheli, Jen Morse, Mike Pace, Mercedes Pascual, Steve Palumbi, Jim Reichman, Alan Townsend.

Guests: Carol Brewer, University of Montana; David Goldston, the House Science Committee; Katherine McCarter, ESA; Diana Rhoten, Hybrid Vigor, Stanford University; Jeff Ruch, Public Employees for Environmental Responsibility;

Ashley Simons, SeaWeb; Vikki Spruill, SeaWeb; Jason Taylor, ESA.

The Committee accepted the resignations of members Rodolfo Dirzo and Jim Ehlringer, and welcomed new Committee member Marisa Martinez (Institute of Ecology, Universidad Nacional Autónoma de México).

The meeting centered around three goals: 1) refocusing the goals of the project and beginning to prioritize actions; 2) developing the ideas and framework for Committee products; and 3) enhancing the "Public Education & Outreach," "Catalyzing Cultural Change," and "Internationalization" Visions.

The Committee received considerable feedback from the ESA membership questionnaire, the breakfast meetings, and the ESA Governing Board. The consensus among these groups was that the priority should be a focus on building an informed public, including students, citizens, consumers, managers, and elected officials.

The Committee discussed the until-now implied goal of sustainability in developing an action plan. Sustainability will be used as the organizing theme of the Initiative.

The Committee's Vision statement was revised:

> Environmental issues define our future; ecological science will help determine our fate. Our world has billions of people and we, like all living organisms, modify our environment and will continue to do so. Our vision of the future is a world with sustainable ecosystems that include those billions of people. Ecology alone can not get us there but our input is essential. The science of ecology can then make it possible for society to achieve sustainability.

The purview of the Ecological Visions Committee was discussed. It was agreed that within each of the Vision areas there are overarching and ambitious goals for the broader audience of environmental scientists, funding agencies, and managers, as well as subsidiary and more immediately attainable goals that are specific to ESA.

Five products to be developed by the Ecological Visions Committee were identified: 1) a Report to the ESA Governing Board to articulate a plan and provide specific actions; 2) publication of a paper in a high-profile journal such as *Science* to elicit a "call to action"; 3) a public forum at the ESA Annual Meeting to get the word out and obtain feedback; 4) presentations at meetings of other societies to forge partnerships; and 5) an issue in *Frontiers* to provide details of the plan and its application to the broad ecological community.

Meeting 4: October 31 – November 3, 2003, Sevilleta Field Research Station, Albuquerque, NM

Committee attendees: Margaret Palmer, Emily Bernhardt, Liz Chornesky, Scott Collins, Cliff Duke, Barry Gold, Robb Jacobson, Sharon Kingsland, Rhonda Kranz, Mike Mappin, Marisa Martinez, Fiorenza Micheli, Jen Morse, Mike Pace, Steve Palumbi, Jim Reichman, Bill Schlesinger, Alan Townsend, Monica Turner.

Guests: Ashley Simons, SeaWeb.

The goal of this meeting was to complete both a draft of the Report to ESA and a draft of a paper to be submitted to the journal *Science.* The committee condensed the five Vision areas into three:

- Innovations (will combine the Research Innovations and Technological Innovation).
- Developing an Informed Public.
- Cultural Change (which will incorporate Internationalization).

The group discussed the form and content of the Report with ESA President Bill Schlesinger.

Appendix 3: Ecological Visions Breakfast Briefings

Margaret Palmer, Clifford Duke and Rhonda Kranz met with 3 small groups of eight to ten people for breakfast meetings in July 2003 to discuss the Ecological Visions project, solicit feedback, and build relationships. Attendees included colleagues from agencies, NGOs, industry, and associations (a participant list closes this document). The discussions were very lively, each lasting well over the scheduled 1.5 hours. Everyone was positive about the project and asked to be kept involved. Below are some of the most interesting comments and suggestions. Many of these were common themes, heard independently from each group.

Collaborations and Users of Ecological Knowledge:

- We have to be more ambitious about education—not just classroom and informal, but the "democratization" of science and making the results important and usable.
- A practical approach for ESA would be to focus on bridging functions to different organizations and types of communities.
- We need to encourage collaboration and projects with stakeholders, not just other scientists.
- We need to target "local folks" and get more ecology into the hands of those making decisions at the local level of government, packaging tools in such a way as to make them usable and available.
- The perspective of the decision maker must be incorporated, as ecologists do not necessarily understand local decision processes.
- We have to break down barriers between community development specialists and scientists.
- Regulators and engineers within the local communities need to work with ecologists.
- Datasets that are useful to management must be developed.
- We should keep in mind the importance of the private sector and NGOs and involve them in the research community.
- We need better dialogue among basic researchers and practitioners at the corporate level. Currently they don't feel as if they have influence and are left out of the process.
- We need ecologists in decision making positions in government.
- We should make use of the large amount of social science literature on perceptions of science by the public. Surveys show that the public respects science. That is part of the problem, as they want to take what is said by scientists as the final truth and scientists know it isn't.
- We need to encourage collaborations with social scientists who have done research in fields such as water use and who are knowledgeable in the use of these types of data.
- We should figure out how we can help get the public/community to think about process instead of issues. Scientists think that "normal" people can't do this, only the highly trained like them. But if the process is scaled down and involves the community it would help with decision-making.
- BEN (Biological Education Network) is an example of groups of biological societies working together. They have already decided on metadata for sharing information.

The Scientific Community:

- Reward systems within the private sector and agencies, as well as in academia, need to be addressed.
- We need to encourage outreach by scientists. A successful model is the Canon Parks Fellowship, where students have to do a paper on the application of their work to management issues in the parks, and they have to make a public presentation on their work.

- The scientific community needs to develop self-awareness and learn how it is perceived as well as how it conducts science in relation to other disciplines.

Lessons from Economists on Data Set Collection Networks:

- Economics benefits from government programs that provide periodically updated data sets. Development of an ecological data collection network would benefit both management needs and research.
- To sell the idea, we need to do as the economists have done and make sure the payoff (benefit) of the network extends beyond research. We need to get the data to members of the public, updated year after year, in the same way that they have become accustomed to getting economic data.
- Even though economics data has holes, economists have agreed to move forward with what they have.
- Economists have been able to put economics into plain, understandable language. Ecologists need to do the same.

Data and Information

- Long-term data sets are key. It is primarily government resources and institutions that have the resources and stability to do this.
- Clarify that we are talking about multi-scale, not just large scale.
- Predictive models are very important. In communicating with the public we need to be able to say what we can or cannot expect.
- A conceptual model on how to use the data is needed—not just what is usable but what is the desirable outcome.
- Coordination of standards and technology are being developed and standards and techniques training taking place globally. We need more training.

International Issues

- Data and information are not as available to decision makers in developing countries.
- We have to build networks of ecologists in developing countries and produce ways to increase data and metadata access.
- The distinction between applied and basic research is very American and strange to scientists in other countries.
- To internationalize ESA towards those parts of the planet where biodiversity and threats to biodiversity are highest, and where capacity to respond to these threats is lowest, will take a range of low-tech solutions, as well as high-tech efforts.
- A major challenge is to get higher priority for environmental concerns in private sector planning. Corporations invest in local infrastructure internationally, but environmental benefits are often a low priority.
- In many countries, environmental knowledge is held locally and is political. We need knowledge about the different local ways of understanding.
- In developing countries, ecology only makes sense when related to improving quality of life. Urban ecology is increasingly important in developing countries.
- We should vet ideas with people who are from, and work in, the international community.

Framing the Discussion:

- We need to ask great simple questions that the public can get excited about. Successful large-scale infrastructure projects draw support by posing clear, simple questions and stating that the project will answer the question.
- Security is an idea people understand. For example, we need to understand the watershed to be able to protect it against terrorism. But we have to be careful, as mentioning security can also be seen as "ambulance chasing."

- The vision has to be from more than the perspective of a research ecologists. Switching the issues around to "what can be learned from ecology" would be more effective.
- Sustainability is a way to encapsulate big ideas. It brings together social science, economics, and ecology in one framework.
- We should emphasize the fundamental importance of taxonomy and systematics and the current extinction crisis.
- People need to be part of the vision. There needs to be a sense of human value in addition to being scientifically interesting and inspiring.
- We need to include the words "private" and "public" in the language we use in the Report.
- The private sector generates lots of information but generally the research is not driven by understanding functions of a system, but rather by getting the information needed for a permit or other immediate need. It is often the consultants who do the interconnecting.

Direction of Research and Funding:

- Future directions of funding are changing for agencies and in many cases going from a disciplinary base to large mega issues. Funding may be eliminated in the competitive process within agencies. Agencies will be moving toward projects that focus on regional problems and involve multidisciplinary teams.
- We need to create financial incentives to cross interdisciplinary boundaries.
- Lots of government funding for research is static or down.
- We should be looking to NIH to fund ecological research in its connections to human health.

Participants in the July 2, 11, 18 Breakfast meetings:

Al Abee, USFS; David Blockstein, National Council for Science and the Environment; Peter Boice, DOD; Tom Brooks, Conservation International; Jim Clark, Exxon/Mobil; Mike Frame, US GS; Thomas Franklin, Wildlife Society; Jeff Frithsen, EPA; Stephen Gasteyer, Rural Community Assistance Program; Susan Haseltine, USGS; Ted Heintz, Council on Environmental Quality; Tony Janetos, Heinz Center; Diana Jerkins, USDA; Janice Larkin, DOD; Nadine Lymn, ESA; Shirley Malcolm, AAAS; Katherine McCarter, ESA; Peter Preuss, EPA; Samuel Rankin, American Mathematical Society; Douglas Ripley, Air National Guard; Keith Robinson, United Nations Environment Program; Craig Schiffries, National Council for Science and the Environment; Fran Sharples, National Academy of Sciences; David Simpson, Resources for the Future; Maggie Smith, ESA; Jason Taylor, ESA; Robin White, World Resources Institute.

Appendix 4: Summary of Responses to the Web-based Survey

A web-based survey was created and posted on the Ecological Visions website from June 3 to August 20, 2003, to solicit input and feedback from ESA members on the project's objectives and progress. The survey was publicized by e-mail to ESA members and at the ESA Annual Meeting in Savannah.

Approximately 280 people (85 percent of whom were ESA members) participated in the survey, answering questions and providing their ideas to improve the Ecological Visions project. About two-thirds of respondents held doctorates, 21 percent had masters degrees, while the remainder had bachelors degrees or other education. Respondents were largely affiliated with academic institutions (68 percent), with 16 percent government, 8 percent non-profit, and 3 percent industry affiliations.

The survey was comprised of five sections on the individual Visions areas and one concluding section.

Section 1. Ecological Research in the 21st Century: A Vision of a Diverse, High-tech and Multi-scale Scientific Approach

Current ESA initiatives to advance ecological research and insight. Participants were asked to provide examples of current ESA projects that will lead to significant advances in ecology. ESA's support for existing programs such as NCEAS and the LTER system, and this Ecological Visions initiative were the main responses, though replies to this question were not numerous.

ESA initiatives to improve ecologists' ability to answer key ecological questions of the coming decades. Each participant was asked to submit three imaginative ideas for ESA initiatives on this topic. Comments were wide-ranging, including facilitating training in new technologies and methods; helping ecologists to develop working relationships with agencies; defining research priorities; and promoting coordinated research approaches and applied research for solving environmental problems.

Barriers to innovation and new technology. Participants ranked a lack of adequate funding as the primary barrier to incorporating innovative tools and approaches into ecological research; followed by cultural barriers to large, coordinated research efforts; insufficient quantitative and technical training of ecologists; and, finally, a lack of appropriate or affordable technology. Other comments included inadequate theoretical basis for research questions; the pressures of publishing; and funding decisions based not on innovation but other goals.

In their own research, respondents said that a lack of money (39 percent) and a lack of training (30 percent) were the main obstacles to using cutting edge technology. Other responses indicated no interest in changing methods (18 percent) or no need for new technologies (7 percent). Only 6 percent of those that responded said that they lacked information about new tools and less than 2 percent said that the tools they need do not exist. Other submissions included concerns about reviewers of proposals and manuscripts, as well as resistance to the implication that big, interdisciplinary research with new technology is the only way to address ecological questions.

Innovative tools. This last question asked participants to describe any single tool that would improve their research. Many responses were intentionally humorous. The serious responses wished for remote sensing and GIS, with land cover, data visualization, or soil moisture sensing capabilities; others included nanosensors; satellite radio collars for birds; and automated instrumentation for plankton measuring.

Section 2. Representing Ecological Knowledge

Synthesis efforts and data sharing. More than half of respondents (57 percent) said they had contributed their data to a synthesis effort, and 36 percent of those had actually participated in the synthesis effort. Twenty-eight percent of respondents said they had been the principal authors of a synthesis paper. Proprietary concerns over sharing data (57 percent) were the greatest barrier to data sharing, followed by data compatibility (51 percent), lack of recognition for sharing data (49 percent), difficulty in providing documentation (37 percent), and non-electronic data storage (18 percent). Twenty-seven percent of respondents said that no one had asked for their data, while 2 percent said they preferred not to share their data at all. Other answers included: time and training barriers to preparation of data for sharing; database compatibility; lack of standards for documentation; lack of clearinghouses for data; and the feeling that the original data collectors should have priority in analyzing their data before being expected to share them.

Data storage and documentation. Less than half of the respondents (35 percent) said they had compiled electronic metadata for their data files. A standard protocol was favored by 60 percent to facilitate the maintenance of metadata, while 54 percent and 44 percent said that more time and money would make it easier. Two technological barriers, appropriate software (41 percent) and more storage space (14 percent) were also sited. From the other responses submitted, it was clear that many participants did not understand the term “metadata” to mean the documentation of data attributes, thus illustrating part of the barriers to data sharing. Data were most frequently stored in field or laboratory notebooks (63 percent), on floppy disks (41 percent), on hard disks (79 percent), in personal databases (49 percent), in managed databases without public access (26 percent) and with public access (18 percent).

Publicly available data for synthesis. Only 11 respondents answered the question as to whether they would be likely to use publicly available ecological data for synthesis purposes. Six said they would be very likely and 5 not at all likely to use these data. However, 162 people expressed their concerns about using publicly available data, citing data quality (78 percent), documentation (65 percent), compatibility of units and methods (52 percent), and a lack of clear guidelines for crediting contributors of data (38 percent). Other concerns included possible bias in data submitted to a repository; using data for other than their intended purpose; and lack of knowledge about the methods of data collection.

Roles for ESA to facilitate data sharing. Ideas submitted included the following: support of a standardized data protocol and criteria for citations in its journals, including guidelines and codes of ethics for using others’ data; lobbying for establishment of a National Ecological Data Archive; and expanding the Ecological Archives.

Section 3. Catalyzing Cultural Change

Collaboration/Interdisciplinary Research. Respondents were asked about barriers to performing collaborative and/or interdisciplinary research. Nearly half cited concerns about impeding professional development (45 percent), closely followed by lack of credit given to multi-authored efforts (38 percent), lack of a common language with other disciplines (34 percent), publication barriers to interdisciplinary work (32 percent), and lack of opportunities to interact with potential collaborators. Only 1 percent said they preferred not to engage in collaborative or interdisciplinary research. Other responses cited lack of time and funds. In particular, respondents described a lack of funding mechanisms for multidisciplinary research and collaboration. Some people also felt that their institutions discouraged interdisciplinary work and collaboration. Others expressed difficulties in identifying potential collaborators. However, many respondents reported no problems or barriers to their collaborative work.

Mentoring. Fifty-four of 154 respondents reported that they had trained graduate students. At the Ph.D. level they produced an average of 5 academic faculty, 3 government scientists, 2 consultants, 2 NGO staff, 2 students who chose other careers, and 1 industry scientist at the Ph.D. level. At the masters level, they advised an average of 3 academic faculty, 4 government scientists, 3 consultants, 1 science writer, 3 NGO staff, 2 industry scientists, and 3 students who had pursued other careers.

Institutional support. Academic participants were asked whether the graduate program at their institution provides training, support, and rewards for graduate students interested in pursuing non-academic career paths. More than half of universities (60 percent) in which the respondents worked were said to provide some support, and twice as many institutions were reported to provide great (26 percent) support compared to no support (13 percent) for non-academic careers.

Impediments to communicating ecological information. Nearly three-fourths (71 percent) of respondents felt that poor communication of ecological information to the public and confusion about the distinction between environmentalism and ecology were the main barriers. Lack of communication, distrust, or misunderstanding between academic and nonacademic ecologists (38 percent) and between ecologists and scientists from other disciplines (31 percent) were also strongly noted. Other impediments identified were a lack of scientific understanding or interest by the public; concerns about compromising scientific objectivity; academia's lack of support for outreach and education; and an inability on the part of ecologists to connect ecological information directly to issues that matter in peoples' lives.

Ecological knowledge in decision-making. Respondents felt that ecological knowledge is not used more often and in more effective and meaningful ways in management and decision-making because: there is a lack of political support (64 percent), or practitioners lack understanding of ecology (55 percent), funds (40 percent) or time to incorporate ecology into their work (36 percent). Respondents also felt that there were problems on the supply side of ecological information: recommendations by scientists are too vague or not achievable (60 percent) and the applicable science has not been done (23 percent). Other views included quick and short-term decision-making; distrust or hostility toward ecological science; and the different goals of ecological science and management.

ESA initiatives. Many respondents expressed interest in ESA's expansion of its education programs to increase ecological and scientific literacy among the public; forming working relationships with agencies and practitioners to improve communication and access to information; fostering better relationships with local communities (for example, with cities that host the annual meetings); expanding *Issues in Ecology*; broadening ESA's outlook to address the views and interests of its non-academic members; and better training opportunities for ecologists to become involved in outreach and public education.

Section 4. International Outreach

Working internationally. Suggestions for how ESA, its membership and other colleagues can help foster greater international collaboration in ecological research were solicited from those who have had experience working internationally, attending international meetings, or teaching international students. More international funding opportunities were at the top of the list (58 percent), followed by better language training for Americans (47 percent), streamlined visa processes and more visas for international researchers (39 percent), wider access (33 percent) and better infrastructure (33 percent) for international research. Participants commented on various successful international collaborations they had been involved in, such as an international Dragonfly Association, American Ornithologists Union, NCEAS working groups, and the Fulbright program. Respondents said they sometimes (43 percent) or never (35 percent) work outside the US. Fourteen percent said they often or always working internationally. International collaborations were more common: 6 percent responded that they always work with scientists from countries other than their own; 53 percent responding that they sometimes do; 20 percent responding that they often do; and 14 percent responded that they never do.

International members of ESA. Members who were not US citizens were asked why they joined ESA. The reasons given were that ESA is the premier ecological society, and because of the journals.

General comments on internationalization and ESA initiatives. Many answers touched on the importance of nonacademic programs in foreign countries, particularly in the tropics, as important areas for research and exchange of ideas. Global questions in ecology and marine ecosystems, and the opportunities for international collaboration and outreach, were seen as exciting. Many respondents also voiced their interest in ESA's cooperating with other societies such as INTECOL, the British Ecological Society, and others, especially in Latin America and Canada, but without losing the American focus of ESA.

Increasing International Membership of ESA. Of those who responded, 71 percent (88 percent US citizens) thought that increasing international membership in ESA was not important. More than half of those who felt it is important thought the following would be helpful: provide funds for foreign members to help offset the cost of attending ESA meetings (54 percent); increase the international focus of ESA journals (53 percent); and hold an annual symposium to highlight the work of international ecologists. Holding annual meetings in other countries (32 percent) and reducing costs of membership (39 percent) and of ESA journals (39 percent) were also supported. Other responses ranged from recalling that ESA is the Ecological Society of America and so should not stray far afield, to providing free or reduced cost journals to foreign educational institutions and scientists, to holding joint meetings with other ecological societies.

Section 5. Building an Informed Citizenry and Public Policy

Public outreach. Of 150 respondents, 67 percent said they had taken part in public outreach activities as volunteers, 44 percent in their professional capacities, 43 percent through the media, 18 percent as expert witnesses, 36 percent as science writers, 5 percent through art, and 4 percent not at all. Other avenues of participation in public outreach were through K-12 education, activism, lobbying, and working with community groups. Asked to identify the top target groups for education and outreach programs by ESA, K-12 teachers were overwhelmingly the top choice, followed by elected representatives, K-12 students, media, government agency staff, local community groups, undergraduates, private businesses, and NGOs.

ESA initiatives. A wide variety of potential projects and initiatives for ESA were identified that might lead to significant change in public understanding and use of ecology. Place-based learning in K-12 schools was cited, as were engaging local communities; improving teacher education and resources; engaging with the private sector; providing more web-based resources for content and links in ecology; and improving training opportunities for ESA members to communicate their information to the public.

Other initiatives outside ESA. Ideas for major initiatives that could be facilitated by ESA, through members, other professional societies, or other groups, were also solicited. Responses included improving access to ecological information for K-12 teachers and students; becoming more active in the media to explain ecology as a science distinct from environmentalism; or networking with other professional societies to create a clearinghouse for information on natural resources and sciences to better inform policymakers.

Section 6. Conclusion

Rating of the 5 Visions. Respondents were asked to rate the Vision areas in terms of the top priority for fostering ecology over the next 20 years. Respondents overwhelmingly chose improving public understanding of ecology (55 percent) as the top priority, followed by cultural change in the institutions where ecologists work (23 percent), increasing or developing tools and capacity for research (9 percent), increasing access to ecological data (7 percent), and increasing international cooperation in ecological research (6 percent).

General comments. Comments included the need for: more money and institutional support for environmental science in general; a higher profile for ecology; development of decision tools for managers and policy makers; funding specifically for developing new ideas into research tools; and broader cultural changes among ecologists to think of innovative approaches to ecological questions.

Feedback on the survey and on the Ecological Visions effort. Respondents were supportive of the Ecological Visions process and were encouraged that ESA is trying to advance ecology in these different ways. Some respondents felt that the project so far was too focused on academics and graduate institutions, to the exclusion of practitioners, undergraduate liberal arts programs, and students at all levels. The tensions between theoretical ecology and applied ecology surfaced repeatedly, as well as those between large-scale, ecosystems science and more local, community or population ecology.