Globalization of labor and capital can increase the rate and extent of global environmental degradation, while enhancing the ability of ecologists to respond rapidly and collaboratively to mitigate these impacts. Nevertheless, ecological research remains focused at local and regional levels, with collaboration limited by national borders and funding. New initiatives are required to increase the utility and availability of environmental research to natural resource owners, managers, and policy makers in the public and private sectors, whose decisions affect land and other forms of natural capital. We propose a four-part strategy to increase the effectiveness of ecological science in addressing environmental issues in an era of globalization: (1) develop an Ecological Knowledge System, (2) increase our ability to anticipate, identify, and rapidly address new research needs, (3) increase the number and diversity of participants in all phases of research and decision-making processes, and (4) increase the flexibility of funding sources.

La globalización de la fuerza de trabajo y del capital puede aumentar el índice y el grado de degradación ambiental global y al mismo tiempo mejorar la capacidad de los ecólogos para mitigar sus efectos negativos. Sin embargo, la investigación ecológica sigue enfocada a una escala local fuera del contexto global, y la colaboración profesional y de investigación está seriamente limitada por fronteras nacionales y por falta de financiamiento. Se requieren nuevas inicativas para aumentar la utilidad y la disponibilidad de la investigación ambiental a los dueños, a los encargados y a los políticos a cargo del manejo y conservación de recursos naturales en los sectores públicos y privados, cuyas decisiones afectan las tierras y otras formas del capital natural de un país. Con el fin de aumentar la eficacia de las ciencias ecológicas para tratar con los temas ambientales en una era de globalización, proponemos una estrategia compuesta por cuatro partes: (1) El desarrollo de un Sistema de Conocimientos Ecológicos (EKS), (2) El incremento de nuestra capacidad de anticipar, identificar y atender rápidamente nuevas necesidades dentro de la investigación, (3) El aumento del número y la diversidad de participantes en todas las fases de los procedimientos de la investigación y la toma de decisiones, y (4) El aumento de la sensibilidad y la flexibilidad de las fuentes de financiamiento hacia este tipo de investigación ecológica enfocada a resolver problemas multidisciplinarios concretos.

The processes associated with globalization – the “growing integration of economies and societies” (World Bank 2001) – can lead to increases in the rate and scale of environmental degradation (MA 2005; Najaf et al. 2007). Patterns of degradation are also changing, in association with new transportation and production systems and interactions with changing climate (Lambin et al. 2003; Aide et al. 2006; Gutiérrez et al. 2006). New technologies and increased labor and capital mobility also mean that opportunities for ecosystem recovery can appear more rapidly (Aide and Grau 2004; de Soysa and Neumayer 2005; Liu et al. 2006).

Environmental degradation and opportunities for restoration increasingly occur in areas of the world where there are few professionally trained ecologists; this includes much of Latin America (Martínez et al. 2006). As a result, the consequences of land-use change in these regions are often unanticipated and there is inadequate knowledge to support the development of more sustainable, alternative management systems.

Even when new challenges and opportunities generated...
by globalization are anticipated, ecologists generally do not have the ability to respond quickly enough to assist decision makers, while decision makers lack access to existing knowledge. Both individually and as a group, ecologists lack the nimbleness of increasingly mobile global capital and labor. Extractive industries, for example, can establish new international operations in less time than it takes to get a research grant proposal written and accepted, and in far less time than it takes to develop new funding sources.

A number of theories, including the “treadmill of production” (Buttel 2004) and the “metabolic rift” (Foster 1999; Clark and York 2005), assert that environmental sustainability is incompatible with global capitalism. Globalization proponents, supported by “ecological modernization” and related theories, argue that manufactured and human capital can often be substituted for natural capital (de Soysa and Neumayer 2005). Where this is true, new ecological knowledge can contribute to the development of substitutable manufactured capital (e.g., constructed wetlands for waste recycling), while more effective communication of ecological knowledge can increase human capital.

We recognize that there are many factors influencing the nature of the relationship between humans and the environment (Ostrom et al. 2002). The objective of this paper is not to debate the ultimate relevance of ecological knowledge, but rather to stimulate discussion of how ecologists’ relevance might be increased (Dietz et al. 2003) from local to global levels, where environmental policy is largely based on creating, regulating, and managing markets (Najaf et al. 2007).

We begin with a brief review of three ecosystem transformations that have occurred in non-forested areas of the Americas over the past 150 years. We selected these studies because they illustrate recurring limitations on the development and application of ecological knowledge relevant to globalization. Furthermore, all three transformations were facilitated by increased global capital flows and were associated with important changes in production systems (see Bennett and Balvanera [2007] in this issue) and human migration patterns (see Meyerson et al. [2007] in this issue). These changes, in turn, promoted the spread of invasive species (see Meyerson and Mooney [2007] in this issue). We then describe several elements of a strategy designed to increase the ability of ecologists and decision makers to more effectively anticipate and respond to future challenges and opportunities, including establishment of an Ecological Knowledge System.

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**Ecosystem transformations associated with globalization**

**Case study 1: Southwestern United States in the late 19th century**

In the past 150 years, much of the grassland in the northern Chihuahuan Desert has been invaded by native shrubs, including *Prosopis* spp, negatively affecting many ecosystem services (Havstad et al. in press). Following the US Civil War, the area experienced dramatic increases in livestock numbers as former officers migrated or returned to establish livestock operations (Stoddart et al. 1975). Mounting demand for beef was fueled by growing domestic consumption and market globalization: exports to Europe became possible through the introduction of canning and refrigerated shipping in the late 19th century (Graham 1960). High profits attracted both US and British investors (Graham 1960), who rapidly expanded livestock populations beyond carrying capacity (Wooton 1908; Figure 1).

The response to the resulting land degradation included the establishment of experimental stations and the creation of rangeland ecology as a science. Local ecological knowledge was used to justify these new research initiatives; the vast majority of more than 1000 ranchers responding to an 1894 US Department of Agriculture survey indicated that perennial grasses were disappearing. Reflecting on the 50-year period that ended with the establishment of the Taylor Grazing Act in 1934, however, Stoddart et al. (1975) state that, “Thoughtful planning and scientific outlook resulted only as time brought to light the errors of earlier [rangeland management] policies”. While it is easy to criticize the past, ecology as a science and ecologists as professionals continue to be more reactive than proactive, and we face similar problems today. The Millennium Ecosystem Assessment (MA 2005) and other initiatives are beginning to change our
approach to research, but the forces associated with globalization are arguably changing the world at a much faster pace.

**Case study 2: Brazil in the late 20th century**

To the untrained eye, mid-20th century Brazilian cerrados (savannas) in the midst of an annual dry season would have appeared quite similar to some mid-19th century southwestern US grasslands, but the rate and extent of change are probably even greater in Brazil. Over 8 million ha of native savannas were lost to cultivation between 1980 and 1995 (Cardille and Foley 2003). The forces of change in Brazil today are surprisingly similar to those operating in the US 125 years ago. Brazil can profitably satisfy increased global demand for an agricultural product (soybeans) because it has (1) low production costs relative to other soybean-producing regions of the world, (2) an expanded transportation network, and (3) domestic and international migration of agricultural entrepreneurs into the region (Fearnside 2001; Aide et al. 2004).

There is an impressive body of research on the cerrados, but much of it has focused on the development of agronomic practices that facilitate replacement of native savannas with more valuable forage species or annual crops (Yamada 2005). The long-term effects of annual cropping on this diverse, high-value ecosystem (Oliveira and Marquis 2002; Grace et al. 2006) have been predicted, but few feasible and economically attractive alternatives (Lubchenco et al. 1991) have been proposed (Fearnside 2001). Additionally, conversion to mechanized agriculture and the associated displacement or preemption of small-scale subsistence landowners is contributing to increased migration to the agricultural frontier in the Amazon (Fearnside 2001).

The case of the southwestern US highlights a missed opportunity for ecologists. In Brazil, as intensive agricultural production continues to expand, opportunities for transformational changes in agricultural production systems (Kirschenmann 2006) are rapidly disappearing (Klink and Machado 2005). In contrast, new opportunities for restoration are emerging in northern and central Mexico (Echavarria Cháirez et al. 2004), where marginally productive croplands are being abandoned by migrants seeking higher wages in the growing cities of Mexico and the US (Zamora and Foladori 2006). Agricultural land abandonment is occurring throughout Latin America (Aide and Grau 2004; Grau and Aide 2006; Guzmán Chávez 2006; Izquierdo et al. 2006; Morales and Villalba 2006). In north-central Mexico, it is being fueled by three factors associated with reduced trade barriers: lower prices for basic grains due to competition from highly subsidized imports, factory jobs in Mexico, and demand for low-wage labor in the US.

Research in forested systems supports the hypothesis that agricultural land abandonment associated with emigration can create opportunities for ecosystem recovery (Lamb et al. 2005; Grau and Aide 2006). However, experience in other regions suggests that the window of opportunity may be relatively narrow. In southern Honduras, farmers who recently abandoned their land for opportunities in the US are investing their earnings in expanding livestock herds beyond the carrying capacity of the steep hillsides (Figure 2). Demand for biomass for biofuel production is a growing threat to the sustainable management of marginal lands (Lal 2005; Raghu et al. 2006). Finally, increased food requirements of a growing popula-

![Figure 2. (a, b) Soil compaction and removal of soil-protecting crop residues and tree litter by increased livestock populations threaten to diminish benefits of the Quesungual agroforestry system in Honduras.](image-url)
tion, together with potential changes in agricultural pro-
duction subsidies, could also rapidly return these lands to
production (Babbitt 2005). This emphasizes the need for
the simultaneous development of new, more sustainable
agricultural production systems (Vandermeer and Perfecto
1997), and for systems that promote the recovery of aban-
doned lands. With the exception of a number of studies
documenting forest recovery, the response of ecologists to
new options associated with land abandonment in the
Americas has been limited at best. Research designed to
develop economically viable strategies (Lamb et al. 2005)
that promote agroecosystem recovery is problematic, due
to its interdisciplinary nature. It is generally poorly funded
and often lacks coordination with similar efforts in other
parts of the world, or even within the same country.

Case study implications

These three case studies show that, while new ecological
challenges and opportunities can emerge in response to
changes in a single factor, they are particularly dramatic
when two or more of the many factors associated with
globalization (eg capital flows, production systems, migra-
tion patterns) change simultaneously. In all three cases,
the ecological community failed to anticipate the magni-
tude of the impending changes associated with these
three factors, and was unable to generate a timely, policy-
relevant response. The case studies also show how global-
ization has linked these three factors more tightly, allowing
feedbacks to occur more quickly and increasing the
probability that dispersed, seemingly unconnected events
at local scales will lead to catastrophic changes to ecosys-
tem function at regional to international scales (Peters et
al. 2004; see also Peters et al. [2007] in this issue). We
argue that these thresholds or tipping points are often
accelerated by shifts in capital flows, migration (see
Meyerson et al. [2007] in this issue), and production (see
Bennett and Balvanera [2007] in this issue), and are often
associated with changes in invasive species dynamics (Theoharis and Dukes 2006; see also Meyerson and
Mooney [2007] in this issue). As our understanding of the
complexity of factors associated with globalization increases (eg Blumenthal 2005), so must our capacity to
respond. In some cases, the social and economic forces
overwhelm potential science-based improvements in pol-
icy, while, in others, more effective communication may
be sufficient (Palmer et al. 2005). In many cases, however,
both increased knowledge and site-specific interpretation of that knowledge are required.

A strategy to increase the impact of ecology

We propose a strategy for ecology that addresses some of
the challenges presented by globalization by taking advan-
tage of the new opportunities it provides. We argue for
a more rapid globalization of ecological science in
order to increase the rate at which ecological knowledge
is developed, communicated, and applied. We believe
that this transformation of ecology must occur in collabo-
ration with local community and government leaders,
and that both small and large enterprises can play a posi-
tive role in the process.

In order to increase our effectiveness in addressing
emerging environmental issues, ecologists need to adopt
the four key attributes of a successful global entrepreneur:
(1) universal, rapid, comprehensive access to relevant
information and knowledge, (2) the ability to anticipate
and pursue new research needs virtually anywhere in the
world, (3) the willingness and ability to form partnerships
with the most qualified individuals and organizations,
independent of nationality or formal education, and (4)
the ability to rapidly redirect resources to generate the
highest rates of return on investment.

Develop an Ecological Knowledge System

An Ecological Knowledge System (EKS) is needed to
facilitate the local and global dissemination and interpre-
tation of ecological information. Policy makers and
resource managers are constantly required to identify,
access, interpret, and apply disparate information sources
to support decisions. Information is becoming increas-
ingly accessible through online databases and decision
support systems, but no single individual has the ability
to locate and interpret all of the information relevant to a
particular environmental issue. Internet search engines
cannot distinguish between tools and databases that are
simply described by websites and those that actually exist.
Furthermore, when users finally arrive at a relevant web-
site, they must navigate a unique path to access informa-
tion. Under intense deadline pressure, even those with
advanced degrees and internet skills resort to simply call-
ing individual experts, who themselves often lack the
time and specific expertise required to address increas-
ingly complex issues (J Matuszak pers comm). For exam-
ple, many large banks involved in international projects
have now adopted the ten “Equator Principles”, including
the requirement that borrowers complete “a Social and
Environmental Assessment (‘Assessment’) process to
address … the relevant social and environmental impacts
and risks … and to propose mitigation and management
measures relevant and appropriate to the nature and scale
of the proposed project” (Equator Principles nd). Implemen-
tation of these principles has been controvers-
ial for many reasons (Missbach 2004), one of which is
that we often lack the information necessary to assess the
environmental impacts of a project (Miranda et al. 2003).

We propose the development of an EKS that facilitates
dynamic access to, and interpretation of, traditional and
non-traditional knowledge sources. This system would
promote the integration and application of a wide variety of
information and knowledge sources, including many that
are already being organized relative to a specific theme,
such as invasive species (Grosse and Sellers 2006; Molnar
et al. 2006; Parks et al. 2006) and biodiversity (Besana and Valdespino 2006; IUCN 2007). As currently envisioned, it would consist of three components (Figure 3).

(1) An ecological information acquisition tool. This internet-based expert system would allow individuals to use a single interface or portal to extract relevant information from existing databases, based on spatial coordinates, current land use and cover type (eg forest), type of land-use change or impact (eg agriculture, irrigation, mining, roads, climate change), and resource concerns (eg soil, water and air quality, hydrology, biodiversity, single species). The tool would serve as a common interface for the many spatial and non-spatial databases, search tools, and decision support tools that already exist or are being developed. Technical staff and a scientific advisory board would be responsible for evaluating, adding, and replacing new information sources (ie websites) as they are developed. This would resolve one of the biggest difficulties for policy makers, managers, and scientists today – keeping up with the growing number of internet databases and tools – and would provide a comprehensive knowledge source as the basis for promoting public participation in policy development (Kasemir et al. 2003). This tool might also be expanded to include a collaborative website (wiki) modeled after Wikipedia, in which individuals could document local data, information, and knowledge not otherwise available, including qualitative observations (eg Liebig and Doran 1999). Although inherently vulnerable to manipulation, Wikipedia has been shown to be roughly as accurate as Encyclopedia Britannica (Giles 2005). Following new initiatives like Citizendium (Leslie 2006), the entries associated with an EKS could be subject to continuous review both by other users and by a voluntary professional committee.

(2) An ecological knowledge identification tool. This global catalog of databases of both traditional and non-traditional experts would serve a function similar to that of the information acquisition tool. An increasing number of expert databases are being developed, but they, like the information databases, are dispersed. Furthermore, few include local and traditional ecological knowledge experts. Using the same user inputs provided for the information acquisition tool, this tool could also provide customized links to relevant online tutorials and the scientific literature through existing products such as Google Knowledge and Wikipedia.

(3) A synthesis, interpretation, and application tool. Using currently available software, this internet-based teleconferencing tool would provide users, including those in remote locations in the developing world (Galperin 2006), the opportunity to consult with several experts simultaneously, and would provide all with relevant information direct to their desktops. This tool would...
facilitate the cooperative development of conceptual models, integrating biophysical and socioeconomic factors, which could then be used to identify areas where management intervention and research are most likely to be effective (Reynolds and Stafford Smith 2002; Ayarza and Reynolds 2006; Callo-Concha 2006; Liu et al. 2006). In the short term, this tool could simply act as an extension of the Ecological Society of America’s (ESA) Rapid Response Network (ESA 2006).

In summary, most of the elements of an EKS already exist, but they are not being used to their full potential. The technology necessary to integrate them already exists or is being developed (eg Tapscott and Williams 2006; IUCN 2007). Our proposal is to take the final step to simplify access to relevant information and the knowledge necessary to apply it, and to provide new options for individuals with diverse types of knowledge to interact directly with each other and the available information.

**Anticipate, identify, and rapidly address new research needs**

We need to anticipate research needs and be willing and able to rapidly shift the focus and location of our research to address those needs. In addition to the development of new centers and networks designed to accomplish this (Palmer et al. 2005), we need local identification of emerging issues (Martínez et al. 2006; Rodrigues and Hogan 2006). As ecologists, we then need to respond to these issues, as suggested in a newly proposed “contract between science and society” (Lubchenco 1998; Mayor 1999).

Today, individuals committed to providing rapid responses to new needs in the environmental arena find themselves working as consultants, because this type of work is not generally rewarded in academia (Castillo et al. 2005; Hobbs 2006). We believe that a restructuring of the academic reward system may be required to encourage academic and government ecologists to take the risks involved in working with managers and policy makers on demand-driven research projects. For example, the promotion requirements for many US government researchers increasingly include demonstrating societal impact, in addition to the number and significance of publications.

**Increase diversity of participants in the research and research application process**

When entrepreneurs seek to develop new businesses, the market obliges them to partner with the most qualified individuals. We need to increase our ability and willingness to rapidly forge new partnerships (Palmer et al. 2005) and to terminate or restructure these partnerships when they no longer support the development of socially and environmentally sustainable solutions, even when this results in a reduction in the size of our own research program (Garcia Barrios 2006).

It is frequently stated that we need interdisciplinary, international teams that can access local knowledge to address future environmental challenges (Palmer et al. 2005). We believe that, in order for local knowledge to be effectively applied, local knowledge experts must play an active role in making decisions. These experts, together with decision makers, must become active participants in the development and application of new ecological knowledge (Sabatier et al. 2005; Contreras 2006; Hall et al. 2006; Hobbs 2006; Figure 4). This requires increasing opportunities for experts in the field to share their knowledge online (Figure 3), changing the way many of us think about local partnerships, and, in some cases, throwing open the search for solutions to the entire online community. This revolutionary approach has led to a number of successes in both traditional industries, such as mining, and in the new online knowledge-based corporations (Tapscott and Williams 2006). At a more local level, Barrios et al. (in press) describe a new type of partnership that was used to generate soil quality indicators for local application. The process involves technical specialists (eg scientists, extension workers, teachers), who bring knowledge about basic soil and ecological processes, and local

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<th>Table 1. Economic benefits of wildlife management units in Mexico (total 1995–2005)</th>
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<tr>
<td>Activity</td>
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<tr>
<td>Intensive plant and animal facilities</td>
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<td>(eg nurseries, zoos)</td>
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<td>Hunting</td>
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<td>Live plant and animal exports</td>
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<td>Whale watching ecotourism</td>
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<td>Taxes</td>
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experts (e.g., farmers), who contribute knowledge of the local environment, the type of information required, and how it can best be organized, presented, and applied.

In the long term, increasing the integration of ecological knowledge into daily decision making requires strategies that will help local individuals and organizations improve their understanding of fundamental ecological principles and their ability to apply these principles (Bartuska 2006; Martinez-Mateos and Castillo-Burguete 2006; Tyler 2006). This requires increasing ecological knowledge at all educational levels in multiple sectors of society (Figure 5). At the university level, ESA’s Strategies for Ecology Education, Development, and Sustainability (SEEDS) program has the potential to serve as a model for broadening the diversity of ecologists by introducing students from different disciplines to professional ecologists and the science of ecology (Parker 2006; Figure 6). For younger students, environmental education, which is often based in natural history, needs to be integrated with environmental science education, which promotes critical thinking about ecological processes. Finally, scientists will need to work with policy makers to develop new programs, such as Mexico’s Environmental Management Units system, which allow local managers to benefit economically from using this knowledge to improve natural resource management (see Sisk and Castellanos [2007] in this issue; Table 1).

**Increase flexibility of funding sources**

Funding sources that allow new issues to be addressed as quickly as possible by the most capable individuals, irrespective of their national or institutional affiliations, are required. In 2004, Mexico spent just US$4.3 billion (US$40 per capita) on all areas of research and development, compared to US$312.5 billion (over US$1000 per capita) in the US (OECD 2006). Only a tiny fraction is allocated to environmental and natural resources research; in 2003, just US$43 million was devoted to these issues in Mexico (INEGI 2003). By contrast, the National Science Foundation’s Environmental Biology Division alone provides over US$100 million to US scientists. It is easy to say that more funding is necessary worldwide, but we also need to find ways to distribute funds more flexibly and efficiently. Recognizing that many ecological issues are now global in scale, national funding agencies need to eliminate restrictions on international expenditures. The National Science Foundation’s International Division supports these efforts, but even these funds have many limitations. A combination of new, innovative funding initiatives and increased flexibility of current funding sources is necessary.

When international ecological research projects are funded by wealthy, developed countries, they are generally led by principal investigators from those countries. These scientists subcontract predefined tasks to local scientists, or send their own representatives, who often have little local knowledge and limited language skills. There are some notable exceptions and the number of truly collaborative relationships increases yearly. An alternative to the subcontracting approach was recently developed by Miguel Ayarza and others working with Centro Internacional de Agricultura Tropical (CIAT) in Brazil and, more recently, in Central America. The Manejo Integrado de Suelos network brought local investigators together twice annually to discuss regional problems of land degradation with internationally trained scientists from CIAT. Before funding was eliminated in 2006 as part of a broader organizational restructuring, the network included a small grant program which provided funding for innovative studies initiated by members. This microcredit, incubator model is similar to the micro-finance model that has been successful in promoting...
local development (Yunus 1998; Rhyne 2001). The bottom-up approach, which combines informal, professional peer-group training with funding, is not a replacement for large, international projects. It does, however, have the potential to cost-effectively help local researchers contribute more pertinently to our ecological knowledge base and improve their ability to generate local solutions, such as the ones described by Ayarza and Reynolds (2006) and Kirschenmann (2006). When combined with the EKS described above, this approach also has the potential to increase the ecological community’s ability to rapidly respond to new threats by increasing the likelihood that relevant research is initiated early.

There are a number of other alternative funding mechanisms, including foreign aid programs, international funds such as the Global Environmental Facility (GEF), and partnerships with non-profits and the private sector (Martínez et al. 2006). These sources remain underexploited, in part because of cultural differences between scientists and many of these new potential funding partners.

Adapting the model of the global entrepreneur

While many of the strategies adopted by globally successful organizations can also be adopted by ecologists, some can be counterproductive if they are not carefully applied. For example, compartmentalizing production systems and subcontracting specific components based on current capacity and cost is often an effective strategy for rapid, low-cost production of new goods, such as cars and computers. The same strategy applied to a research project can limit ecologists’ ability to increase local capacity and integrate local knowledge. It can also breed resentment, leading to failure of the project. The balance between rapid response and maximizing knowledge and involvement is difficult to achieve, as local involvement requires the development of long-term relationships, often at the expense of short-term efficiency. However, the potential benefits of opening up the development of ecological solutions to the global community are tremendous. The creation of a set of principles, similar to those proposed for “Wikinomics” (Tapscott and Williams 2006) and the “Conservation Commons” (IUCN 2007) could increase the probability of success of this endeavor.

Conclusions

In order to more effectively address emerging environmental issues associated with globalization, and to be more relevant to society, ecologists need to broaden what and for whom we study. We also need to be more strategic about where and with whom we study, and about how and with whom we communicate. Finally, we must take advantage of the tools of globalization to increase our ability to rapidly develop and implement research projects, in addition to continuing curiosity-driven basic research. The quality and relevance of our research will increase as we work together with those who are prepared to apply it. The strategy proposed here is designed to accelerate this transformation, which is already occurring, while increasing access to new and existing ecological knowledge through the development of an Ecological Knowledge System.

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