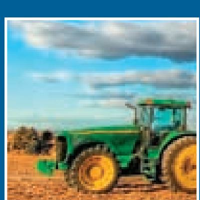
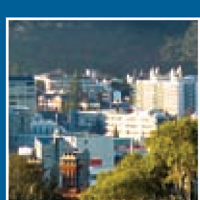
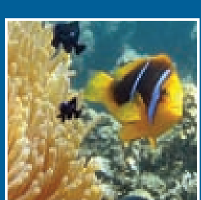
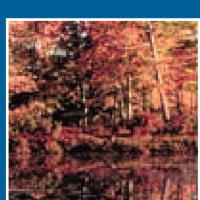



Integrative Science for Society and Environment

A Strategic Research Initiative

Integrative Science for Society and Environment: A Strategic Research Initiative

Developed by the Research Initiatives Subcommittee of the LTER Planning Process Conference Committee and the Cyberinfrastructure Core Team

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OVERVIEW & OBJECTIVES

We live in unprecedented times. The global human population, which may reach 10 billion by 2050, is making increasing demands on natural resources, resulting in rapid, extensive, and pervasive changes (Fig. 1) in Earth's systems (1, 2, 3, 4). Many of these changes are also presenting unprecedented challenges to our understanding of how the biosphere works—how the systems on which we depend will be altered by changes in climate, land use, biodiversity, and a host of related environmental attributes. In short, we need to understand how the planet will operate in the coming decades, and what we can do to sustain and improve its habitability.

Interdisciplinary research is a process of collaboration among scientists with varied, complementary expertise to make discoveries that would not be attainable otherwise.

Integrative science seeks to produce new understanding of complex issues by bringing together and coordinating diverse expertise, programs, and infrastructure.

Synthesis seeks a new, unified understanding by combining different ideas and information.

To meet these challenges requires a different approach to U.S. environmental research, one that is integrated, systems-oriented, and holistic at multiple scales. Fundamental questions require interdisciplinary approaches that can

- detect important changes in Earth's systems,
- understand change in the context of integrated social and ecological systems, and
- provide the information needed for successful solutions.

A new fundamental research initiative is warranted. Integrative Science for Society and Environment (ISSE) is intended to elevate environmental science in the U.S. to a new level of integration, collaboration, and synthesis needed to address these pressing, emerging challenges. The ISSE is based on the belief that the transformative knowledge needed for this effort can be delivered best through a programmatic framework that explicitly identifies the basic socio-ecological linkages that underlie the biosphere's response to environmental change.

The issues involved transcend traditional boundaries between the biophysical and social sciences and cross all ecosystem types. Thus the ISSE has been created by a diverse group of biophysical and social scientists—ecologists, sociologists, geologists, economists, oceanographers, and geographers, among others. This interdisciplinary strength is at the core of the program.

Ecosystem Services

Goods and services that humans receive from nature are called ecosystem services. Human impacts affect the ability of ecosystems to provide these services. The following are some types of ecosystem services.

- **Provisioning services** are products such as food, fuel, fiber, fresh water, natural biochemicals, and genetic resources.
- **Regulating services** are benefits that people obtain from natural regulation of air quality, climate, erosion, disease, soil, and water quality.
- **Cultural services** are nonmaterial benefits that people obtain from the aesthetic, educational, recreational, and spiritual aspects of ecosystems.

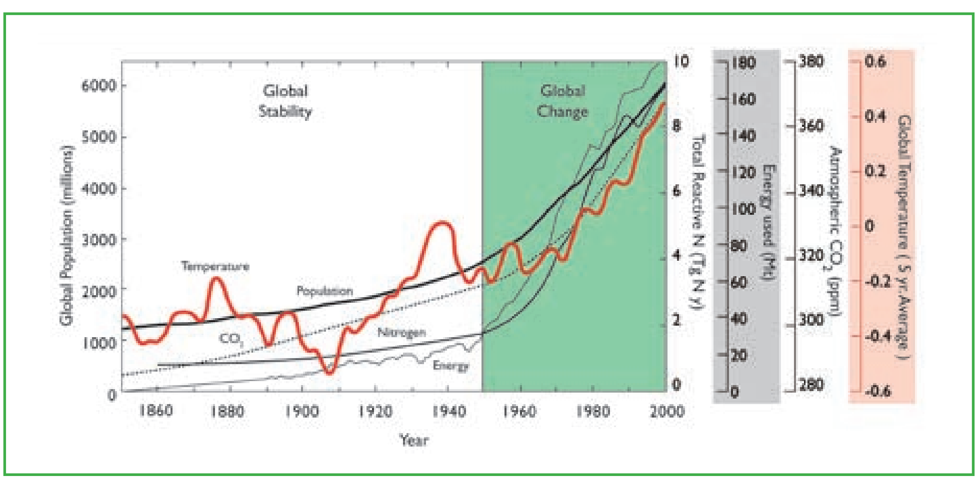


Figure 1. Long-term trends in the global human population, human energy consumption, reactive N produced by humans, CO_2 concentration of the atmosphere, and the global temperature anomaly. Note the directional and cumulative increase in these metrics of global human impacts over the past 50 years. Population data are from the US Census Bureau (www.census.gov); energy consumption from the US Department of Energy Energy Information Administration (www.eia.doe.gov); total reactive N from Galloway et al. (2003); atmospheric CO_2 concentrations from the Carbon Dioxide Information Analysis Center (CDIAC, cdiac.esd.ornl.gov); and global average temperature anomaly data (Brohan et al. 2006) from the Met Office Hadley Centre for Climate Change (hadobs.metoffice.com). Modified from Smith et al. (2008).

AN INTEGRATED RESEARCH FRAMEWORK

Today's environmental issues cannot be investigated sufficiently with existing disciplinary approaches or with the limited interdisciplinary funding opportunities that are currently available. Scientists have repeatedly called for more opportunities for collaborative research between the ecological, geological, and social sciences (8, 10, 11, 12, 13, 14, 15, 16, 17). They often identify needs yet rarely put forward viable mechanisms for promoting interdisciplinary science. A comprehensive framework is needed to encourage relevant disciplinary research and enable integrative research among disciplines.

Through workshops with ecologists, geologists, and social scientists, we have developed a proposed framework for ISSE that explicitly integrates these disciplines via a series of broad questions (Fig.2). These questions can be operationalized locally, regionally, and globally to address specific issues related to biophysical systems, ecosystem services, and human responses and outcomes. They also can be addressed over time frames from seconds to centuries. Unlike other more linear approaches (e.g., 14), the ISSE framework is an interactive network of linkages and feedbacks among biophysical and social sciences. The framework will rely on theoretical, empirical, and methodological contributions that connect the disciplines. This framework also will contribute substantially to development and testing of theory within these disciplines

MOTIVATION FOR THIS INITIATIVE

This initiative is motivated by fundamental observations about the environmental impacts of resource consumption and human population growth at international, national, and local scales. Some environmental impacts are long-term changes, or presses, that occur over decades or centuries, such as buildup of atmospheric carbon dioxide. Other impacts are short-term events, or pulses, that happen over brief periods once or repeatedly, such as wildfires and El Niño. Human-caused global environmental change is increasing the strength of the long-term impacts and altering the frequency and intensity of the short-term impacts. Fundamental processes in ecosystems—such as hundred-year fire cycles and nutrient cycles—are being reshaped by human activities with largely unknown long-term consequences.

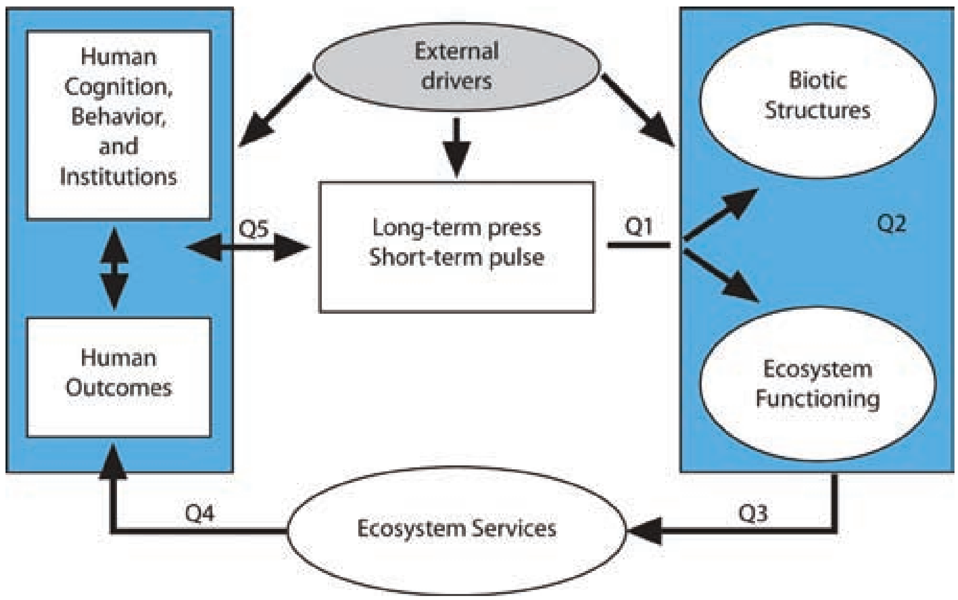


Figure 2. An integrative and iterative conceptual framework for socio-ecological research. Interactions within this framework are driven by a set of general questions (Q1-Q5, see next page) that create information pathways for linking the ecological, geological, and social sciences. This very general framework can be operationalized for a variety of ecosystem types (see Box 1 for an example), and across spatial scales. Indeed, this framework is designed to accommodate the potentially disparate scales of research across these disciplines.

At global and national scales, the ecological and sociological changes are creating an environmental crisis. As human population continues to expand (5, 6) with attendant land-use, technological, and economic changes, additional demands will be placed on ecosystem services (7). These demands will require integrated, long-term research that spans multiple disciplines and ultimately can provide solutions for the environment and society.

At the core of this initiative is the increased understanding that humans are embedded in Earth's ecological systems and that studying ecological systems without consideration of the sociological system does little to advance our ability to solve complex environmental problems. It is widely acknowledged that research must treat humans as integral to ecosystems and that forward-looking research is essential to help maintain Earth's systems while meeting human needs (8). Schematically, we view socio-ecological systems as embedded within and interacting with an increasingly variable and changing climate system.

Geologists, ecologists, and social scientists examine how systems are organized and the influences of internal versus external factors (9). Moving environmental science to a new level of research collaboration, synthesis, and integration requires a shift from viewing humans as external drivers of natural systems to that of agents acting within socio-ecological systems (10).

RECOMMENDATIONS

General Research Questions in ISSE Framework

Q1

How do long-term and short-term human impacts interact to alter ecosystem structure and function?

Q2

How can biological characteristics of an ecosystem be both the causes and consequences of fluxes of energy and matter?

Q3

How do changes in ecosystem dynamics affect ecosystem services?

Q4

How do changes in ecosystem services feed back to alter human behavior?

Q5

Which human actions influence the frequency, magnitude, and form of human impacts across ecosystems, and what determines these human actions?

The ISSE will increase society's awareness of environmental problems and its ability to develop solutions by (1) expanding understanding at many scales of geography and time, (2) developing cyberinfrastructure for integration and collaboration, and (3) building intellectual capacity for integration and public engagement.

I. Expand understanding at many scales of geography and time. To fulfill the ISSE research goals, we recommend the following actions:

Action 1: Enhance and expand collaborative research opportunities.

Action 2: Expand opportunities for interdisciplinary collaboration.

Action 3: Expand opportunities for long-term research.

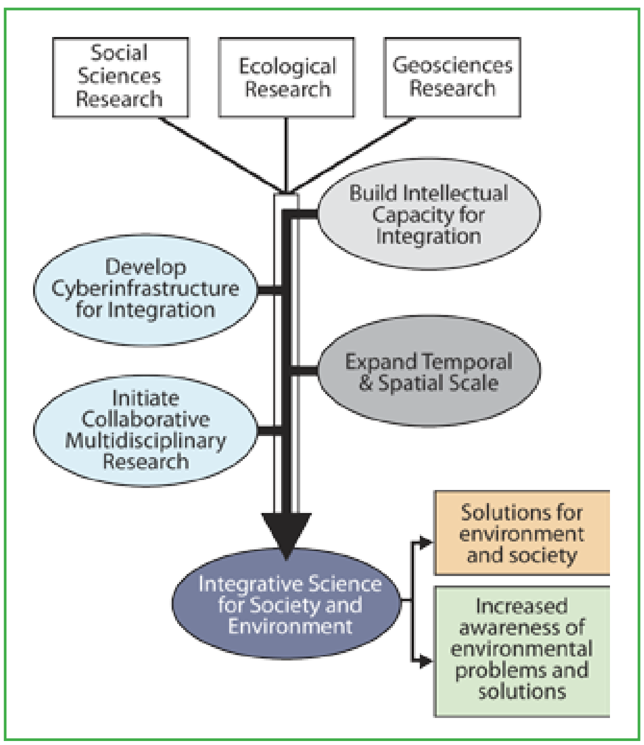
Action 4: Expand opportunities for synthesis.

Action 5: Create a long-term, multi-site, socio-ecological research program.

Human activities are an integral part of ecosystems, and environmental research must become more forward-looking and focused on maintaining Earth's systems and meeting human needs (3, 4, 8). Challenges include organizing interdisciplinary partnerships, coordinating research networks, and making information more readily available. A long-term approach is essential to understand complex socio-ecological systems where events are interdependent, play out in the long term, and respond strongly to both long-term and short-term impacts. Crucial scientific questions can be answered only with long-term data, yet programs supporting such investigations are few and those that do exist are insufficiently funded. It is imperative that social science be an integral part of these long-term research and education initiatives (18, 19).

Understanding the complex interactions in socio-ecological systems requires new levels of information synthesis as huge quantities of data—often highly detailed from diverse sources—become available and as the issues we face become more urgent and interdependent. The importance of both retrospective and predictive synthesis has never been greater.

Many recent reports have identified critical barriers to creating knowledge that can provide the generality and predictive capabilities needed for solutions to environmental and societal problems. In ISSE we recommend more opportunities for long-term research by individual investigators and teams, more resources for interdisciplinary research, more opportunities for synthesis of existing research, and the creation of a network-scale, interdisciplinary, long-term research program.



Cyberinfrastructure

Cyberinfrastructure describes research environments "that support advanced data acquisition, data storage, data management, data integration, data mining, data visualization and other computing and information processing services over the Internet. In scientific usage, cyberinfrastructure is a technological solution to the problem of efficiently connecting data, computers, and people with the goal of enabling derivation of novel scientific theories and knowledge" (20). Cyberinfrastructure also includes people and organizations that operate and maintain equipment, develop and support software, create standards and best practices, and provide other key services such as security and user support.

Many issues facing society today are complex and occur over long time periods and broad spatial scales. Yet no mechanisms currently exist for network-scale, long-term, multi-site, interdisciplinary research programs built on a socio-ecological framework. Network-scale interdisciplinary research would address fundamental theoretical issues in socio-ecological research and lay the groundwork for the syntheses of the future.

II. Develop cyberinfrastructure for integration and collaboration. To fulfill the ISSE cyberinfrastructure goals, we recommend the following actions:

Action 6: Support the deployment, integration, and interoperability of cyberinfrastructure, standards, and people across environmental networks.

Action 7: Support curated repositories for data and models to expand the knowledge base for synthetic research.

Action 8: Invest in programs for technology transfer and training of information specialists and scientists.

Action 9: Support technology developments in socio-ecological informatics.

Action 10: Enhance data collection and information management systems relevant to socio-ecological research.

Investments in cyberinfrastructure and workforce development are necessary to meet the challenges of the ISSE initiatives for integrative research and education at multiple scales; across disciplines; and using resources, data, and expertise at geographically distributed sites. These investments will create new capacity for collaboration, scientific integration, and information transfer.

Interdisciplinary research initiatives require more coherent, interoperable systems to locate, access, and integrate information from multiple disciplines as well as provide findings in forms useful to educators and the public. Major technological barriers exist for researchers, data service providers, and educators. Resolving these issues will involve expanded resources of people, technology, and capacity at dispersed sites and at centralized facilities.

Significant new investment in information technology must include programs for technology transfer and training of information specialists, scientists, and educators. Creating virtual organizations of science teams and working groups through implementation of collaboration technology will be a crucial component of the information technology-enabled knowledge environment for ISSE science.

Existing online data and documentation are valuable resources for integrative, synthetic research, but new data volumes and data types create challenges for data throughput and quality. In many cases, data mediation solutions are still areas of active research in information technology. Socio-ecological research projects of the ISSE represent a valuable opportunity to test and implement these evolving technologies.

ISSE demands the development of new integrative models, advanced analytical and visualization tools, and scientific workflow environments. The research initiatives will require reliable, usable, and extensible information systems to achieve their objectives.

III. Building intellectual capacity for integration and public engagement. To fulfill the ISSE goals for building intellectual capacity, we recommend the following actions:

Action 11: Support environmental education research focusing on learning progressions, curriculum development, and pedagogy that facilitates science literacy.

Action 12: Support network-level efforts to engage broad participation representing our diverse society.

Action 13: Engage K-16 students in inquiry-based science education that integrates socio-ecological disciplines and focuses on working with data.

Action 14: Provide opportunities for graduate students to conduct interdisciplinary research within the context of large temporal and spatial scales.

Box 1. Social and Ecological Cycles in Lake Management

Human activities and lake ecosystems of Madison, Wisconsin, have undergone several cycles of change since European settlement in 1840 (30). In each cycle, human activities affected hydrology, water chemistry, or the food web, leading to changes in lake water levels, water quality, fisheries, or recreational uses. The shifts in ecosystem services spurred social responses, such as formation of new institutions for lake management and changes in mandates of existing institutions. The intent has been to modify human activity and the ecosystem to improve ecosystem services. But in each cycle, new problems caught managers by surprise, just as they were beginning to solve the old problems.

In the late 1940s, for example, water quality deteriorated sharply because of increased pollution from sewage and agricultural fertilizer. In 1971, sewage was diverted, but the lakes failed to recover as people had hoped. Thirty years of intensive use of fertilizer had transformed soils into a persistent source of non-point pollution. In the 1980s, an initial attempt to mitigate non-point pollution failed because of inadequate attention to farmer behavior and farm microeconomics.

From 1987 to 1994, managers restored game fish to the lake food web, leading to reductions in nuisance algae and better water quality. Despite these improvements, toxic algae blooms episodically choked the lakes. In 1997, a new initiative sought to address the problem of non-point pollution with a wider diversity of policy instruments. By then, however, land development had increased the impervious surface in the watersheds, causing greater variation in lake levels and flushing rates.

Point- and non-point pollution with phosphorus in lakes of the North Temperate Lakes LTER can cause blooms of toxic and noxious cyanobacteria. For more information, see http://lter.limnology.wisc.edu

The nature and scope of environmental science as envisioned in ISSE requires a new approach to recruiting and training future scientists at the undergraduate and graduate levels. The composition of the research community must reflect the diverse public that we serve and from whom we seek support (21, 22). And we must engage students in scientific inquiry that includes an interdisciplinary approach to understanding global issues.

We recognize these two goals—engaging a more representative student body and improving science education, particularly in the realm of socio-ecological sciences—as separate but interconnected. We can accomplish these goals through innovative curriculum and research experiences that are designed to expand recruitment and retention of a diverse student body. Studies have demonstrated that an innovative, authentic curriculum improves recruitment and retention of students from diverse ethnic and gender groups (23, 24, 25, 26, 27, 28, 29).

We propose an integrative approach to student diversity and curriculum. This approach would include implementing near-peer mentoring, promoting collaboration in undergraduate research, integrating curricula across biophysical and social science disciplines, and broadening our definition of ecological science career pathways. At the graduate level, increasing numbers of students must be engaged in interdisciplinary research that includes broad spatial and temporal perspectives.

To move us wisely into the future, all citizens need environmental science literacy to understand the challenges and opportunities presented by environmental issues. Educators and scientists can provide students with opportunities to develop two critical abilities that, in combination, define environmental science literacy: understanding and evaluating arguments from evidence and using scientific knowledge effectively in arguments and decisions about human freedom, opportunity, and justice.

The ISSE framework includes research and outreach activities to foster environmental science literacy. Initiatives at the national level will focus on identifying relevant socio-ecological content in K-12 education, understanding how students learn this content, and promoting implementation of teaching practice and standards to facilitate environmental science literacy. Local and regional efforts will engage teachers and students directly and will foster relationships among scientists, undergraduate and graduate students, and the K-12 community. The scope and urgency of environmental issues obliges us to prepare future scientists and a public that understands the complexity, nature, and limitations of our shared resources.

Sevilleta researchers demonstrate hantavirus handling techniques at the groundbreaking ceremonies for Sevilleta Education and Research Facility, July 6, 2005.

International Perspectives

A theme that will run throughout the ISSE initiative—from research to cyberinfrastructure to education—is the need to incorporate international awareness and participation. Working with colleagues around the world—learning from their models, data, and expertise—is invaluable for researchers. And to truly understand the role of humans in the environment, we need to understand the role of all humans and their cultures.

Niwot Ridge LTER students learn how to identify flowers.

The Challenge & the Potential

Rapid, extensive changes in Earth's systems, the conditions responsible for the changes, and the societal responses to them demand a new, interdisciplinary science. The proposed Integrated Science for Society and Environment initiative will significantly increase the capacity of the research community to detect, understand, and respond to the known and anticipated changes in our socio-ecological systems, and to transfer that information to key user groups. These anticipated changes include the following:

- Global climate change, variability, and related risk.
- Altered hydrologic cycles.
- Altered biogeochemical cycles.
- Altered biotic structure.
- Dynamics of land use, land management, and land cover.
- Altered ecosystem function and ecosystem services.
- Changes in human health, well-being, and security.

The Integrated Science for Society and Environment initiative can move us to a new level of science and education that is recognized as essential in these unprecedented times. ISSE will increase the capacity of educators and society to respond to these challenges. ISSE will encompass the diversity of socio-ecological science; generate the scientific and cyberinfrastructure tools needed to understand complex socio-ecological systems; and establish the educational programs that are necessary for the next generation.

LITERATURE CITED

(1) Steffen, W., A. Sanderson, J. Jäger, P.D. Tyson, B. Moore III, P.A. Matson, K. Richardson, F. Oldfield, H.-J. Schellnhuber, B.L. Turner II, and R.J. Wasson. 2004. Global change and the Earth system: a planet under pressure. Springer-Verlag, N.Y.

(2) Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: current state and trends. Island Press, Washington, DC.

(3) Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: scenarios. Island Press, Washington, DC.

(4) Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: synthesis. Island Press, Washington, DC.

(5) Lutz, W., W. Sanderson, and S. Scherbov. 2001. The end of world population growth. Nature 412:543-545.

(6) Cohen, J.J. 2003. Human population: the next half century. Science 302:1172-1175.

(7) Daily, G.C., T. Soderqvist, S. Aniyar, K. Arrow, P. Dasgupta, P.R. Ehrlich, C. Folke, A. Jansson, B-O. Jansson, N. Kautsky, S. Levin, J. Lubchenco, K-G. Maler, D. Simpson, D. Starrett, D. Tilman, and B. Walker. 2000. The value of nature and the nature of value. Science 289:395-396.

(8) Palmer, M.A., E. Bernhardt, E. Chornesky, S.L. Collins, A. Dobson, C. Duke, B. Gold, R. Jacobson, S. Kingsland, R. Kranz, M. Mappin, F. Micheli, J. Morse, M. Pace, M. Pascual, S. Palumbi, J. Reichman, W.H. Schlesinger, A. Townsend, M. Turner, and M. Vasquez. 2004. Ecology for a crowded planet. Science 304:1251-1252.

(9) Pickett, S.T.A., M.L. Cadenasso, J.M. Grove, C.H. Nilon, R.V. Pouyat, W.C. Zipperer, and R. Constanza. 2001. Urban ecological systems: linking terrestrial ecological, physical and socioeconomic components of metropolitan areas. Annual Review of Ecology and Systematics 32:127-157.

(10) Grimm, N.B., J.M. Grove, S.T.A. Pickett, and C.L. Redman. 2000. Integrated approaches to long-term studies of urban ecological systems. BioScience 50:571-584.

(11) Robertson, G.P., J.C. Broome, E.A. Chornesky, J.R. Frankenberger, P. Johnson, M. Lipson, J.A. Miranowski, E.D. Owens, D. Pimentel, and L.A. Thrupp. 2004. Rethinking the vision for environmental research in U.S. agriculture. BioScience 54:61-65.

(12) Newell, P. 2005. Race, class and the global politics of environmental inequality. Global Environmental Politics 5:70-94.

(13) Palmer, M.A., E. Bernhardt, E. Chornesky, S.L. Collins, A. Dobson, C. Duke, B. Gold, R. Jacobson, S. Kingsland, R. Kranz, M. Mappin, F. Micheli, J. Morse, M. Pace, M. Pascual, S. Palumbi, J. Reichman, W.H. Schlesinger, A. Townsend, M. Turner, and M. Vasquez. 2005. Ecology for the 21st century: an action plan. Frontiers in Ecology and the Environment 3:4-11.

(14) Kremen, C. and R.S. Ostfeld. 2005. A call to ecologists: measuring, analyzing and managing ecosystem services. Frontiers in Ecology and the Environment 3:540-548.

(15) Balmford, A. and W. Bond. 2005. Trends in the state of nature and their implications for human well-being. Ecology Letters 8:1218-1234.

(16) Farber, S., R. Costanza, D.L. Childers, J. Erickson, K.L. Gross, M. Grove, C.S. Hopkinson, J. Kahn, S. Pincetl, A. Troy, P. Warren, and M.A. Wilson. 2006. Linking ecology and economics for ecosystem management. BioScience 56:121-133.

(17) Haberl, H., V. Winiwarter, K. Andersson, R.U. Ayres, C. Boone, A. Castillo, G. Cunfer, M. Fischer-Kowalski, W.R. Freudenburg, E. Furman, R. Kaufmann, F. Krausmann, E. Langthaler, H. Lotze-Campen, M. Mirtl, C.L. Redman, A. Reenberg, A. Wardell, B. Warr, and H. Zechmeister. 2006. From LTER to LTSER: conceptualizing the socioeconomic dimension of long-term socioecological research. Ecology and Society 11(2):13. [online] URL: www.ecologyandsociety.org/vol11/iss2/art13/.

(18) Briggs, J.M., K.A. Spielman, H. Schaafsma, K.W. Kintigh, M. Kruse, K. Morehouse, and K. Schollmeyer. 2006. Why ecology needs archaeologists and archaeology needs ecologists. Frontiers in Ecology and the Environment 4:180-188.

(19) Magnuson, J.J., T.K. Kratz, and B.J. Benson. 2006. Long-term dynamics of lakes in the landscape: long-term ecological research on north temperate lakes. Oxford University Press, London, UK.

(20) Atkins, D., K. Kroegemeier, S. Feldman, H. Garcia-Molina, M. Klein, D.G. Messerschmitt, P. Messina, J.P. Ostriker, and M.H. Wright. 2003. Revolutionizing science and engineering through cyberinfrastructure: report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure. National Science Foundation, Arlington, VA.

(21) Committee on Science, Engineering and Public Policy (COSEPUP). 2005. Rising above the gathering storm: energizing and employing America for a brighter economic future. National Academies Press, Washington, DC.

(22) Ortega, S., A. Flecker, K. Hoffman, L. Jablonski, J. Johnson-White, M. Jurgenson-Armstrong, R. Kimmerer, M. Poston, A. Socha, and J. Taylor. 2006. Women and minorities in ecology II (WAMIE II) report. Ecological Society of America.

(23) Kardash,C.M. 2000. Evaluation of an undergraduate research experience: perceptions of undergraduate interns and their faculty mentors. Journal of Educational Psychology 92:191-201.

(24) Bauer, K.W., and J.S. Bennett. 2003. Alumni perceptions used to assess undergraduate research experience. Journal of Higher Education 74:210-230.

(25) Rahm, J., M-P Reny, and J.C. Moore. 2005. The role of after-school and summer science programs in the lives of urban youth. School Science and Mathematics 105:1-9.

(26) Rahm, J., H.C. Miller, L. Hartley, and J.C. Moore. 2003. The value of an emergent notion of authenticity: examples from two student/teacher-scientist partnership programs. Journal of Research in Science Teaching 40:737-756.

(27) Lopatto, D. 2004. What undergraduate research can tell us about research on learning. Project Kaleidoscope 4:1-8.

(28) Seymour, E., A.B. Hunter, S.L. Laursen, and T. DeAntoni. 2004. Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study. Science Education 88:493-534.

(29) Russell, A. and C. Siley. 2005. Strengthening the science and mathematics pipeline for a better America. American Association of State Colleges and Universities 2(11).

(30) Carpenter, S.R., R.C. Lathrop, P. Nowak, E.M. Bennett, T. Reed, and P.A. Saranno. 2005. The ongoing experiment: restoration of Lake Mendota and its watershed. In: J.J. Magnuson, T.K. Kratz, and B.J. Benson, eds. Long-term dynamics of lakes in the landscape. Oxford Univ. Press, London, UK. Pages 236-256.

BioCON (Biodiversity, CO_2, and Nitrogen) is an ecological experiment designed to study the ways in which plant communities will respond to 3 environmental changes that are known to be occurring on a global scale: increasing nitrogen deposition, increasing atmospheric CO_2, and decreasing biodiversity.

Swimming pools are a common feature of the hot, desert city of Phoenix, AZ. The urban heat island has worsened summer heat. For more information, see http://caplter.asu.edu

The mangrove forest at Florida Coastal Everglades LTER Program before (top) and after Hurricane Wilma's landfall in October 2005 (see http://fcelter.fiu.edu for details).