Robertson, G.P. 2012. Long-Term Ecological Research (LTER). Pages 237-240 *in* I. Spellerberg, D.S. Fogel, S.E. Fredericks, and L.M. Butler Harrington, editors. Berkshire Encyclopedia of Sustainability: Vol. 6. Measurements, indicators, and research methods for sustainability. Berkshire Publishing, Great Barrington, Massachusetts, USA.

Long-Term Ecological Research (LTER)

Long-term ecological research provides the opportunity to investigate important environmental questions that require long periods to resolve—from decades to centuries. Without established sites where observations can be made and experiments can be conducted for an extended time, it is difficult to identify the effects of long-term changes in climate, biodiversity, and ecosystem processes crucial for understanding and managing ecological sustainability.

Environmental change often happens slowly and can be difficult to detect until effects accumulate to the point that they become obvious, by which time they may be much more difficult to mitigate. Even when change happens quickly, it can be difficult to understand its importance to ecological sustainability unless there is a long-term, background record against which the change can be evaluated.

There are many examples of subtle environmental change that have required years of observation to detect. Global climate change is perhaps the best known and most widespread example: change has occurred slowly since the 1750s and has been difficult to detect against short-term variability, and solutions have become more difficult to attain with every passing year of inaction. Other examples of long-term change abound: acid rain, invasive pests including weeds that change grassland fire regimes, insects that kill specific types of trees, mussels that change freshwater lake quality, fisheries depletion, pollinator decline, and lake and coastal eutrophication, to name a few. All affect the habitability and sustainability of the ecosystems on which we depend.

Environmental change thus occurs within all ecosystems, from rain forests to tundra to oceans, and across all ecosystem levels, from communities and populations to the resources upon which they rely such as organic matter and nutrients. And change at every level can occur at different time scales, from slowly over decades to abruptly with little warning.

Without the opportunity to observe and experiment over time scales relevant to the organisms and systems they study, ecologists cannot fully understand the complex dynamics that play out in these systems. Processes that occur slowly over decades are hidden in the "invisible present" of short-term observations and experiments (Magnuson 1990). And change that occurs episodically can be missed if the period being studied doesn't happen to include the time that the change occurs. With short-term studies, then, ecologists risk missing change as it happens and therefore missing the opportunity to study many of the cause-and-effect relationships that are essential for understanding, predicting, and managing environmental change.

US Long-Term Ecological Research Network

To address this problem of the short-term observations and the invisible present, the US National Science Foundation established the US Long-Term Ecological Research (LTER) Network in 1980. The network has since grown to include twenty-six sites in many different biomes of North America and beyond. (See figure 1 on the next page.) At each site, scientists have the opportunity to ask questions not answerable through short-term research efforts alone.

Long-term research at these sites spans years to decades to a century or more, and it allows scientists to ask questions in the context of a wide range of environmental conditions; allows them to consider the occurrence of episodic events such as pest and pathogen outbreaks, the effects of which can last for decades; and

Figure 1. Map of the 26 US LTER Sites

Note: See the LTER Network website (www.lternet.edu) for descriptions of the sites and data.

Source: LTER Network Office.

This map shows the locations of each research facility in the research network, across North America, in Antarctica, and in Tahiti. The table below lists ecosystems and the research facilities studying them.

Biome	**Abbreviation**
Antarctic	PAL, MCM
Arctic	ARC
Boreal Forest	BNZ
Coniferous Forest	AND
Eastern Deciduous Forest	CWT, HBR, HFR, LUQ
Tropical Wet Forest	LUQ
Alpine Tundra	CWT
Desert	JRN, SEV
Grassland	CDR, SGS, KNZ
Lake	NTL
Coastal Marine	PIE, VCR, GCE, FCE, SBC, CCE, MCR
Urban	BES, CAP
Agriculture	KBS

allows them to detect important but slow-acting phenomena such as changes in soil carbon, climate, and land use. Results also allow the most accurate calibration and validation of ecosystem models used to forecast ecological change (Hobbie et al. 2003).

For example, in the Antarctic, research includes questions about long-term changes in penguin populations as changing distributions of ice and krill push penguin populations poleward; in the Pacific Northwest, questions addressed include how and how much carbon is stored by old-growth and younger forests; in southern Florida, questions include how the Everglades removes phosphorus and other nutrients draining from agricultural areas to the north; in Puerto Rico, scientists ask how hurricanes influence the structure and function of wet tropical forests; and in Minnesota long-term questions include the role of plant biodiversity for maintaining ecosystem functions such as productivity and soil carbon accumulation. Such inquiries are common to every site as all address questions related to primary production; plant, animal, and microbial biodiversity; carbon and nutrient cycling; and natural and anthropogenic disturbance

Cross-Site Comparative and Experimental Research

Because LTER sites are part of a network, they provide a powerful context in which to ask comparative questions about how different ecosystems respond to common factors such as warmer winters, more-episodic precipitation, species introductions, nitrogen in rainfall, land use change, and other environmental factors that are likely to have different effects in different ecosystems. The geographic array of sites provides natural gradients such as temperature (from high to low latitudes), ecosystem type (from terrestrial to marine), aridity (from desert to rain forest), and human influence (from almost pristine to urban).

Common measurements among all sites provide a way to identify many of the differences that lead to compelling cross-site questions. While every site performs measurements important for addressing the scientific questions specific to its particular research theme, a set of common measurements is taken at all sites to ensure that comparative questions can be addressed. Thus at every site regular measurements are made of climate (e.g., rainfall, temperature, and precipitation chemistry), plant productivity (e.g., how much grass and tree and phytoplankton biomass are produced each year), populations of organisms important at that site (e.g., changes in the abundance and diversity of trees or penguins or bacteria or fish), carbon and nutrient reservoirs in soil and sediments, and major disturbances—whether natural, such as fire or insect outbreaks, or anthropogenic, such as species introductions or harvests. These common measurements provide not only a long-term record of background information for detecting change at a particular site but also a means for comparing changes across gradients.

Information Management and Education

Crucial to measuring environmental change is making measurements permanently and openly available to the scientific community and others with interests in tracking change. Every LTER site thus posts its data on a website that provides access to the data itself and to the metadata needed to interpret it. Information management is an important priority for network science: data must be curated and shared in ways that promote its long-term integrity and use.

Education is also an important component of LTER. Data from observations and experiments at long-term sites provide a means for K–12, undergraduate, graduate, and public audiences to better understand environmental change and what it means for their communities. LTER data posted on websites can be used for inquiry-based science instruction, and sites can be used for classroom experiments. Long-term ecological research sites are especially important for graduate training, wherein future environmental scientists gain a better understanding of long-term ecological processes and change in order to better inform their future professional activities.

International LTER

Stimulated by the success of the US LTER Network, similar networks have been formed in other countries and together make up the International LTER Network (ILTER); descriptions of the sites and data can be found on their website (www.ilternet.edu). The ILTER is a network of networks, comprising over forty networks devoted to long-term research around the world to help understand global environmental change. As in the US LTER effort, ILTER's focus is on long-term, site-based research.

Future Directions

Long-term ecological research has shown high value for documenting and understanding ecological change in and across a variety of ecosystems. For example, the effects of acid rain in the United States were first identified at the Hubbard Brook LTER site in New Hampshire. Decades of subsequent research have shown how rainfall acidity and nitrogen additions have altered forest productivity, stream chemistry, and various terrestrial and aquatic communities. Acid rain is but one example of how humans influence ecosystems, often unintentionally. Even ecosystems far afield are affected by atmospheric carbon dioxide fertilization and climate change, for example. In response to this influence, LTER research is now transitioning to a paradigm that more explicitly includes humans (Robertson et al. forthcoming 2012), blending the ecological and social sciences in order to better understand and forecast environmental change.

Socioecological questions are now important components of research in the US and European LTER networks (Collins et al. 2011). This approach will provide a better understanding of how humans perceive the services provided by nature at multiple scales, how these perceptions change behaviors and institutions, and how behavior and institutional changes in turn feed back to alter ecosystem structure and function—and the ability of ecosystems to continue to deliver services over the long term.

Of the environmental problems that challenge the sustainability of ecosystems—their current and future ability to provide the services on which we depend—there are few that can be adequately addressed with short-term study. Detecting population and ecosystem change, whether slow or episodic, often requires long-term observations, and fully understanding the causes and consequences of change often requires careful long-term experimentation. Long-term ecological research provides this essential context.

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See also Biological Indicators (*several articles*); Challenges to Measuring Sustainability; Computer Modeling; Ecological Impact Assessment (EcIA); Ecosystem Health Indicators; Geographic Information Systems (GIS); Land-Use and Land-Cover Change; Remote Sensing; Strategic Environmental Assessment (SEA); Sustainability Science; Systems Thinking; Transdisciplinary Research

Further Reading

Callahan, James T. (1984). Long-term ecological research. *BioScience, 34,* 363–367.

Collins, Scott L., et al. (2011). An integrated conceptual framework for social-ecological research. *Frontiers in Ecology and the Environment, 9,* 351–357.

Hobbie, John E.; Carpenter, Stephen R.; Grimm, Nancy B.; Gosz, James R.; & Seastedt, Timothy R. (2003). The US long term ecological research program. *BioScience, 53,* 21–32.

International Long Term Ecological Research (ILTER). (2011). Homepage. Retrieved December 7, 2011, from www.ilternet.edu

Magnuson, John J. (1990). Long-term ecological research and the invisible present. *BioScience, 40,* 495–500.

Robertson, G. Philip, et al. (2008). Long-term agricultural research: A research education, and extension imperative. *BioScience, 58,* 640–643.

Robertson, G. Philip, et al. (forthcoming.) Long term ecological research in a human dominated world. *BioScience.*

US Long Term Ecological Research Network. (2011). Homepage. Retrieved December 7, 2011, from www.lternet.edu

