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A Basis for Understanding Responses to Global Change

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Long-Term Trends in Ecological Systems:

A Basis for Understanding Responses to Global Change

Debra P.C. Peters, Christine M. Laney, Ariel E. Lugo, Scott L. Collins, Charles T. Driscoll, Peter M. Groffman, J. Morgan Grove, Alan K. Knapp, Timothy K. Kratz, Mark D. Ohman, Robert B. Waide, and Jin Yao

Abstract

Peters, D.P.C., C.M. Laney, A.E. Lugo, et al. 2013. Long-Term Trends in Ecological Systems: A Basis for Understanding Responses to Global Change. U.S. Department of Agriculture, Technical Bulletin Number 1931.

The EcoTrends Editorial Committee sorted through vast amounts of historical and ongoing data from 50 ecological sites in the continental United States including Alaska, several islands, and Antarctica to present in a logical format the variables commonly collected. This report presents a subset of data and variables from these sites and illustrates through detailed examples the value of comparing long-term data from different ecosystem types. This work provides cross-site comparisons of ecological responses to global change drivers, as well as long-term trends in global change drivers and responses at site and continental scales. Site descriptions and detailed data also are provided in the appendix section.

Keywords: atmospheric chemistry, climate change, cross-site comparisons, disturbance, ecology, ecological response, ecosystem, EcoTrends, experimental forests, global change, human demography, human population growth, long-term datasets, Long Term Ecological Research (LTER), precipitation, rangeland, rangeland research stations, surface water chemistry.

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While supplies last, single copies of this publication can be obtained at no cost from Debra Peters, USDA-ARS Jornada Experimental Range, Box 30003, MSC 3JER, NMSU, Las Cruces, NM 88003-0003 or by e-mail at debpeter@nmsu.edu.

Copies of this publication may be purchased in various formats (microfiche, photocopy, CD, print on demand) from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, (800) 553-6847, www.ntis.gov.

This publication in its entirety also is freely accessible on the Internet at http://www.ars.usda.gov/is/np/indexpubs.html.

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Preface

Long-term ecological research within the United States dates back to 1902, when areas were set aside as research centers. By 1980, when the Long Term Ecological Research (LTER) program was established, 78 experimental forests and more than 10 rangeland research stations had been conducting research, in most cases for more than 40 years. This suite of sites supported by the National Science Foundation (NSF) and the U.S. Department of Agriculture (USDA), including 26 LTER sites, represents a wide range of ecosystem types, including forests, grasslands and shrublands, and freshwater lakes and streams, near coastal marine areas and estuaries, urban areas, and arctic, alpine, and antarctic systems.

A variety of different kinds of data have been collected from these sites through time, ranging from primarily climatic and human demographic data since the 1800s to more recent quantitative monitoring of plant, animal, and microbial populations and communities, hydrological and biogeochemical cycles, biodiversity, and disturbance regimes. However, for the most part, these data have not been easily accessible to others. The EcoTrends project began in 2004, when two scientists (D. Peters and A. Lugo) saw a need to synthesize and make easily accessible long-term datasets in order to compare continental-scale and national-level trends in ecological responses to changing environmental drivers.

Because Peters (USDA Agricultural Research Service) and Lugo (USDA Forest Service) are employed by different USDA agencies with existing networks of sites and are actively involved in the LTER program, the EcoTrends project began as a multiagency collaboration. As the complexity of the project became clearer in terms of the number and types of long-term datasets available (climate, atmospheric deposition and fertilization, natural disturbance, and human activities), a group of experts were convened to make decisions about these diverse data types from many ecosystem types. This active and productive group of experts, the EcoTrends Editorial Committee (the authors of this book), sorted through the vast amounts of historical and ongoing data from all 50 sites to select and present in a logical format and organization the variables commonly collected.

Considerable time and effort was invested by scientists, information managers, and technical staff at every site to locate the data, verify data quality and quantity, and provide the data and metadata in standard formats. A group of technical consultants assisted in data standardization and accessibility issues needed for website development and for use by a broad community.

Two products resulted from these activities: a book and an initial website (http://www.ecotrends.info), where data contained in the book and their metadata are accessible for discovery, visualization, download, and analysis. This book and the website would not have been possible without these combined efforts.

The goals of the EcoTrends Project include—

- Provide a platform for synthesis by making long-term data more readily accessible.
- Illustrate the application of this platform in addressing within-site and network-level scientific questions.
- Demonstrate the importance of collaborative activities among State universities and multiple Federal agencies.

This book and the associated website contain a small subset of data and variables from 50 ecological sites in the United States. More variables, datasets, and sites will be needed in the future to meet our goals.

A large number of people and agencies made this book possible, including students, faculty, and researchers working alone or together to collect data over time. Institutional support for data archiving and standardization of methods and metadata allowed this project to be successful. Credit is given to each investigator when appropriate. In a project of this magnitude, it is impossible to provide appropriate recognition to

the hundreds of individuals who have contributed to the final product. We apologize in advance for any inadvertent omissions.

The authors thank the USDA-ARS Jornada Experimental Range for continued logistical, hardware, software, and personnel support. The authors also thank the following: the National Science Foundation for support to New Mexico State University (DEB 0618210) for project management, coordination, and personnel; the University of New Mexico (DEB 0832652) for website development; the LTER sites for providing data and metadata; USDA Agricultural Research Service and USDA Forest Service for providing personnel, time, and resources for collecting and making available series of data covering very long periods; and the scientists and information managers at each site for their time and effort in providing data, metadata, and illustrations for this massive project.

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Chapter 1

Long-Term Trends in Ecological Systems: An Introduction to Cross-Site Comparisons and Relevance to Global Change Studies

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Earth's environment is changing in many ways at local, regional, and global scales. Dramatic changes in climate, land cover, and habitat availability have occurred over the past several centuries. Long-term data (exceeding 10 years) are needed to assess the rate and direction of change, to distinguish directional trends in these changes (such as persistent increases or decreases) from short-term variability (of multiyear cycles, for instance), and to forecast environmental conditions in the future. As an indication of global changes, for example, carbon dioxide in Earth's atmosphere has been increasing since 1958 at Mauna Loa in Hawaii (Keeling et al. 2001, 2005). Although this "Keeling Curve" fluctuates from year to year, global atmospheric concentrations of carbon dioxide (CO_2) are clearly rising (figure 1-1) (Keeling et al. 2001, 2005). This global increase in CO_2 is likely responsible for the observed rise in global average temperatures and acidification of the ocean, which lead to coral bleaching and loss of coral reefs (IPCC 2007). The spread of invasive species and of infectious diseases constitutes additional drivers of global change that have significant ecological and economic consequences. Finally, human populations are increasing in numbers, changing in economic status, and moving around the country, resulting in uneven spatial distribution of ecological impacts (Grimm et al. 2008a, 2008b).

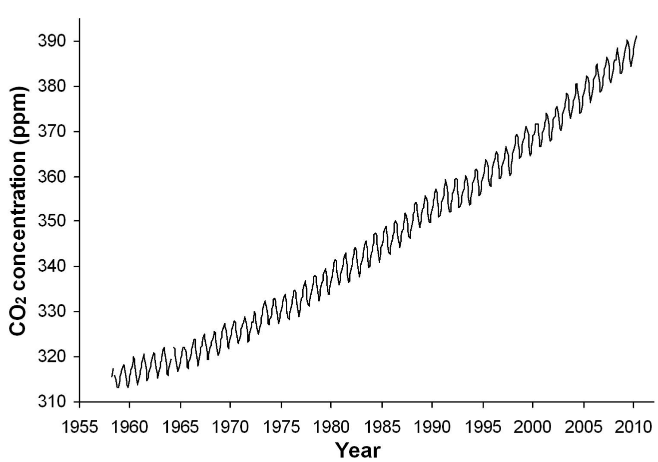

Figure 1-1. Monthly average atmospheric carbon dioxide concentration (CO_2 in parts per million in the mole fraction) through time at Mauna Loa Observatory, Hawaii (19.5°N, 155.6°W) (Keeling et al. 2001, 2005). (Data from http://scrippsco2.ucsd.edu/data/atmospheric_co2.html.)

Only by using long-term data can these changes and their effects be detected and monitored. These changes have important consequences for the services that ecological systems provide to humans, such as clean air and water and food, fiber, and energy (Daily 1997, Palmer et al. 2004, 2005). Thus, long-term data are vital for assessing status and trends of a variety of components of ecological systems and for predicting and managing future environmental conditions needed for a sustainable Earth (Magnuson 1990, Moran et al. 2008, Janzen 2009).

Fortunately, ecological research in the United States has a long history, dating from the 1800s. Sites were initially established by United States Department of Agriculture (USDA), Forest Service (FS) to preserve forests in the face of widespread fires and increasing human population density. Rangeland sites as part of USDA, Agricultural Research Service (ARS) were established to limit land degradation from overgrazing by livestock, particularly during periods of severe drought. In many cases, the initial research was observation based and focused on vegetation properties, such as plant cover.

Through time, a systems approach has become prevalent among ecologists such that many components of a system are studied, including soil properties and plant, animal, and microbial populations and communities, as well as nutrient cycling (Golley 1993). Linking ecological responses with environmental drivers was made possible initially with the National Weather Service's network of sites, which started collecting meteorological data in 1870 (http://www.nws.noaa.gov/), and more recently with site-based weather stations that are part of a large network of sites in the United States (http://www.ncdc.noaa.gov) and globally (http://www.wmo.int). Other drivers include streamflow, which has been monitored at some sites for over 100 years by the U.S. Geological Survey (http://waterdata.usgs.gov), and the census of human demography and economy by the U.S. Census Bureau since 1830 (http://www/census.gov).

With the advent of computational resources in the 1960s, long-term data collection became more practical because large quantities of information could be collected, aggregated, managed, stored, analyzed, and made accessible to others. Advances in information management and software development allowed these vast amounts and kinds of data to be accessible by current and future users (Michener and Brunt 2000). Measurement technology and coordinating activities also improved. For example, sites began monitoring precipitation chemistry in 1978 through the National Atmospheric Deposition Program (http://www.nadp.isws.illinois.edu/). As technology advanced into the 21st Century, long-term research and information systems design have become more sophisticated (Baker et al. 2000, Hobbie et al. 2003). Small, plot-based experiments have been complemented with patch- and landscape-scale extrapolations and manipulations that can be studied over long periods (Cottingham and Carpenter 1998, Carpenter 2002). Aerial photographs obtained by the U.S. Government starting in the 1930s and updated every decade have been combined since the 1970s with remotely sensed satellite images. Analyses of these images through time and space using large computational resources and new algorithms have shown fine- to broad-scale dynamics. More recent advances include wireless technology that allows data to be collected remotely and simultaneously for many locations (Porter et al. 2005, Collins et al. 2006). Theoretical, statistical, and simulation models have been developed that allow the synthesis of different sources and kinds of data for many systems, provide new insights into dynamics, guide development of new studies, and improve prediction about future dynamics for many sites and ecosystem types (for example, Parton et al. 1993, Rastetter et al. 2003).

Networks of long-term research sites and observation systems, such as the Long Term Ecological Research Network (LTER), have become increasingly important as our understanding expands about the complexities and interconnections among components of Earth as a system (Gosz 1999, Peters et al. 2008). These networks often collect similar types of data that can be used to compare sites, both within the same biome (such as multiple grassland sites) and among different biomes (for example: deserts, grasslands, and forests) (Hobbie et al. 2003). Cross-site comparisons are valuable in determining generalities in ecological responses to different drivers and in examining variation in responses to the same driver (Hobbie 2003).

However, multisite comparative studies have not reached their full potential because of limitations in our understanding of data system design and of the data themselves—their types, organization, management, and practices. In most cases, the data have been used primarily by the scientists who collected the data or their close collaborators because of issues relating to content, format, exchange, contextualization, and standards. The reasons for these data issues and resulting limitations on their use include that data—

- are collected to address site- or system-specific questions (often using site-designed methodologies),
- are recorded in unique local or proprietary formats,
- are available only directly from individual researchers or from research site web pages,
- have limited metadata, the descriptive information required to understand the sampling design and repeat the sampling methods, and
- do not include cross-references because of a lack of local or domain level vocabularies and standards.

In many cases, the data have been published either as individual studies or as part of site synthesis volumes (see http://www.oup.com/us/catalog/general/series/TheLongTermEcologicalResearchNet for an example). In cases in which synthetic papers were published to address multiple site questions (for example, Magnuson et al. 1991, Kratz et al. 1995, Riera et al. 1998, 2006; Knapp and Smith 2001, Parton et al. 2007), the data were primarily obtained directly from scientists.

The amount of data available remotely has increased with the World Wide Web; however, these data are typically in an "original" form—the way in which the data were recorded and delivered. Fully comprehending the data is often a complex undertaking because there is detailed information specific to the sampling design to consider, such as transect number, quadrat number, day of sampling, and sample number. Users often require "derived" data products that are aggregations of the originally submitted data reconfigured to allow cross-site comparisons. For example, plant production of a community can be obtained by collecting biomass samples by individual plants in a large number of small quadrats (1 m^2) located along transects designed to capture the spatial variability in a system. Total biomass of all plants (g/m^2) collected at multiple times during the year is needed to determine the change in biomass through time as an estimate of net primary production ($g/m^2/y$). It is the annual primary production of an ecosystem that is most commonly compared across sites rather than the complex original data. Precipitation provides another example of the need for derived data when comparing sites. Precipitation is collected daily, yet it is monthly or annual aggregations of precipitation that are the most useful for comparing sites.

As our ability to collect data over broad areas and long time periods increases, and our need to understand multisite dynamics increases, it will be increasingly important that these data are well documented, easy to access and use, and stored and maintained in common formats for use by future generations (chapter 16). This report and its accompanying web page (http://www.ecotrends.info) represent initial steps in the process of understanding data requirements and developing standards for long-term datasets for cross-site studies. Further, our work provides a foundation for the inclusion of additional data and sites in the dynamic online component of the project.

Purpose and Audience

The intent of this book is twofold—

- Illustrate the importance of long-term data in comparing dynamics across sites and in providing the context for understanding ecological dynamics of relevance to society (chapters 3-10), and
- Present long-term ecological data from different sources and a large number of sites in a common format that is easily understood and used by a broad audience (chapters 11-14).

The writing style, background information, and photos allow users across a range of expertise to grasp and access this information. A perusal of the figures for a specific site or region can lead to the discovery of interesting patterns, such as "Air temperature is increasing through time for a site in my area, yet precipitation is decreasing." Or "Air temperature is decreasing in my area, yet it is increasing in many other parts of the country." In this sense, the book is analogous to an amateur astronomer's telescope: It provides access to a universe of long-term data that were previously available only to a small group of scientists.

Second, the large number of detailed graphs showing long-term data for many sites serves as a key reference for students, educators, and scientists interested in detailed patterns in both global change drivers and ecosystem responses. Because these data can be downloaded from our website (http://www.ecotrends.info), more detailed analyses can be conducted by individual users.

Finally, for most of these sites, data are still being collected. This book, then, serves as an important benchmark of historical patterns that can be compared with future observations as Earth continues to change. Because data are frequently interpreted differently by different people, we present the data and trend lines with limited explanation as a prompt for users to provide their own interpretations.

Practical Applications

This book has practical applications that add to its usefulness and relevance. Land managers can use the data and figures to provide a basis for interpreting local patterns in vegetation and soils observed and managed on the ground. These patterns may be short term and can be misleading without the long-term context provided by historical data. In some cases, a short-term trend can be confirmed by long-term data, demonstrating that a change in management policy may be required. In other cases, long-term data are needed to determine whether short-term changes, such as periodic drought, are cyclic. This information can be used to justify a local, short-term management action rather than a broader scale or long-term change in policy. In addition, climate and other drivers are themselves changing and modifying these patterns in potentially unique ways. Depicting long-term trends in both drivers and ecological responses can be extremely useful for interpreting the complex patterns observed by land managers (chapter 15).

The information in this book can also help explain complex issues to the general public. There is increasing public awareness of the importance of climate change to the daily lives of people, as made popular by the movie "An Inconvenient Truth" (http://www.climatecrisis.net/). However, it is important to differentiate climate variability from a directional change in climate. For example, extremely high air temperatures in one year that kill fruit and row crops need to be differentiated from a long-term change in temperature that shifts the growing season conditions and the locations where crops can be successfully grown. Although climate change has become a favorite topic in the popular press, long-term data on temperature and precipitation at specific sites as well as the consequences of climate change to ecosystem dynamics are not readily available. This book presents a variety of data in forms that are accessible to people who are interested in distinguishing short-term variability from long-term trends in many different areas.

Scientists will find this book particularly useful for a number of reasons. In addition to being used to distinguish short-term variability from long-term trends, the information in this book can be used to identify gaps in knowledge that require new research (chapter 17). Equally important is the re-examination of results from previous research given the additional information provided by more years of data. For example, in southern New Mexico, the drought of the 1950s was often implicated in the demise of grasslands and shift to broad-scale shrub dominance associated with desertification (Buffington and Herbel 1965). Recent analyses of long-term quadrats show that grasses persist to the current day in some quadrats and were lost prior to the 1950s drought in others (Yao et al. 2006). Thus, the importance of the drought must be examined within the context of the long-term climate and vegetation record from 1915 (or earlier if possible) to the present.

Scientists can also use long-term data to help interpret results from short-term studies. Most experiments and observations in ecology are less than 5 years long; this study duration is related to the length of most research grants from State and Federal agencies in the United States (3-4 years). However, the implications of these results to ecosystem dynamics need to be extrapolated to decades or longer. Long-term data are often used in combination with simulation models as a reliable approach to making these extrapolations more meaningful. Federal agencies, such as the USDA Agricultural Research Service and Forest Service, provide a structure to support this type of long-term research that goes beyond competitive grants. The U.S. National Science Foundation through the Long Term Ecological Research Network and Long Term Research in Environmental Biology programs are also critical to the collection of long-term data by providing long-term funding (5-6 years) through competitive awards.

Site, Variable, and Data Selection

This book illustrates the value of long-term studies in two ways. First is the comparison of the dynamics of multiple sites by synthesizing published data in eight themes (chapters 3-10). Second is the comparison of data through time for four types of variables using graphs and maps (chapters 11-14). The focus is on data from 50 ecological research sites funded by U.S. agencies and located in North America and Antarctica, with one site in French Polynesia (figure 1-2, table 1-1). Twenty-six of the sites are individually funded by the National Science Foundation as part of the LTER Network (http://www.lternet.edu). Most of the remaining sites are USDA federally operated sites, either experimental forests (USFS, 14 sites) or rangelands (ARS, 7 sites); and 9 sites are affiliated with both LTER and USDA (USFS or ARS). The remaining three sites are operated by other Federal or State agencies (Loch Vale Watershed by the U.S. Geological Survey [USGS], Walker Branch Watershed by the U.S. Department of Energy, and Santa Rita Experimental Range by the University of Arizona).

These sites represent six ecosystem types common globally (arctic and alpine [including Antarctica], arid lands, coastal systems, forests, temperate grasslands and shrublands, and urban systems) (table 1-1, figure 1-3) and cover much of the range in average annual temperature and average total annual precipitation for these ecosystems (figure 1-4). The terrestrial ecosystem types broadly characterize biomes, but in many cases our ecosystem types include multiple terrestrial biomes as defined by the World Wildlife Fund (http://www.wwf.org) and others (table 1-2).

In some cases, our sites represent finer spatial resolution of ecosystem types than shown by biomes. For example, Niwot Ridge and Loch Vale are classified here as alpine sites based on the sampling location of most of their data in this book, although these locations are classified as coniferous forests based on the surrounding biome of larger spatial extent. In other cases, we generalize ecosystem types in order to simplify the presentation of data. For example, we distinguish forests, a large and diverse collection of sites, into western and eastern forests based only on their geographic location relative to the Mississippi

River. Two urban sites are distinguished in our analysis because their data collection focuses on urban effects (Baltimore Ecosystem Study and Central Arizona Phoenix); we show the biomes surrounding these cities in tables 1-1 and 1-2 to allow comparisons with similar natural ecosystems. Because coastal sites often collect data in adjoining land as well as in coastal waters, we show the land-based ecosystem type in table 1-2 to allow comparisons with similar terrestrial systems.

Variables were selected to characterize either a global change driver (climate, precipitation and stream water chemistry, human demographics) or a biotic response to drivers, primarily by plants and animals. A total of 37 variables were selected for inclusion in this book if data were available from at least 5 sites for at least 10 years and if both the original source data and the associated metadata were available (tables 1-3, 1-4, 1-5). More variables can be found on the EcoTrends website (http://www.ecotrends.info).

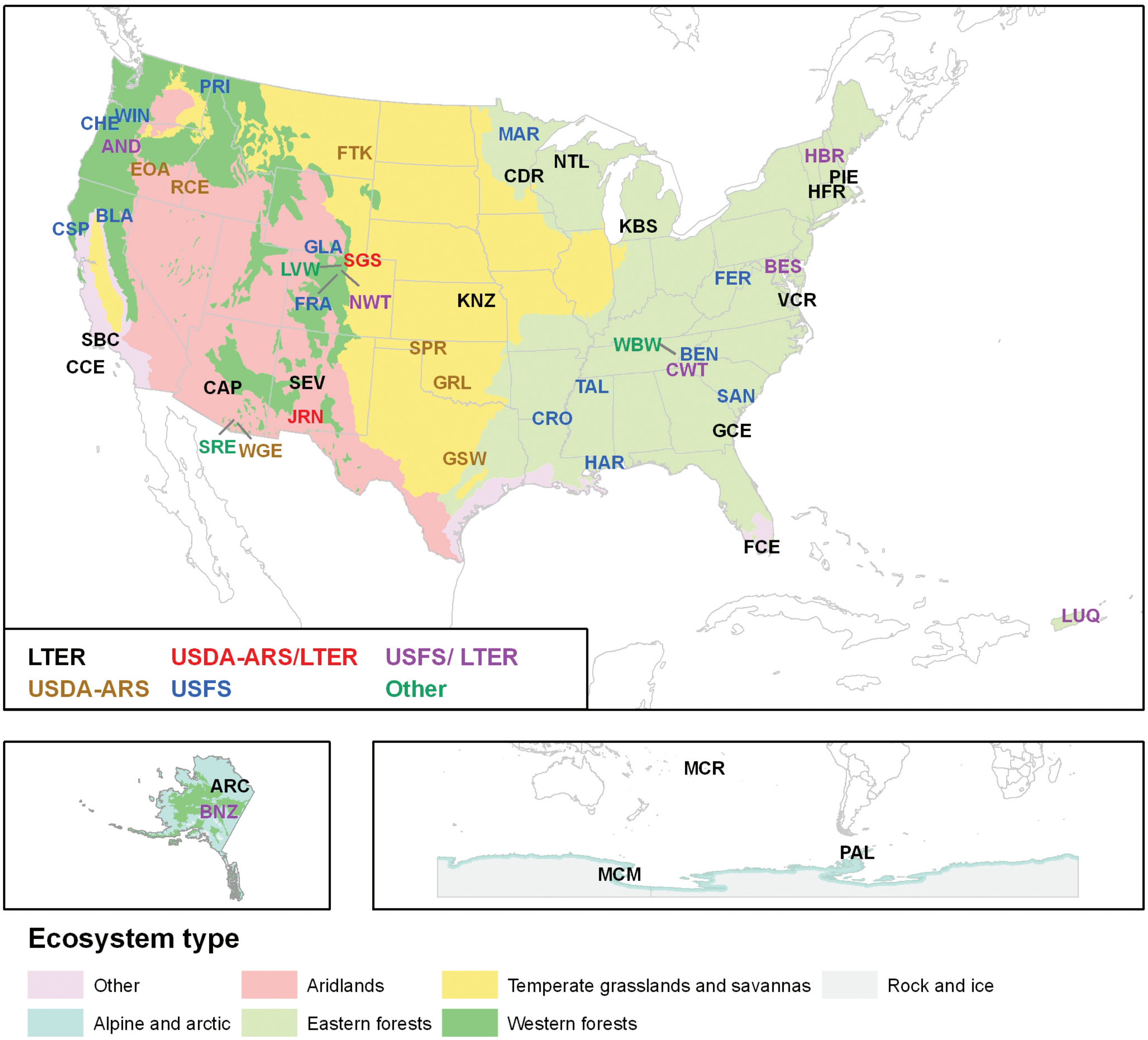

Figure 1-2. Location of sites identified by their program or funding agency, network, and agency names. Background color shows terrestrial ecosystem type used in EcoTrends from table 1-2. These colors are used throughout the book. See table 1-1 for site names and program acronyms.

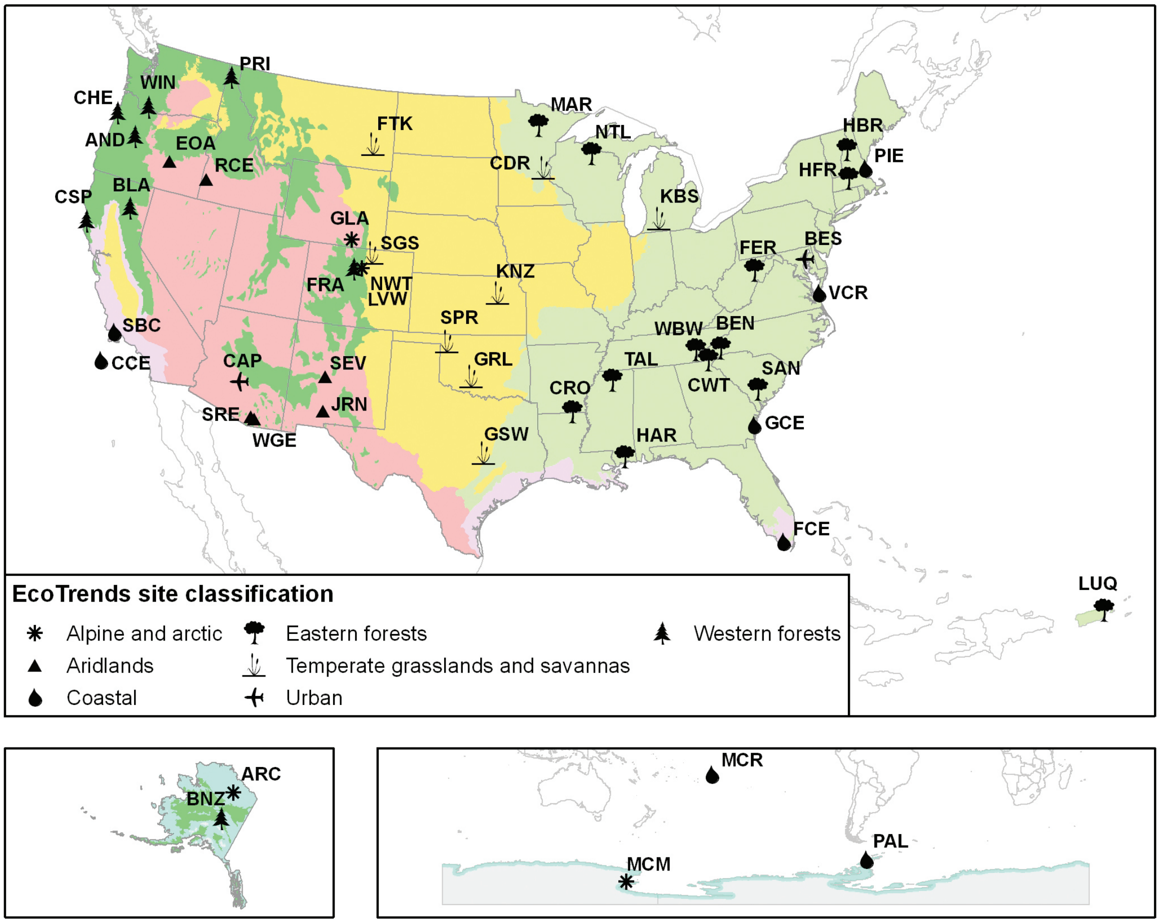

Figure 1-3. Location of sites shown by EcoTrends ecosystem type differentiated by symbols. See table 1-1 for site names.

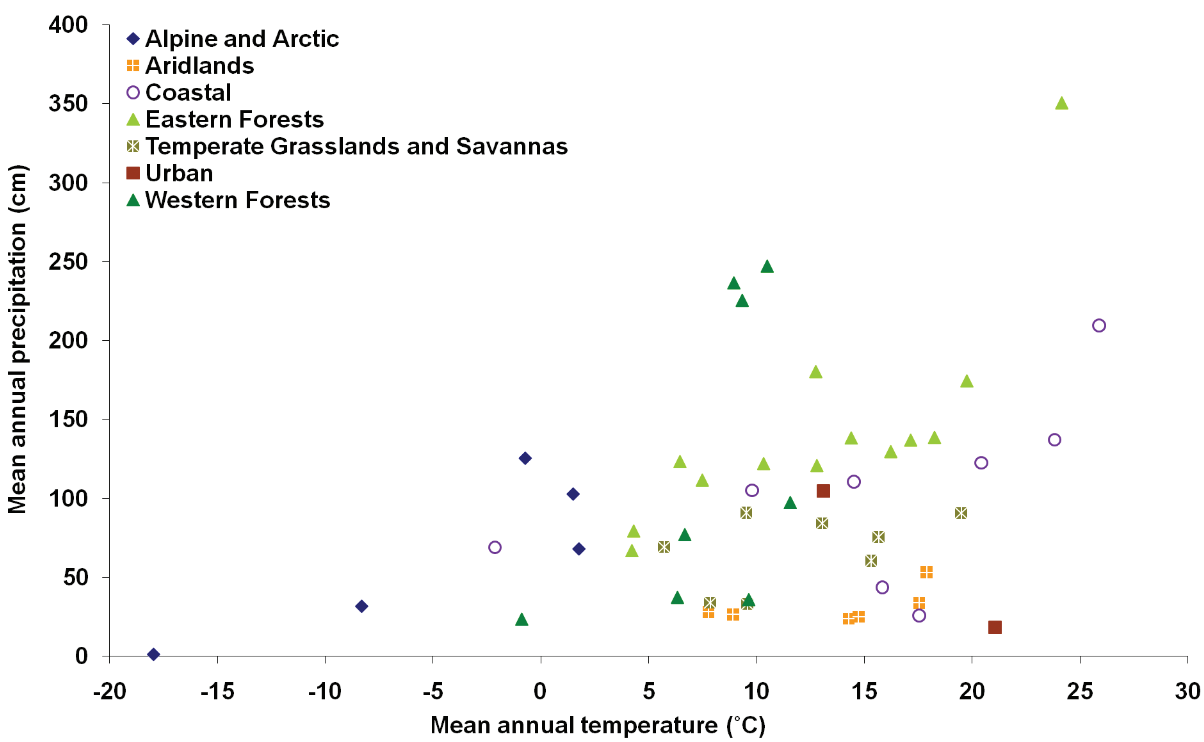

Figure 1-4. Mean annual temperature (°C) and precipitation (cm/y) of the 50 sites labeled by ecosystem type. Adjacent land area shown for coastal sites.

Data were obtained from one of three sources:

- Internet portals where data and metadata quality and standardization were already complete for many sites
- Individual research site web pages
- Individual researchers

Although data are often collected at more than one location within each research site, space constraints limit our analyses to a representative sampling location. We created derived data products by either averaging or summing the data from a single source, such as a weather station, or across a detailed study design to obtain one value per time step, which is typically a year or a month. Data and metadata in this book have undergone initial quality control for errors, have been formatted to a common standard, and are now available to the public from a single website (http://www.ecotrends.info). Users are encouraged to verify the accuracy of the data downloaded from the EcoTrends site by checking the original source of data.

Statistical Considerations

The original intent of this book (that is, to present the data in a straightforward, transparent manner to stimulate further exploration and analysis) guided the minimalist statistical treatment of the data. We present variables one at a time to allow readers to readily evaluate the data and compare datasets. We have not used ordination or classification methods, nor have we calculated multivariate measures of association. Our hope is that readers will be stimulated by the data presented in this book to conduct additional analyses on their own using data available on the EcoTrends website.

The exploration of long-term trends in measurements and the consistency of such trends across a range of measurement variables, biomes, and geographic regions involve significant challenges because of the need to present several hundred time-based series of diverse variables measured at different intervals. Measurement methods vary greatly and have an array of different error structures. Accordingly, to explore temporal trends in a consistent manner across all variables in the space allowed, we rely principally on simple linear regression methods using $p \leq 0.05$ as our level of significance. Probability values for the significance of linear regressions have not been corrected for the effects of serial autocorrelation (Pyper and Peterman 1998). We do not attempt to use alternative trend analysis or smoothing methods, either parametric or nonparametric, other than the calculation of a running mean for some variables. We test only for a linear relationship with time, although we are aware that some variables change in a nonlinear manner and higher order polynomials may be better descriptors of the underlying changes in certain datasets. In some cases, thresholds or relatively abrupt transitions may be apparent, but it was not practical to test for such responses across all variables. Again, we encourage readers to take the next steps on their own.

Organization of the Book

There are four main parts to this book. After a brief history (chapter 2), the first part consists of eight chapters (chapters 3-10) that illustrate the importance of long-term research across sites to address scientific questions or hypotheses. The research themes were selected based on their ecological importance and by the availability of long-term data for many sites, either previously published or in the EcoTrends database, that allow cross-site comparisons.

The second part consists of four chapters (chapters 11-14) that show long-term data and trends for each site. Each chapter contains a brief introduction to the topic and methods of measurements, selection of variables, and their data source. Each chapter consists primarily of a large number of figures showing long-term data for different variables. The figures are organized first by variable (for example, nitrogen), then by large-scale patterns in that variable across the country. For variables with many sites, we present the site-specific data through time for each ecosystem type. For variables with fewer than nine sites, we imbed the site graphs through time within a continental map to display broad-scale patterns in the variable.

The third part of this book consists of three chapters (chapters 15-17) containing management implications, recommendations for data accessibility in cross-site studies, and a synthesis of trends in the book followed by an identification of research needs.

The fourth part contains 28 appendices. Appendix 1 provides a short description of each site, and the other 27 appendices provide detailed information and summary statistics in a tabular format for each variable in chapters 11-14.

Table 1-1. Site names and codes with home page URL, funding agency and/or research program, and general characteristics

Site name (URL)	Site code[1]	Program/ agency[2]	MAP[3]	MAT[4]	Latitude	Longitude	Ecosystem type[5]
			cm	*°C*	°	°	
H. J. Andrews Experimental Forest (http://andrewsforest.oregonstate.edu/)	AND	USFS/LTER	226	9	44.21	-122.26	Western forests
Arctic (http://ecosystems.mbl.edu/ARC/)	ARC	LTER	33	-9	68.63	-149.60	Alpine and arctic
Baltimore Ecosystem Study (http://www.beslter.org/)	BES	USFS/LTER	105	13	39.10	-76.30	Urban (eastern forest)
Bent Creek Experimental Forest (http://www.srs.fs.usda.gov/bentcreek/)	BEN	USFS	122	13	35.48	-82.63	Eastern forest
Blacks Mountain Experimental Forest (http://www.fs.fed.us/psw/ef/blacks_mountain/)	BLA	USFS	--	--	40.67	-121.17	Western forest
Bonanza Creek Experimental Forest (http://www.lter.uaf.edu/)	BNZ	USFS/LTER	--	-1	64.80	-148.00	Western forest
California Current Ecosystem (http://ccelter.sio.ucsd.edu/)	CCE	LTER	26	18	32.87	-120.28	Coastal
Cascade Head Experimental Forest (http://www.fsl.orst.edu/chef/)	CHE	USFS	247	10	45.07	-123.97	Western forest
Caspar Creek Experimental Watershed (http://www.fs.fed.us/psw/ef/caspar_creek/)	CSP	USFS	102	11	39.38	-123.67	Western forest
Cedar Creek Ecosystem Science Reserve (http://www.lter.umn.edu/)	CDR	LTER	69	6	45.40	-93.20	Temperate grassland and savanna

Table 1-1. Site names and codes with home page URL, funding agency and/or research program, and general characteristics—*Continued*

Site name (URL)	Site code[1]	Program/ agency[2]	MAP[3]	MAT[4]	Latitude	Longitude	Ecosystem type[5]
			cm	*°C*	°	°	
Central Arizona-Phoenix (http://caplter.asu.edu/)	CAP	LTER	19	21	33.43	-111.93	Urban (Aridland)
Coweeta (http://coweeta.ecology.uga.edu/)	CWT	USFS/LTER	180	13	35.00	-83.50	Eastern forest
Crossett Experimental Forest (http://www.srs.fs.usda.gov/)	CRO	USFS	139	17	33.03	-91.95	Eastern forest
Eastern Oregon Agricultural Research Center (http://oregonstate.edu/dept/EOARC/)	EOA	ARS	28	8	43.50	-119.50	Aridland
Fernow Experimental Forest (http://www.fs.fed.us/ne/parsons/)	FER	USFS	128	10	39.05	-79.69	Eastern forest
Florida Coastal Everglades (http://fcelter.fiu.edu/)	FCE	LTER	141	24	25.47	-80.85	Coastal
Fort Keogh Livestock & Range Research Laboratory (http://ars.usda.gov/)	FTK	ARS	34	8	46.26	-105.53	Temperate grassland and savanna
Fraser Experimental Forest (http://www.fs.fed.us/rm/fraser/)	FRA	USFS	42	6	39.91	-105.88	Western forest
Georgia Coastal Ecosystems (http://gce-lter.marsci.uga.edu/)	GCE	LTER	131	20	31.43	-81.37	Coastal
Glacier Lakes (http://www.fs.fed.us/rmrs/experimental-forests/glacier-lake-ecosystem-experiments-site/)	GLA	USFS	132	-1	41.38	-106.26	Alpine and arctic

Table 1-1. Site names and codes with home page URL, funding agency and/or research program, and general characteristics—*Continued*

Site name (URL)	Site code[1]	Program/ agency[2]	MAP[3]	MAT[4]	Latitude	Longitude	Ecosystem type[5]
			cm	*°C*	°	°	
Grassland, Soil and Water Research Laboratory (http://ars.usda.gov/)	GSW	ARS	91	19	31.06	-97.20	Temperate grassland and savanna
Grazinglands Research Laboratory (http://ars.usda.gov/)	GRL	ARS	77	16	34.88	-98.00	Temperate grassland and savanna
Harrison Experimental Forest (http://www.srs.fs.usda.gov/)	HAR	USFS	176	20	30.63	-89.05	Eastern forest
Harvard Forest (http://harvardforest.fas.harvard.edu/)	HFR	LTER	111	8	42.50	-72.20	Eastern forest
Hubbard Brook Ecosystem Study (http://www.hubbardbrook.org/)	HBR	USFS/LTER	124	6	43.94	-71.75	Eastern forest
Jornada (http://jornada-www.nmsu.edu/)	JRN	ARS/LTER	26	15	32.62	-106.74	Aridland
Kellogg Biological Station (http://lter.kbs.msu.edu/)	KBS	LTER	91	9	42.40	-85.40	Temperate grassland and savanna
Konza Prairie Biological Station (http://www.konza.ksu.edu/)	KNZ	LTER	85	13	39.10	-96.40	Temperate grassland and savanna
Loch Vale Watershed (http://www.nrel.colostate.edu/projects/lvws)	LVW	USGS	103	2	40.29	-105.66	Alpine and arctic
Luquillo Experimental Forest (http://luq.lternet.edu/)	LUQ	USFS/LTER	351	24	18.30	-65.80	Eastern forest

Table 1-1. Site names and codes with home page URL, funding agency and/or research program, and general characteristics—*Continued*

Site name (URL)	Site code[1]	Program/ agency[2]	MAP[3]	MAT[4]	Latitude	Longitude	Ecosystem type[5]
			cm	*°C*	°	°	
Marcell Experimental Forest (http://nrs.fs.fed.us/ef/locations/mn/marcell/)	MAR	USFS	67	4	47.53	-93.47	Eastern forest
McMurdo Dry Valleys (http://www.mcmlter.org/)	MCM	LTER	1	-18	-77.00	162.52	Alpine and arctic
Moorea Coral Reef (http://mcr.lternet.edu/)	MCR	LTER	210	26	-17.48	-149.82	Coastal
Niwot Ridge Research Area (http://culter.colorado.edu/NWT/)	NWT	USFS/LTER	69	2	39.99	-105.38	Alpine and arctic
North Temperate Lakes (http://lter.limnology.wisc.edu/)	NTL	LTER	79	4	46.00	-89.70	Eastern forest
Palmer Station, Antarctica (http://pal.lternet.edu/)	PAL	LTER	69	-2	-64.70	-64.00	Coastal
Plum Island Ecosystems (http://ecosystems.mbl.edu/PIE/)	PIE	LTER	110	10	42.76	-70.89	Coastal
Priest River Experimental Forest (http://forest.moscowfsl.wsu.edu/ef/pref/)	PRI	USFS	79	7	48.35	-116.68	Western forest
Reynolds Creek Experimental Watershed (http://ars.usda.gov/)	RCE	ARS	27	9	43.08	-116.72	Aridland
Santa Barbara Coastal (http://sbc.lternet.edu/)	SBC	LTER	44	16	34.42	-119.95	Coastal

Table 1-1. Site names and codes with home page URL, funding agency and/or research program, and general characteristics—*Continued*

Site name (URL)	Site code[1]	Program/ agency[2]	MAP[3]	MAT[4]	Latitude	Longitude	Ecosystem type[5]
			cm	*°C*	°	°	
Santa Rita Experimental Range (http://cals.arizona.edu/SRER/)	SRE	U of A	56	18	31.80	-110.90	Aridland
Santee Experimental Forest (http://www.srs.fs.usda.gov/charleston/)	SAN	USFS	138	18	33.14	-79.79	Eastern forest
Sevilleta (http://sev.lternet.edu/)	SEV	LTER	24	14	34.35	-106.88	Aridland
Shortgrass Steppe (http://www.sgslter.colostate.edu/)	SGS	ARS/LTER	32	9	40.80	-104.80	Temperate grassland and savanna
Southern Plains Range Research (http://www.ars.usda.gov/)	SPR	ARS	63	15	36.62	-99.59	Temperate grassland and Station savanna
Tallahatchie Experimental Forest (http://www.srs.fs.usda.gov/)	TAL	USFS	140	17	34.50	-89.44	Eastern forest
Virginia Coast Reserve (http://amazon.evsc.virginia.edu/)	VCR	LTER	110	14	37.28	-75.91	Coastal
Walker Branch Watershed (http://walkerbranch.ornl.gov)	WBW	DOE	139	14	35.90	-84.30	Eastern forest
Walnut Gulch Experimental Watershed (http://www.tucson.ars.ag.gov/)	WGE	ARS	36	17	31.72	-110.68	Aridlands
Wind River Experimental Forest (http://www.fs.fed.us/pnw/exforests/wind-river/)	WIN	USFS	239	9	45.81	-121.98	Western forest

[1] Three-letter site codes used throughout this report; individual sites may use different acronyms.
[2] Program and agency abbreviations:

- DOE: Department of Energy
- LTER: Long Term Ecological Research Network
- ARS: USDA Agricultural Research Service
- USFS: USDA Forest Service
- USGS: U.S. Geological Survey
- U of A: University of Arizona

[3] MAP: mean annual precipitation.
[4] MAT: mean annual temperature.
[5] Natural ecosystems near cities are shown in parentheses for the two urban sites. NTL is the only lake ecosystem currently in EcoTrends; this site is classified as eastern forest to allow cross-site comparisons. "Eastern forest" and "western forest" are used to indicate location of the site either east or west of the Mississippi River.

Table 1-2. Site classification by EcoTrends ecosystem type and World Wildlife Fund terrestrial biomes, using same color codes to denote ecosystem types as those used in figures in chapters 11-13

EcoTrends ecosystem type	World Wildlife Fund biome[1]	Site code
Alpine and arctic	Temperate coniferous forests	GLA, LVW, NWT
	Tundra	ARC, MCM
Aridlands	Deserts and xeric shrublands	EOA, JRN, RCE, SEV, SRE, WGE
Coastal[2]	Flooded grasslands and savannas	FCE
	Mediterranean forests, woodlands, and scrub	CCE, SBC
	Temperate broadleaf and mixed forests	PIE
	Temperate coniferous forests	GCE, VCR
	Tropical and subtropical moist broadleaf forests	MCR
	Tundra	PAL
Eastern forests[3]	Temperate broadleaf and mixed forests	BEN, CWT, FER, HBR, HFR, MAR, NTL[4], TAL, WBW
	Temperate coniferous forests	CRO, HAR, SAN
	Tropical and subtropical moist broadleaf forests	LUQ
Temperate grasslands and savannas	Temperate broadleaf and mixed forests	KBS[5]
	Temperate broadleaf and mixed forests/ Temperate grasslands, savannas, and shrublands	CDR
	Temperate grasslands, savannas, and shrublands	FTK, GRL, GSW, KNZ, SGS, SPR
Urban[6]	Deserts and xeric shrublands	CAP
	Temperate broadleaf and mixed forests/ Temperate coniferous forests	BES
Western forests[3]	Boreal forests/Taiga	BNZ
	Temperate coniferous forests	AND, BLA, CHE, CSP, FRA, PRI, WIN

[1] http://wwf.panda.org/

[2] For coastal sites, terrestrial biomes are listed for the location of nearby land-based instrumentation (precipitation, temperature, precipitation chemistry).

[3] Forests are separated into two groups (western, eastern forests) for ease of presentation based only on their geographic location relative to the Mississippi River.

[4] NTL, a lake site, is classified here as eastern forest to allow cross-site comparisons.

[5] KBS, an intensive row-crop ecosystem site, is classified here as temperate grasslands and savannas to allow cross-site comparisons.

[6] For urban sites, the biomes of the surrounding natural ecosystems are given.

Table 1-3. Length of record of climate variables for each site

Site code	Air temperature	Precipitation	PDSI[1]	Ice duration	Sea level	Streamflow	Water clarity	Water temperature
AND	1958-2006	1958-2006	1895-2008	-	-	1953-2008	-	1977-2006
ARC	1989-2005	1989-2005	-	1988-2005	-	1983-2004	1989-2004	1975-2004
BEN	1949-2008	1949-2004	1895-2008	-	-	1935-1986	-	-
BES	1940-2008	1940-2008	1895-2008	-	1903-2008	1957-2007	-	-
BLA	-	-	1895-2008	-	-	-	-	-
BNZ	1989-2009	1990-2008	-	-	-	1969-2007	-	-
CAP	1894-2002	1894-2002	1895-2008	-	-	1941-2007	-	-
CCE	1927-2008	1927-2008	1895-2008	-	1906-2008	-	1969-2007	1917-2006
CDR	1893-2007	1837-2008	1895-2008	-	-	-	-	-
CHE	1950-2008	1949-2008	1895-2008	-	-	-	-	-
CRO	1916-2008	1916-2008	1895-2008	-	-	-	-	-
CSP	1935-2008	1913-2007	1895-2008	-	-	1986-2004	-	1989-2004
CWT	1943-2008	1944-2008	1895-2008	-	-	-	-	-
EOA	1937-2008	1937-2008	1895-2008	-	-	-	-	-
FCE	1950-2008	1950-2008	1895-2008	-	1913-2008	1964-2008	2000-2004	1993-2008
FER	1899-2006	1905-2006	1895-2008	-	-	1952-2007	-	-
FRA	1898-2006	1909-2006	1895-2008	-	-	1941-1984	-	-
FTK	1938-2008	1938-2008	1895-2008	-	-	-	-	-
GCE	1915-2008	1918-2008	1895-2008	-	1936-2008	1932-2008	-	2002-2008
GLA	1989-2005	1995-2005	1895-2008	-	-	-	-	-
GRL	1893-2006	1893-2006	1895-2008	-	-	-	-	-
GSW	1940-2008	1938-2008	1895-2008	-	-	1940-2008	-	-
HAR	1955-2004	1955-2006	1895-2008	-	-	-	-	-
HBR	1957-2007	1978-2008	1895-2008	1968-2005	-	1963-2007	-	-
HFR	1964-2008	1964-2008	1895-2008	-	-	-	-	-
JRN	1916-2008	1919-2008	1895-2008	-	-	-	-	-
KBS	1934-2008	1931-2008	1895-2008	1924-2006	-	1931-2009	-	-
KNZ	1899-2008	1898-2008	1895-2008	-	-	1980-2008	-	-
LUQ	1996-2004	1988-2004	-	-	1963-2008	1987-2006	-	-
LVW	1984-2006	1984-2006	1895-2008	-	-	1984-2004	-	1992-2006
MAR	1916-2007	1916-2007	1895-2008	-	-	1962-2006	-	-

Table1-3. Length of record of climate variables for each site—*Continued*

Site code	Air temperature	Precipitation	PDSI[1]	Ice duration	Sea level	Streamflow	Water clarity	Water temperature
MCM	1988-2007	1995-2006	-	-	-	1969-2004	-	1990-2005
MCR	1977-2007	1977-2007	-	-	1976-2008	-	-	-
NTL	1904-2008	1904-2008	1895-2008	1856-2008	-	1975-2007	1981-2007	1982-2008
NWT	1953-2006	1965-2006	1895-2008	1982-2006	-	1982-2001	-	-
PAL	1975-2008	1990-2008	-	1979-2006	-	-	-	-
PIE	1901-2008	1901-2008	1895-2008	-	1921-2008	1945-2009	-	-
PRI	1901-2008	1901-2008	1895-2008	-	-	1950-2008	-	-
RCE	1962-2007	1962-2007	1895-2008	-	-	1963-1995	-	-
SAN	1946-2005	1946-2007	1895-2008	-	-	1990-1999	-	-
SBC	1895-2006	1952-2007	1895-2008	-	1924-2008	1941-2007	-	1955-2004
SEV	1893-2008	1899-2008	1895-2008	-	-	-	-	-
SGS	1944-2008	1944-2008	1895-2008	-	-	-	-	-
SPR	1909-1976	1909-2007	1895-2008	-	-	-	-	-
SRE	1951-2004	1951-2004	1895-2008	-	-	-	-	-
TAL	1902-2008	1905-2008	1895-2008	-	-	-	-	-
VCR	1956-2007	1956-2007	1895-2008	-	1912-2008	-	1992-2008	-
WBW	1949-2008	1949-2008	1895-2008	-	-	1982-2005	-	-
WGE	1898-2007	1898-2007	1895-2008	-	-	1958-2008	-	-
WIN	1931-2009	1931-2008	1895-2008	-	-	-	-	-

[1] PDSI: Palmer Drought Severity Index.

Table 1-4. Length of record for each site for precipitation and surface water chemistry and for human population and economy variables

Site code	Precipitation chemistry	Water chemistry	Population and economy[1]
AND	1981-2008[2]	1982-2006[2]	1850-2000
ARC	1988-2003[2]	1990-2006[2]	1970-2000
BEN	1985-2008	--	1800-2000
BES	1984-2008[2]	1999-2008[2]	1790-2000
BLA	2000-2008	--	1870-2000
BNZ	1993-2008[2]	--	1970-2000
CAP	1999-2007[2]	1998-2008	1880-2000
CCE	--	1984-2005[2]	1850-2000
CDR	1997-2008	--	1860-2000
CHE	--	--	1860-2000
CRO	1983-2008	--	1850-2000
CSP	1980-2007	--	1850-2000
CWT	1979-2008	--	1820-2000
EOA	--	--	1890-2000
FCE	1982-2008	2001-2008	1830-2000
FER	1979-2008	1980-2006[2]	1860-2000
FRA	1984-2008	--	1880-2000
FTK	--	--	1880-2000
GCE	2004-2008	--	1790-2000
GLA	1986-2008	--	1870-2000
GRL	1984-2006	--	1910-2000
GSW	--	--	1860-2000
HAR	--	--	1850-2000
HBR	1979-2008	1965-2005[2]	1790-2000
HFR	1985-2008	--	1790-2000
JRN	1984-2008	--	1860-2000
KBS	1980-2008	--	1840-2000
KNZ	1983-2008	1985-2004[2]	1860-2000
LUQ	1986-2008	1986-2007[2]	1910-2000
LVW	1984-2008	1992-2006	1870-2000
MAR	1979-2008	--	1850-2000
MCM	--	1993-2007	-
MCR	--	--	-
NTL	1980-2008	1982-2007	1840-2000
NWT	1984-2008	1982-2006[2]	1870-2000
PAL	--	1994-2007[2]	-
PIE	1982-2008	1994-2003	1790-2000

Table 1-4. Length of record for each site for precipitation and surface water chemistry and for human population and economy variables—*Continued*

Site code	Precipitation chemistry	Water chemistry	Population and economy[1]
PRI	2003-2007	--	1910-2000
RCE	1984-2008	--	1870-2000
SAN	1985-2008	--	1890-2000
SBC	--	2001-2007[2]	1850-2000
SEV	--	--	1850-2000
SGS	1980-2008	--	1870-2000
SPR	--	--	1900-2000
SRE	--	--	1870-2000
TAL	1985-2008	--	1840-2000
VCR	1990-2007	1992-2007	1790-2000
WBW	1981-2008	1989-2005	1810-2000
WGE	2000-2008	--	1870-2000
WIN	--	--	1860-2000

[1] Earliest and latest years among all available data at a site are shown. There may be shorter lengths of record for some variables at a site.
[2] Not all years or variables were sampled. See appendix 27 for details.

Table 1-5. Length of record for each site for biotic variables

Site code	ANPP[1]	Production—other measures[2]	Aquatic production[3]	Plant biomass	Plant richness	Animal abundance[4]	Animal richness[5]
AND	1983-2005 [6]	-	-	1988-2005	1962-2008	1987-2007	-
ARC	1982-2000 [6]	-	1983-2004 [6]	1982-2000 [6]	-	-	-
BEN	-	1961-2001 [6]	-	-	-	-	-
BNZ	1991-1998	-	-	-	-	-	-
CAP	-	-	-	-	-	1998-2004 [6]	-
CCE	-	-	1984-2005	-	-	-	-
CDR	1982-1998	-	-	1988-2003	1988-2006	1989-2004	1989-2004
CHE	-	1935-2003	-	-	-	-	-
CRO	-	1948-2004 [6]	-	-	-	-	-
FCE	-	-	2001-2007 [6]	2001-2007 [6]	-	-	1996-2005
FTK	1993-2004	-	-	-	-	-	-
GCE	-	-	-	2000-2007	-	2000-2008	-
HAR	-	1960-2000	-	-	-	-	-
HBR	1987-1996	1965-2002	-	1965-2002	-	1969-2004 [6]	1969-2004
HFR	2002-2006	1969-2001	-	-	-	-	-
JRN	1990-2008	-	-	-	1989-2008	1995-2008 [6]	-
KBS	1991-2008 [6]	-	-	-	1991-2008 [6]	1989-2008	-
KNZ	1984-2005	-	-	-	-	1981-2004 [6]	1982-2004
LUQ	-	-	-	-	-	1987-2008 [6]	-
MCM	-	-	1989-2007 [6]	-	-	-	-
MCR	-	-	1998-2008	-	-	2000-2008	2000-2008
NTL	-	-	1987-2007	1983-2008	1983-2008	1981-2008	1981-2008
NWT	1982-1997	-	-	-	-	-	-
PAL	-	-	1991-2006	-	-	1975-2008	-
PIE	1985-2005 [6]	-	-	1984-2005	-	-	-
SBC	-	-	-	2002-2008	-	-	-
SEV	1999-2008 [6]	-	-	-	1999-2008 [6]	1989-2008	-

Table 1-5. Length of record for each site for biotic variables—*Continued*

Site code	ANPP[1]	Production—other measures[2]	Aquatic production[3]	Plant biomass	Plant richness	Animal abundance[4]	Animal richness[5]
SGS	1983-2007 [6]	-	-	-	-	1995-2008	1994-2008 [6]
SPR	-	-	-	1984-2005	-	-	-
SRE	-	-	-	-	1972-2006	-	-
VCR	-	-	-	1993-2006	-	1989-2004	-
WGE	-	-	-	-	1967-2007 [6]	-	-

[1] ANPP: Aboveground Net Primary Production.

[2] Production: other measures include diameter at breast height (DBH), tree height, tree volume, and seed production.

[3] Aquatic production includes chlorophyll A concentration and primary production.

[4] Animal abundance includes aquatic animals (crayfish, fish, frogs, shrimp, snails), birds, insects, and mammals.

[5] Animal richness includes birds, fish, and insects.

[6] Not all years were sampled for all stations. See appendix 28 for details.

Chapter 2

History and Organization of the Ecotrends Project

C.M. Laney, D.P.C. Peters, and K.S. Baker

Cross-site synthesis initiatives offer important opportunities for learning. The internal organizations and histories of these projects are not always documented in detail, but their lessons can inform future projects or sites that would like to participate in larger projects (chapters 16 and 17). In this chapter, we describe the internal organization and timeline of the EcoTrends Project as background to the data and recommendations that follow in subsequent chapters.

The EcoTrends Project began in 2004 when two scientists (Debra Peters and Ariel Lugo) saw a need to synthesize, and make easily accessible, long-term datasets to compare continental-scale and national-level trends in ecological responses to changing environmental drivers (figure 2-1). Because Peters (of USDA, Agricultural Research Service [ARS]) and Lugo (of USDA, Forest Service) are employed by different Federal agencies with existing networks of sites and were actively involved in the Long Term Ecological Research (LTER) program, the EcoTrends project began as a multiagency collaboration, initially funded by ARS. The project's organizational structure expanded over the next 6 years to include many activities and dozens of individuals from six major groups.

Project Organization

Broad organizational structures and a well-defined set of objectives and communication processes were needed to make the project successful. These arrangements were a critical aspect of the project because of the data management differences between sites and agencies as well as the large variety and number of datasets. The six major groups (figure 2-2) each contributed to infrastructure and produced new knowledge and data products (table 2-1):

1. The EcoTrends Project Office (EPO) in Las Cruces, NM, consisted of a director (scientist) (D. Peters), a project coordinator (C. Laney), a spatial analyst (J. Yao), and several graduate and undergraduate student assistants. The information manager of the Jornada Basin LTER (JRN) (K. Ramsey) assisted with designing, building, and maintaining the in-house information management system. The EPO provided overall direction and leadership for the project and worked closely with the other five entities to assemble, correct, and verify long-term data and metadata; to create the derived data products; to coordinate documentation of the derived datasets; and to make them publicly available via a website (http://www.ecotrends.info). ARS and JRN began funding work at EPO in 2004. National Science Foundation supplements to the JRN site provided support for the period 2006-2009.
2. The EcoTrends Editorial Committee (EEC) was formed in 2005 and consisted of a group of 12 scientists (authors of this book) with different expertise (including population ecology and biogeochemistry) and experience with different habitat types (such as lakes, urban, forests, grasslands, oceans) or system components (plants, animals, soils). Members of this committee sorted through the vast amounts of historic and ongoing data from all 50 sites and made decisions about the variables to be included and the content and organization of the book and the website.
3. The EcoTrends Technical Committee (ETC) was also formed in 2005 and consisted of a group of nine computer scientists and information managers drawn from the LTER Network Office, the National Center for Ecological Analysis and Synthesis (NCEAS), and the LTER information managers. Members of this committee provided advice on data and metadata best practices and functionality of the website. The members of this committee are the technical consultants for this book.
4. Participating site scientists, information managers, and technical staff were engaged in the project at various times and provided their datasets to EPO, verified data quality and quantity, and assisted EPO in creating corrected, derived datasets. They provided important insight into the needs of site personnel, issues with creating and comparing derived datasets, and the lessons learned while building their own information management systems and while coordinating data and information transfer with other sites.

2004

- EcoTrends Project initiated
- EPO unsuccessfully attempted unassisted data collection from websites
- EPO emailed requests to solicit data from selected lead researchers
- Book endorsed by LTER Publications Committee

2005

- EcoTrends Project approved as an LTER Network Information System (NIS) module by the LTER Coordinating Committee
- Project Coordinator hired, EEC and ETC formed

2006

- EPO emailed another solicitation for data to all site lead researchers and information managers
- Dialogue between project coordinator and sites initiated
- Key attributes list finalized by the EEC
- Internal website developed by the JRN to help the EEC view accumulated datasets
- LTER ASM talks: Keynote by EcoTrends PI, presentation by EcoTrends Project coordinator to the LTER information manager community, and presentation by LNO developer on the infrastructure to support the website.
- Infrastructures , databases and website designed
- Data derivation started

2007

- Development of infrastructures , databases and website started
- Initial population of website databases started
- EcoTrends Project included in LTER Decadal Plan
- Data derivation continued

2008

- Book prospectus approved by USDA for publication
- Website opened to site researchers and information managers for data checking
- Spreadsheet reporting system created to support data checking process
- Data derivation continued

2009

- Data derivation continued
- Data check by sites for data represented in the book
- Six science-driven working groups met to work on science products
- Website and datasets made publicly available
- EcoTrends working groups met at the All Scientist's Meeting

2010

- Book manuscript finalized with community input, reviewed, and submitted to the USDA ARS publisher
- EcoTrends website reloaded with clean derived data and released to the public domain.

Figure 2-1. EcoTrends timeline from 2004 to 2010.

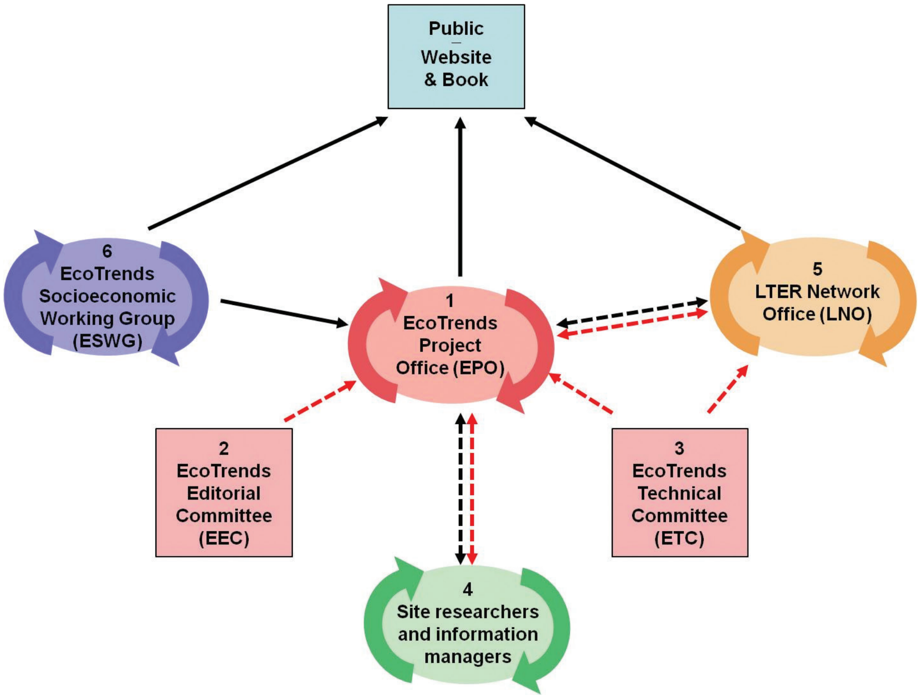

Figure 2-2. EcoTrends organizational arrangements and products. Each work arena is depicted by an ellipse with thick curved arrows that represent internal, dynamic information systems. The advisory committees are shown as rectangles. Straight arrows indicate interactions between the work arenas. Solid black arrows show dataset transfer. Dashed black arrows depict communications between arenas about data issues. Dashed red arrows depict flow of advice.

5. The LTER Network Office (LNO) formed parts of the EEC and ETC, helped design the EcoTrends website, developed routines to create derived dataset documentation and to support website functionality, and deployed the website from its local servers. LNO provided travel support for meetings of the EEC in 2006-08. National Science Foundation supplements to LNO supported work from 2006 to 2009.
6. The EcoTrends Socioeconomic Working Group (ESWG) was composed of one member of the EEC (J. Grove) and two LTER scientists (T. Gragson and C. Boone). This group used supplemental funding from the U.S. Department of Agriculture, Forest Service and National Science Foundation to New Mexico State University to compile historical census data for the participating sites (comprising about 1,000 counties and 32 variables) from several sources. This group also developed a complementary website, the LTER Socioeconomic Catalog (table 2-1), to make these data publicly accessible. A subset of these data were used in this book and are posted on the EcoTrends website.

Timeline

Gathering datasets took a substantial amount of time and effort by a large number of participants in all six groups. Dataset gathering began in 2004 when an undergraduate student from New Mexico State University was hired to find, download, and document long-term datasets (10 years or longer) from websites of research sites. However, this task was more substantial than anticipated. Few web pages provided tools to differentiate long-term datasets within large data stores. Some datasets were insufficiently documented or quality checked and verified for accuracy. Accordingly, the EPO was expanded in 2005 to include a project coordinator and a support position at JRN. ECC and ETC were formed to help assess the status of the data gathering effort and to solicit further contributions. In addition, the project was approved as an LTER Network Information System module (Brunt 1998, Baker et al. 2000) by the LTER Network governing body (the LTER Coordinating Committee), and the book was approved as an LTER publication by the LTER Publications Committee.

Prior and subsequent to the ECC's first meeting in 2006, email solicitations for datasets, without restriction on variable type or documentation level, were sent to the lead scientist at each site. At some sites, requests were handled by the lead scientist or a team of ecologists. At other sites, the request was transferred to the site information manager who often responded

Table 2-1. EcoTrends entities: knowledge, infrastructure, and data products[1]

EcoTrends entities	Knowledge products	Infrastructure products	Data products
EcoTrends Project Office (EPO)	Synthesis book	Local database, project-level data repository	Derived datasets with metadata
EcoTrends Editorial Committee (EEC)	Cross-site scientific publications; advice for website front end and the EPO	Interactions and support between site researchers	Selection of data products
EcoTrends Technical Committee (ETC)	Technical publications; advice for website back end	Interactions and support between site information managers, LNO, and EPO	
Site researchers, information managers	Scientific publications	Information systems, including data repositories and digital libraries	Original datasets with metadata
LTER Network Office (LNO)	Technical publications	Information system, data repository, and website	
EcoTrends Working Group (ESWG)	Cross-site scientific publications	LTER Socioeconomic Catalog database and website	Population and economy datasets

[1]A distinction is made here between knowledge products (such as scholarly works), infrastructure products (such as database or website development), and data products (such as data tables, metadata documents, and graphs) (Gibbons et al. 1994, Hine 2006).

by sending datasets or links to online datasets. Several hundred datasets were submitted that were then categorized by common variable (such as temperature, nitrogen deposition, or plant cover) and examined for consistency among sites by the ECC. Where critical datasets appeared to be missing, followup e-mail requests were sent to the site contacts to check the availability of the datasets, resulting in further submissions.

In addition to the directly submitted datasets, data from other organizations were downloaded from public websites (See table 2-2 for definitions of acronyms and Internet links). Climate and hydrological data were downloaded from the LTER Climate Database (Henshaw et al. 2006), the National Climate Data Center (NCDC), the National Oceanic and Atmospheric Administration (NOAA), and the United States Geological Survey (USGS). Atmospheric chemistry data were downloaded from the National Atmospheric Deposition Program (NADP). The ESWG coordinated the downloading and processing of human population and economy data from the InterUniversity Consortium for Political and Social Research and GeoLytics (http://www.geolytics.com/). A nearly complete working list of key variables and datasets was agreed upon at the ECC and ETC meeting in July 2006 and confirmed at the following meeting in February 2007.

From 2006 to 2008, solicitation of site-level datasets continued while computer programs in R (http://www.r-project.org) were written to process and graph the data. Throughout this period, EEC communicated frequently with EPO to review data progress and make recommendations on further work. In 2008, EPO asked the LTER community to review source and derived datasets online in the form of tables and graphs. Dataset review was divided into several stages. Sites were first asked to check the derived climate, biogeochemistry, and human population data and some months later to review the complete set, including biological data. Site personnel were asked to review and update their source data when necessary.

Dialogue among members over design issues progressed over several years of database and website design and implementation. At the EPO, a database, a data store, and a versioning repository system were developed to track the source data, manage the derivation processes, and document the derived datasets. A local website was developed at JRN to assist with database management, to allow EEC to review book graphics remotely, and to comment on the products and overall progress of the project. The design process for the EcoTrends website also began. A website designer was contracted, and the initial website design was sent to LNO for refinement and implementation. LNO designed and developed an automated system for harvesting each derived dataset and associated metadata into the databases underlying the website, using the EPO database and file naming structures, and for generating an Ecological Metadata Language (EML) documentation file for each derived data product. LNO also built the underlying website structure and tools necessary for data searching, browsing, viewing, and visualizing graphically.

In 2009-2010, EPO tested the usefulness of the derived data and website through six scientist-led working groups. These groups, each working with a different theme, explored how synthesis of EcoTrends-derived datasets could inform research. Each group also explored the EcoTrends data repository, downloaded useful data from the website, and analyzed these data in the context of other non-time-series data. This exercise resulted in valuable feedback about the usability of the website and the data it contains.

Near the end of 2009, EPO asked all participants to extensively check in detail the graphics presented in this book, the derived data, and the associated content on the EcoTrends website, providing another opportunity for community-level participation. Each chapter of this book was written by a small set of site participants and posted online for review by all site participants. An early version of the EcoTrends website was made available to the participants to explore datasets, provide recommendations on future website redesign, and comment on missing data types. Although sites had been asked several times over the past couple of years to check their data, this final check elicited further feedback from the community, likely stimulated by the immediacy of seeing their data and text in print.

Table 2-2. EcoTrends project-related organizations: acronyms or terms and Internet links

Acronym/term	Name	Link
EML	Ecological Metadata Language	http://knb.ecoinformatics.org/software/eml/
EPA	Environmental Protection Agency	http://www.epa.gov
FGDC	Federal Geographic Data Committee	http://www.fgdc.gov
GeoLytics	GeoLytics demographic data	http://www.geolytics.com
ICPSR	Inter-University Consortium for Political and Social Research	http://www.icpsr.umich.edu
LNO	LTER Network Office	http://lno.lternet.edu
LTER	Long Term Ecological Research Network	http://www.lternet.edu
EcoTrends Socioeconomic Catalog	EcoTrends Socioeconomic Catalog	http://coweeta.uga.edu/trends/
Metacat	Ecoinformatics Metadata Catalog	http://knb.ecoinformatics.org
NADP	National Atmospheric Deposition Program	http://nadp.sws.uiuc.edu
NCDC	National Climatic Data Center	http://www.ncdc.noaa.gov
NOAA	National Oceanic and Atmospheric Administration	http://www.noaa.gov
R	R project for statistical computing	http://www.r-project.org
ARS	United States Department of Agriculture, Agricultural Research Service	http://www.ars.usda.gov
USFS	United States Department of Agriculture, Forest Service	http://www.fs.fed.us/

Contributions to Information Management

A set of formalized databases and communication systems were needed to address organizational and technological challenges of managing the hundreds of submitted and downloaded datasets (source datasets) within and between EPO and LNO. As projects of this size and scope are complex and relatively rare, advice on how best to proceed was needed from a broad community. ETC advised EPO and LNO on technical issues, data management practices, organizational mechanisms, and website development. Presentations made at various meetings engaged participants and elicited further input from the science and information management communities. EcoTrends information management also drew upon participants' past experiences with collaborative, cross-site research activities and existing network infrastructures, principally LTER.

Experience gained through data handling, web development, and technology committee and information management community discussions motivated the development of other LTER Network-level cyberinfrastructure projects, principally the Provenance-Aware Synthesis Tracking Architecture (PASTA) (Servilla et al. 2006, 2008). PASTA was conceived and prototyped to support the EcoTrends website, originally as the tool to automate harvesting of the derived data into a repository that was accessible to the website. The EcoTrends experience also contributed to further development of EML and of Metacat, a system developed by the Knowledge Network for Biocomplexity for cataloging EML documents.

Conclusions

The EcoTrends Project is a scientist-driven initiative that has, since 2004, drawn upon a large and diverse community of researchers, information managers, and computer scientists for advice and support. Interactive cycles of refinement were based on community feedback and lessons learned. Where possible, the project attempted to use and support further development of community data practices and metadata standards, while maintaining flexibility for datasets that did not fully meet these practices or standards. This approach facilitated an evolving trend toward data sharing and synthesis. Lessons learned throughout the process (chapters 16 and 17) will inform future multiagency, cross-site, multidisciplinary projects.

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