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Abstract	<p>The Long-Term Ecological Research (LTER) Network is the largest and longest-lived ecological network in the United States. Designed to provide long-term data from a broad range of key ecosystems, the LTER Network represents a unique national resource to address pressing environmental issues such as climate change, loss of biodiversity, and changes in patterns of land use. LTER is recognized internationally as one of the best organized and most successful large groups conducting research in ecology. With over 1,500 scientists, educators, and students, the network spans 26 sites located in 16 states in the contiguous United States, Alaska in the Arctic, Antarctica, and islands in the Caribbean and the Pacific Ocean (Fig. 1).</p>	



2 **Long-Term Ecological Research**
3 **Network (LTER)**

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7 **Article Outline**

- 8 Definition of the Subject
- 9 Introduction
- 10 Major Milestones in LTER
- 11 The LTER Network Today
- 12 Future Directions
- 13 Bibliography

14 **Glossary**

- 15 **Biodiversity** Variation of life at all levels of biological
16 organization.
- 17 **Disturbance** A relatively discrete event in time and
18 space that alters populations, communities, and
19 ecosystems, including their attendant processes.
- 20 **Ecology** The study of the relationship of organisms or
21 groups of organisms to their environment.
- 22 **Ecosystem dynamics** The observed changes in the
23 characteristics of an ecosystem over time.
- 24 **Ecosystem** The organisms living in a particular area
25 in combination with the physical elements of the
26 environment in which they live.
- 27 **Episodic** Limited in duration or temporary.
- 28 **Invisible present** Relating to an observation whose
29 importance cannot be evaluated for lack of context.
- 30 **Scale** Refers to differences in the spatial or temporal
31 extent of a set of observations or measurements.
- 32 **Synthesis** The creation of new knowledge by combin-
33 ing observations from diverse sources.

Transformative research Scientific investigations 34
whose results lead to radical changes in understand- 35
ing of fundamental concepts. 36

Definition of the Subject 37

The Long-Term Ecological Research (LTER) Network is 38
the largest and longest-lived ecological network in the 39
United States. Designed to provide long-term data 40
from a broad range of key ecosystems, the LTER Net- 41
work represents a unique national resource to address 42
pressing environmental issues such as climate change, 43
loss of biodiversity, and changes in patterns of land use. 44
LTER is recognized internationally as one of the best 45
organized and most successful large groups conducting 46
research in ecology. With over 1,500 scientists, educa- 47
tors, and students, the network spans 26 sites located in 48
16 states in the contiguous United States, Alaska in the 49
Arctic, Antarctica, and islands in the Caribbean and the 50
Pacific Ocean (Fig. 1). 51

The network's formal vision is a society in which 52
long-term ecological knowledge contributes to the 53
advancement of the health, productivity, and welfare 54
of the global environment, thereby advancing human 55
well-being [2]. Within this vision, LTER's mission is to 56
provide the scientific community, policy makers, and 57
society with the knowledge and predictive understand- 58
ing necessary to conserve, protect, and manage the 59
nation's ecosystems, their biodiversity, and the services 60
they provide. The LTER Network achieves this mission 61
by using long-term observations and experiments to 62
generate and test ecological theory at local to regional 63
scales. 64

The National Science Foundation (NSF) created the 65
LTER program in 1980. For three decades, the network 66
has generated rigorous, site-based scientific research 67
that has led to important regional and continental 68
syntheses. LTER provides the scientific expertise, 69
research platforms, and long-term datasets necessary 70
to document and analyze environmental change. 71

72 Introduction

73 Because some of the most interesting and important
74 ecological phenomena take place over long periods,
75 long-term observations or experiments are necessary
76 to truly understand their impacts. Processes such as
77 climate change, recovery after disturbances such as
78 forest fires, and changes in land cover are ecological
79 processes that must be studied over the time scale of
80 their occurrence (see, e.g., [3, 4]). Consequently, stud-
81 ies over sufficiently long time periods and large geo-
82 graphical scales are necessary to permit generalizations
83 and theory about long-term events – such as defores-
84 tation, acid deposition, grazing, fire, and changes in
85 trace gas fluxes [5].

86 In the concluding summary to a special report
87 entitled “Long Term Ecological Research: An Interna-
88 tional Perspective,” Risser [6] noted that long-term
89 ecological studies are especially useful under four con-
90 ditions: (1) the phenomena being studied are long term
91 in their dynamics; (2) are episodic in nature, rare,
92 complex, or subtle, such that long-term experiments
93 are needed to isolate their dynamics and the control
94 processes; (3) are poorly understood and cannot be
95 predicted from short time scales; or (4) when long-
96 term records are needed to make policy decisions.

97 Although important, such long-term studies are
98 generally rare, with only a few examples all across the
99 globe (Fig. 2). According to Risser [6] long-term eco-
100 logical studies are rare because: (1) long-term studies
101 may not be considered innovative science, making their
102 continuous funding difficult; (2) sites where the mea-
103 surements are taken may change, making the long-term
104 results meaningless or difficult to interpret; (3) experi-
105 mental designs may be too ambiguous for consistent
106 long-term measurements or may not include adequate
107 auxiliary studies to unravel controlling processes;
108 (4) resources or incentives may be inadequate for ded-
109 icated scientists or research leaders to continue the
110 studies; (5) new instrumentation may render the orig-
111 inal methodology obsolete, coupled with insufficient
112 attention to calibrating the old and new technologies;
113 (6) new scientific advances may make the original
114 question or hypothesis uninteresting or may provide
115 a definitive answer, making the studies unnecessary.

116 It was this dearth of reliable information on key
117 long-term ecological processes that prompted NSF to

create the LTER Network in 1980 (see section “Major 118
Milestones in LTER” in this document for a brief his- 119
tory of LTER’s formation). Acting on the recommen- 120
dations of three working groups comprising members 121
of the ecological community [9–11], the Division of 122
Environmental Biology at NSF constructed a call for 123
proposals designed to “(1) initiate the collection of 124
comparative data at a network of sites representing 125
major biotic regions of North America and (2) evaluate 126
the scientific, technical, and managerial problems asso- 127
ciated with such long-term comparative research” [12]. 128
Although the early emphasis of the LTER program was 129
on expanding the time scale at which ecological 130
research was conducted, a concomitant expansion of 131
the spatial scale of research was also expected (Fig. 3). 132
This broadening perspective led to the twin concepts of 133
the “invisible present” and the “invisible place.” 134

Time and the Invisible Present 135

Magnuson [4] coined the term “invisible present” to 136
describe ecological processes that result in significant 137
change over decades but are hidden to the investigator 138
conducting short-term studies. Ecologists working in 139
this “invisible present” are not able to place current 140
conditions in perspective without additional data from 141
a longer span of time. Magnuson noted that short-term 142
observations often could not identify cause and effect 143
relationships because of inherent time lags of a year or 144
longer between cause and effect. For example, changes 145
in biomass accumulation in a forest as a result of 146
disturbance may take years or decades to perceive. In 147
short-term observational studies, it is rare to actually 148
observe infrequent but important events. However, it is 149
common to observe responses of an ecological system 150
to an event that occurred long before observations 151
began. Short-term manipulative studies often observe 152
a system in transition rather than the complete trajec- 153
tory to a new system state. 154

A good example of the importance of long-term 155
data on the interpretation of ecological processes is 156
given by observations of the ice cover records of Lake 157
Mendota, WI (Fig. 4, [14]). The duration of ice cover in 158
a single winter (1997–1998 in the example) might seem 159
unremarkable without any other context. However, 160
examination of successively longer segments of the 161
142-plus years of ice duration data provides the context 162

163 to see the importance of that single year. A 10-year
164 segment of data reveals that duration of ice cover in
165 1997–1998 was significantly less than the other 9 years
166 of record [15], and that duration of ice cover varies
167 considerably from year to year. A relationship between
168 ice cover and an important feature of global climate,
169 the southern ocean oscillation index [16, 17], is evident
170 in the 50-year data segment, with 1997–1998 and other
171 El Niño years having shorter durations of ice cover. The
172 general warming trend in the data only becomes appar-
173 ent within the complete record. What's more, the end
174 of the little ice age about 1890 [18, 19] is reflected in the
175 decrease in the duration of ice cover on Lake Mendota.
176 The single observation from 1997 to 1998, viewed in
177 the context of the complete data set, is revealed to be
178 the year of shortest ice duration in the entire 142-year
179 record. Thus, the long-term nature of this set of obser-
180 vations provides a clear context to interpret patterns at
181 multiple temporal scales.

182 Space and the Invisible Place

183 In the same way that a point in time requires long-term
184 temporal context for complete understanding, so
185 a point in space requires a broad-scale spatial context
186 [20]. Interpretation of observations at a single site (the
187 invisible place) requires a spatial context that often
188 spans multiple scales. In the LTER Network, observa-
189 tional or experimental studies are often designed and
190 implemented at the plot scale, where the plot may
191 encompass less than 1 m² or an entire watershed.
192 Most LTER site research focuses on plot to landscape
193 scales (Fig. 3), but the use of remote sensing and
194 modeling approaches, the steady development of
195 networked interactions among sites [21], and the
196 growth of the long-term approach internationally pro-
197 vides the means to expand the research focus to
198 regional, continental, and global scales [20].

199 The study of glacial lakes at the North Temperate
200 Lake's LTER site in northern Wisconsin illustrates
201 a typical approach to linking ecological elements in
202 a broader spatial context. Although lakes in this land-
203 scape have many shared characteristics, the relative
204 position of lakes connected along elevation gradients
205 explains much significant dissimilarity, even in areas of
206 slight relief. Lakes that are higher in the landscape are
207 smaller, clearer, more dilute chemically, less diverse,

and less affected by human use [22]. This pattern
208 pertains to other lake districts throughout the northern
209 hemisphere.
210

LTER scientists use two general approaches to
211 extend results from small-scale and short-term studies
212 to regional and broader scales [23]. An empirical
213 approach correlates values of ecological processes
214 with aspects of the physical environment that are mea-
215 surable at broad spatial scales using specialized tools
216 including remotely sensed imagery. For example, Kratz
217 et al. [24] compared patterns of spatial and temporal
218 variability across 12 LTER sites using normalized dif-
219 ference vegetation indices (NDVI) from Landsat
220 scenes. They found that variability within sites for
221 a given year was considerably greater than variability
222 among sites, indicating that studies of spatial hetero-
223 geneity must be coupled with long-term data to achieve
224 an understanding of long-term dynamics at landscape
225 and regional scales.
226

A second approach uses mechanistic models to
227 simulate interactions among ecological processes mea-
228 sured at sites and predict patterns at broader scales
229 [23]. Data from the LTER Network facilitate construc-
230 tion of mechanistic models in two important ways.
231 Coordination among sites within the network pro-
232 duces consistent, multidisciplinary data sets over
233 a broad geographic range. The existence of data on
234 slow ecosystem processes, which govern long-term eco-
235 system dynamics, allows estimation of rate constants
236 needed to model these dynamics. One example of the
237 interaction between long-term data and mechanistic
238 models is the photosynthesis and evapotranspiration
239 model (PnET) developed by Aber and colleagues to
240 predict ecosystem processes at regional scales [23].
241 The PnET models form a nested hierarchy of three
242 models estimating (1) gross and net carbon (C) gain
243 on a daily time step, (2) net C and water fluxes at
244 variable time steps, and (3) biomass, litter fall, decom-
245 position, and nitrogen (N) cycling. Together the three
246 models allow prediction of the integrated function of
247 ecosystems. Predictions from the models have been
248 compared with long-term C, water, and nutrient bal-
249 ance data from the Harvard Forest and Hubbard Brook
250 LTER programs. Discrepancies between predictions
251 and empirical data instruct model improvement and
252 guide site research. The PnET models allow regional
253 scale prediction of integrated ecosystem characteristics
254

255 over a wide range of future environmental conditions
256 and previous land use histories [23].

257 Networks of integrated research sites provide the
258 opportunity to examine continental scale ecological
259 patterns and the drivers of those patterns. One multi-
260 site, long-term experiment (the Long Term Intersite
261 Decomposition Experiment or LIDET) manipulated
262 substrate quality across a broad range of vegetation
263 and climate conditions to understand the factors con-
264 trolling decomposition. Results from standardized
265 measurements at 26 sites (17 LTER sites) indicated
266 that decomposition of low-quality litter across
267 a broad range of environmental conditions was slower
268 than had been previously thought [25] and that signif-
269 icant variability resulted from ecosystem-specific fac-
270 tors such as the composition of the decomposer
271 community. Studies such as these led LTER scientists
272 to develop a conceptual framework for continental-
273 scale research based on connectivity of flows of mate-
274 rials, organisms, and information across scales [26].
275 This framework emphasizes the importance of coordi-
276 nated approaches across different research networks at
277 continental and global scales.

278 Coordination of long-term ecological research at
279 a global scale was initiated in 1993 through the forma-
280 tion of the International Long Term Ecological
281 Research Network [27], which now has research net-
282 works in 40 countries. As a founding member of this
283 global network, the US LTER Network continues to
284 play a central role in developing research to address
285 global ecological issues. In addition, many LTER sites
286 perform observations and conduct experiments as part
287 of global networks focused on specific research ques-
288 tions. For example, LTER sites are engaged in global
289 comparisons of forest structure through the Center for
290 Tropical Forest Science at the Smithsonian Tropical
291 Research Institute. This network includes 40 plots in
292 21 countries encompassing 4.5 million individual trees
293 of 8,500 species.

294 **Major Milestones in LTER**

295 Scientific investigation at and among LTER sites is
296 dynamic and evolves continuously in response to
297 increasing knowledge and new opportunities. The
298 commitment of LTER sites to long-term observations

and experiments does not imply rigidity in focus and 299
approach. The ability of LTER researchers to respond 300
nimble to new opportunities results from a flexible 301
network structure with a minimum of requirements 302
and uniform site activities. This flexibility would not 303
be possible in a more monolithic network design. Thus, 304
during the first decade of LTER (the 1980s), key con- 305
cepts of long-term ecological research were explored 306
and clarified. In the 1990s, there was an increased 307
emphasis on large spatial scales and multiple interac- 308
tions of ecological processes, species, and element 309
cycles. In addition, interactions with physical and social 310
scientists also increased. The third decade of the LTER 311
program focused on synthesis. Using data and knowl- 312
edge gained over the preceding 20 years, the LTER 313
Network sought to reach new levels of understanding 314
of long-term and large-scale ecological patterns and 315
processes. This summary of the intellectual evolution 316
of LTER provides context for a description of the major 317
milestones in the development of LTER research. 318

Formation of the Network

319
The seeds of LTER were planted by the National Science 320
Foundation (NSF) when it sponsored three workshops 321
(in 1977, 1978, and 1979) to initiate and maintain close 322
consultation with the ecological sciences community. 323
At these workshops, the philosophy of collaborative 324
research was developed and a centralized working 325
hypothesis approach to collaboration proposed. Five 326
core areas of research (Box 1) were defined to orient 327
long-term ecological research projects toward ques- 328
tion/hypothesis formulation and resolution over long 329
time and broad spatial scales. 330

Major Milestones in the First LTER Decade

331
1980 – NSF selected an initial set of six sites (North 332
Temperate Lakes, H.J. Andrews Experimental Forest, 333
Coweeta Hydrological Laboratory, Konza Prairie, 334
North Inlet Marsh, and Niwot Ridge) funded at 335
\$250,000 per year. Lead scientists from each site met 336
in Washington, DC, and constituted a steering com- 337
mittee to begin the tasks of LTER communication, 338
coordination, and accommodation of mutual goals. 339

340 1981 – Dick Marzolf (Konza Prairie) was elected the
341 first Chair of the Steering Committee and NSF awarded
342 a network coordination grant to Kansas State Univer-
343 sity (with Marzolf as PI). Subsequently, a second com-
344 petition added five new sites to the network (Central
345 Plains Experimental Range (now called Shortgrass
346 Steppe), Okefenokee, Illinois Rivers, Cedar Creek
347 Natural History Area, and Jornada Basin).

Box 1. Core Research Areas

The core areas are five research themes that are common to research at all sites and thus central to the coordination of network science. Core areas were originally selected by NSF to ensure appropriate breadth in LTER research programs and to guard against divergence among sites over time. Combined, the five core areas describe most of the major structural components of ecosystems. Although discussions about adding new core areas (e.g., biodiversity, social patterns and processes) have taken place within the LTER Network, none of these have been officially adopted.

The core areas are:

1. *Pattern and control of primary production* – Plant growth in most ecosystems forms the base or “primary” component of the food web. Spatial and temporal patterns of production and the controls of these patterns are major factors in structuring ecosystems.
2. *Spatial and temporal distribution of populations selected to represent trophic structure* – Populations of organisms are dynamic over space and time, and long-term trends in populations can be important indicators of environmental change.
3. *Movement of organic matter* – The sequestration of carbon by primary producers and its eventual fate in ecosystems have important implications for trophic dynamics, nutrient cycling, and global climate.
4. *Movement of inorganic matter* – Nitrogen, phosphorus, and other mineral nutrients are cycled through the ecosystem by way of decay and disturbances such as fire and flood. Availability of these nutrients exerts important controls over ecosystem structure and function.

5. *Disturbance patterns* – Disturbances often shape ecosystems by periodically reorganizing physical or community structure, resulting in significant changes in ecosystem services available to humans.

1982 – LTER held the first Data Management work- 348
shop and the first LTER Meteorological Committee 349
(now Climate Committee) meeting, while the Steering 350
Committee created a policy for workshops supported 351
under the coordination grant. 352

1983 – NSF conducted the first national review of 353
the LTER Program and the LTER Network Office 354
(Box 2) was established through a coordination grant 355
awarded by NSF to Oregon State University (with Jerry 356
Franklin as PI). 357

Box 2. The LTER Network Office

The LTER Network Office (LNO) was established in 1983 through a coordination grant awarded by NSF to Oregon State University to support and coordinate network and site activities of the LTER Network. In 1989, NSF awarded another coordination grant to enlarge and establish LNO at the University of Washington-Seattle. The office officially moved to the University of New Mexico in 1997, and added the position of Executive Director. Robert B. Waide, formerly co-principal investigator of the Luquillo LTER program, was the first Executive Director of the LNO. With a core staff of 18 people and an annual budget of \$1.5 million, the LNO’s current service mandate includes:

- Providing an efficient computational and communication infrastructure for LTER research and education
- Developing and deploying state-of-the-art techniques in information management
- Maintaining a strong public outreach program
- Coordinating interactions with other scientific networks, agencies, and entities
- Providing administrative support
- Contributing to an efficient and effective environment in which site, cross-site, and synthetic research and education can be conducted

358 1985 – LTER held its first All Scientists Meeting
359 (Box 3) at Lake Itasca, MN.

Box 3. All Scientists Meetings

Triennial All Scientist Meetings are used by the LTER Network to promote team building for cross-site research and synthesis. These 3–4 day meetings focus the LTER scientific community on new challenges, result in the formation of new research collaborations, help to integrate new sites and scientists into the LTER community, and provide the only opportunity for community-wide discussions of the future of the LTER program. In contrast to the usual scientific conference, an All Scientists Meeting focuses less on the presentation of individual research results and more on brainstorming, discussion, and synthesis of results from researchers addressing similar questions in different ecosystems. Moreover, All Scientists Meetings present excellent opportunities to share expertise, to transfer technology among sites, and to generate new scientific concepts, approaches, and experiments.

The most recent meeting in 2009 was attended by nearly 800 participants including many graduate students and broad representation for the International LTER community. The program included six plenary talks, 75 working group meetings, over 400 posters, four evening mixers, and pre-meetings for information managers, graduate students, education representatives, international attendees, and the LTER Executive Board.

360 1986 – NSF announced the third call for proposals
361 for long-term ecological research sites; the LTER
362 Intersite Climate Committee (formerly Meteorological
363 Committee) developed standards for meteorological
364 measurements at LTER sites [28, 29].

365 1987 – Five new sites (Arctic Tundra, Bonanza
366 Creek Experimental Forest, Hubbard Brook Experi-
367 mental Forest, Kellogg Biological Station, and Virginia
368 Coast Reserve) joined the network; the LTER Intersite
369 Climate Committee summarized climate information
370 at the first 11 LTER sites [30]; and NSF announced the
371 fourth call for long-term ecological research proposals.

372 1988 – Three new sites (Luquillo Experimental Forest,
373 Sevilleta National Wildlife Refuge, and Harvard Forest)

were added to the program, while two (Illinois Rivers and
Okefenokee) were withdrawn (Box 4); the NSF Advisory
Committee on Scientific and Technological Planning
for LTER identified scientific issues addressed by the
sites and recommended network-wide capabilities to
address them; and the minimum standard installation
(MSI) for LTER site data management was developed.

1989 – NSF conducted a second national LTER Pro-
gram review and awarded a coordination grant to enlarge
and establish the LTER Network Office at the University
of Washington-Seattle (with Jerry Franklin as PI); an
LTER working group developed the “Global Change
Research Action Plan”; acquisition of satellite imagery
and aerial photography for all sites began; an LTER-
Chinese Ecological Research Network (CERN) exchange
was developed; and the first LTER Network Strategic Plan
resulted from the 1989 LTER Coordinating Committee
Meeting at Harvard Forest (“A long-range Strategic Plan
for the Long Term Ecological Research Network”).

Major Milestones in the Second LTER Decade

Box 4. Evaluation of LTER Sites

NSF funds each LTER site independently for 6-year periods, with renewal of awards based on proposals describing accomplishments and plans for future activities. Renewal proposals are reviewed by special panels of experts convened by NSF. The review panel may recommend continued funding, preparation of an addendum addressing specific points, or probation. An LTER site that is placed on probation receives only 2 years of funding and must write a new proposal addressing shortcomings for the next renewal cycle 2 years later. If the new proposal addresses criticisms successfully, 4 more years of funding are awarded. If not, the site is provided with terminal funding to close operations. The purpose of the probation process is to ensure that NSF’s long-term investment is protected from transient problems, such the death or retirement of leading investigators, while still maintaining high standards of rigor in peer review. Four sites have been terminated during the 30-year history of the LTER program.

NSF also conducts mid-term program reviews as an essential part of NSF's ongoing evaluation cycle of the LTER program. Midway through the funding period, external peer review teams visit each site to evaluate the quality of science, education, and outreach as well as how well the site is managed and how integrated the sites are with the entire LTER Network [31]. The site reviews also serve as opportunities for site scientists and staff to get constructive criticism from the review team and to identify potential problems that require correction [32].

394 1990 – The LTER Coordinating Committee devel-
 395 oped site data management policy guidelines; LTER
 396 held its second All Scientists Meeting at Estes Park, CO.

397 1991 – Following an NSF Antarctic research pro-
 398 posal competition, a new site, Palmer Station LTER,
 399 Antarctica, was added to the network supported by
 400 funds from Polar Programs and Environmental Biol-
 401 ogy divisions; Geographic Information Systems (GIS)
 402 working group analyzed the status of LTER Network
 403 technical supplements and assessed future technical
 404 needs; and Global Positioning Systems (GPS) units
 405 were acquired for shared LTER site use and GPS train-
 406 ing provided for representatives from all sites.

407 1992 – The LTER Coordinating Committee, at the
 408 request of NSF, developed an 8-year vision (“LTER
 409 2000”) for the creation of a global environmental
 410 research network based upon approaches established
 411 in the LTER Program.

412 1993 – A second Antarctic site, McMurdo Dry Valleys,
 413 was selected for the LTER Network; the NSF commis-
 414 sioned a 10-year review of the LTER Program; the third
 415 LTER All Scientists Meeting was held at Estes Park, CO; an
 416 International LTER Summit at the Estes Park meeting led
 417 to the establishment of the International LTER (ILTER)
 418 Network, with Jerry F. Franklin (U.S. LTER Chair) as
 419 Steering Committee Chair; the LTER Network Internet
 420 (gopher) server was established at the Network Office; the
 421 LTER All-Site Bibliography, Core Data Set Catalog, and
 422 Personnel Database were developed and put online in
 423 searchable form; and the North Inlet LTER site was with-
 424 drawn, leaving 18 sites in the network.

425 1994 – In response to the 10-year review of the
 426 LTER Program, NSF conducted a special competition
 427 for cross-site and international comparisons and syn-
 428 thesis; nine grants ranging from \$109,353 to \$200,000

were made to LTER and non-LTER sites in the United 429
 States, Ireland, Scotland, Costa Rica, Argentina, and 430
 Russia; NSF announced a special competition for aug- 431
 mentation of LTER projects (Box 5) for regionalization, 432
 comprehensive site histories, and increased disciplin- 433
 ary breadth; LTER established a World Wide Web site at 434
 the Network Office; the first International LTER 435
 (ILTER) Steering Committee meeting was held at 436
 Rothamsted, U.K.; and NSF signed Memoranda of 437
 Agreement with the U.S. Forest Service and the 438
 National Biological Survey to cooperate/collaborate in 439
 LTER Program research. 440

1995 – Jerry Franklin retired after 12 years of service as 441
 Chair of the Coordinating Committee and was replaced 442
 by James Gosz; LTER established a National Advisory 443
 Board; NSF announced 13 new awards for cross-site 444
 comparisons and synthesis at LTER and non-LTER sites; 445
 the LTER Publications Committee developed a plan for 446
 publication of Network research synthesis volumes; and 447
 NSF/DOE/NASA/USDA Joint Program Awards, Terres- 448
 trial Ecology and Global Change (TECO), were awarded 449
 to seven LTER recipients, including researchers at 450
 Bonanza Creek, Cedar Creek, Central Plains, Harvard 451
 Forest, H.J. Andrews, and Jornada. 452

1996 – The first LTER site synthesis volume (Palmer 453
 LTER) was published by the American Geophysical 454
 Union (AGU). 455

Box 5. Augmented LTER Sites

In 1996, NSF began an experiment that involved augmenting two LTER sites at a funding level that was double the network standard. The two sites, North Temperate Lakes in Wisconsin and Coweeta in the southern Appalachian mountains, were selected based on competitive proposals [33]. The successful proposals contained significant commitments to involve social and economic sciences and plans for developing regional-scale research.

The increased funding gave these sites the opportunity to focus on complex interactions between humans and ecological processes across a range of scales and to make significant advances in understanding the spatial, temporal, and decision-making components of land use and land-use change, and to build regional, national, and international collaborations.



The site augmentation experiment led to several significant findings by the participating sites. For example, North Temperate Lake researchers found that the economically optimal phosphorus input to lakes is often far less than estimates based on assumptions that lakes are linear, equilibrium systems with no stochastic factors and no time delays. By calculating the net economic value of water quality (based on the economics of farming, value of housing near the lake, and the recreational economy derived from boating, fishing, etc.), the researchers showed that the economically optimal phosphorus loading (which maximizes net costs and benefits to society as a whole) was about one third the current loading rate of the lake. These analyses show that the total economic value (i.e., the net benefit from all uses of the watershed, including agriculture, lakeshore property values, fishing, and other recreation) generated by the Lake Mendota watershed would increase substantially if less fertilizer were used.

At Coweeta, a spatially explicit model of land-use change over a 40-year period (1950–1990) identifying physical and human factors and determining land-use patterns for representative areas across the region showed that land-cover changes were more frequent at lower elevations and near roads. Bird diversity declined with forest patch size, which in turn influenced plant community composition. Some plant groups (e.g., *Liliaceae* and *myrmecochores*) with diaspores dispersed by ants were scarce or absent in patches subjected to intensive past land use. Land-use history was more important than patch size in explaining variation in abundance and composition of seed-dispersing ants. Fish density and diversity, in particular, were more affected by upstream than streamside deforestation. The “legacy effect” and the relative importance of upstream process pointed the way toward large-scale and long-term restoration given the implication that localized efforts often had little effect.

The discovery of these dramatic effects of land-use patterns and environmental heterogeneity on populations and communities led the Coweeta LTER to begin a new 30-year study in 2000 of stream regions forecast to differ over time in type and risk of development.

1997 – A special competition resulted in addition of two new urban LTER sites (Central Arizona Phoenix and Baltimore Ecosystem Study); the Network Office officially began operation from the University of New Mexico.

1998 – An NSF competition resulted in a former Land Margin Ecological Research (LMER) site (Plum Island Ecosystem) joining the network; the LTER Network signed a contract to produce a Science Synthesis Series with Oxford University Press; Schoolyard LTER Supplements (\$15,000 per year to each site) were added to LTER grants.

1999 – NSF provided funding supplements to enhance Internet connectivity at LTER sites; the LTER Social Science Committee was created; the LTER Network Office, the National Center for Ecological Analysis and Synthesis, the San Diego Supercomputer Center, and University of Kansas collaborated on the “Knowledge Network for Biocomplexity”; and a synthesis volume, “Standard Soil Methods for Long Term Ecological Research,” was published by Oxford University Press.

Major Milestones in the Third LTER Decade

2000 – Three new coastal sites joined the network (Georgia Coastal Ecosystem, Florida Coastal Everglades, and Santa Barbara Coastal); the fourth LTER (and first ILTER) All Scientists Meeting was held in Snowbird, Utah, in association with the annual meeting of the Ecological Society of America; and LTER entered into a collaborative relationship with the Organization of Biological Field Stations.

2001 – NSF conducted a 20-year review of the LTER Network; LTER celebrated its twentieth Anniversary; and the LTER Education Strategic Plan was published.

2002 – The first of what became an annual series of NSF-LTER Mini Symposia was held in Washington, DC; the LTER Network Information System Advisory Committee (NISAC) was formed; and the LTER Strategic Plan (“LTER 2000–2010: A Decade of Synthesis”) was published.

2003 – The Cooperative Agreement for the LTER Network Office at the University of New Mexico was renewed; the fifth LTER All Scientists’ Meeting was held in Seattle, Washington, in association with the Estuarine Research Federation; a Special Issue of *BioScience*



501 focused on the Long-Term Ecological Research Net-
 502 work; the LTER Coordinating Committee approved
 503 a formal set of bylaws for the LTER Network; and the
 504 U.S. International Committee was formed.

505 2004 – The first LTER children’s book, “My Water
 506 Comes from the Mountains,” was published; two new
 507 sites (California Current Ecosystem and Moorea Coral
 508 Reef) joined the LTER Network; and the LTER Network
 509 received a grant from NSF to conduct network-level
 510 strategic planning.

511 2005 – The first LTER Graduate Student Collaborative
 512 Research Symposium took place at Andrews
 513 Experimental Forest; and the LTER Network Office
 514 “Strategic Plan” and “Implementation Plan” were
 515 published.

516 2006 – Jim Gosz stepped down after 10 years as
 517 Chair of the LTER Coordinating Committee and was
 518 replaced by John Magnuson; the Sixth LTER All Scien-
 519 tists’ Meeting was held at Estes Park, CO; and the LTER
 520 Coordinating Committee approved a new LTER gov-
 521 ernance structure consisting of a Science Council and
 522 an Executive Board (Box 6).

523 2007 – Phil Robertson was elected Chair of the
 524 LTER Executive Board and Science Council; the
 525 “Decadal Plan for LTER,” incorporating an integrated

Box 6. Governance Structure

The Network is governed by bylaws enacted in 2003 by the *Coordinating Committee*, at that time the governing body of the LTER Network. The bylaws established a new governance structure consisting of an elected *Chair* and an *Executive Board* comprising nine rotating site representatives and one non-voting member selected to provide expertise on information management. Site representatives are the lead principal investigators of each LTER site. The Chair and the *Executive Director* of the LTER Network Office are ex officio members of the Executive Board. The *Science Council*, with a membership that includes two representatives from each site and the chairs of each Standing Committee, establishes the scientific direction and vision of the LTER Network. The voting membership of the Science Council (the 26 lead principal investigators from each site) reserves ultimate authority for decisions affecting the network. Ten *Standing Committees* (Climate,

Communications, Education, Graduate Students, Information Management, International, Network Information System, Networks Coordination, Publications, and Social and Economic Science) support and inform the governance process. A *Network Office*, (see Box 2) funded separately by the National Science Foundation, facilitates research, education, information management, and governance activities (Fig. 5).

research plan, a description of the EcoTrends project, 526
 a Strategic Plan for Education, a Strategic Plan for 527
 Cyberinfrastructure, a new governance plan, and the 528
 “Integrative Science for Society and the Environment” 529
 document, was published; and “Principles and Stan- 530
 dards for Measuring Primary Production” was 531
 published as part of the LTER series by Oxford Univer- 532
 sity Press. 533

2008 – The LTER Network and the National 534
 Phenological Network signed a MOU for cooperation 535
 in phenological monitoring and assessment. 536

2009 – The seventh LTER All Scientists Meeting was 537
 held at Estes Park, CO; the LTER Network Office core 538
 funding was renewed and a separate award was made 539
 by NSF to facilitate synthesis and the development of 540
 network cyberinfrastructure. 541

2010 – The LTER Network received the Distin- 542
 guished Scientist Award from the American Institute 543
 of Biological Sciences (AIBS); NSF initiated a 30-year 544
 review of the LTER Program; and LTER created 545
 a Communications Committee and a Networks Coordi- 546
 nation Committee. 547

2011 – Scott Collins was elected Chair of the LTER 548
 Executive Board and Science Council. 549

The LTER Network Today

550
 Twenty-six research sites and a central coordinating 551
 office constitute the LTER Network at present, and 552
 more than 1,500 scientists are involved in research at 553
 these sites. The annual budget of the LTER program 554
 approaches \$30 million (Fig. 6). The Network includes 555
 a wide range of ecosystem types spanning broad ranges 556
 of environmental conditions and human domination 557
 of the landscape. The geographic distribution of sites 558
 ranges from Alaska to Antarctica and from the Carib- 559
 bean to French Polynesia and includes agricultural 560

561 lands, alpine tundra, barrier islands, coastal lagoons,
562 cold and hot deserts, coral reefs, estuaries, forests,
563 freshwater wetlands, grasslands, kelp forests, lakes,
564 open ocean, savannas, streams, and urban landscapes.
565 Collectively, the sites in the LTER Network provide
566 opportunities to contrast marine, coastal, and conti-
567 nental regions, the full range of climatic gradients
568 existing in North America, and aquatic and terrestrial
569 habitats in a range of ecosystem types. All sites are
570 sufficiently large to incorporate moderate to large land-
571 scape mosaics, and most sites include human-
572 manipulated as well as natural ecosystems. Most sites
573 embody considerable within-site variability in habitats
574 and ecosystem processes and attempt to characterize
575 this variability in the context of broad regional gradi-
576 ents covering hundreds of kilometers.

577 In accordance with the factors driving the develop-
578 ment of long-term ecological research in the United
579 States, the LTER Network has adopted a central, orga-
580 nizing intellectual aim: to understand long-term pat-
581 terns and processes of ecological systems at multiple
582 spatial scales. To achieve this aim, the LTER Network
583 focuses on six interrelated goals [7]:

584 *Understanding:* Gaining ecological understanding
585 of a diverse array of ecosystems at multiple spatial
586 and temporal scales.

587 The mission of the LTER Network begins with
588 research based at individual sites, each of which has
589 a unique theme. This site-based focus has allowed for
590 key scientific advances at each of the sites, while the
591 common focus on long-term research in a diverse array
592 of ecosystems and landscapes has facilitated broad
593 comparisons and syntheses across sites. Together the
594 network of sites covers a wide range of subjects at
595 multiple temporal and spatial scales.

596 *Synthesis:* Using the network of sites to create gen-
597 eral ecological knowledge through the synthesis of
598 information gained from long-term research and
599 development of theory.

600 The products of LTER research extend beyond the
601 accumulation of knowledge about diverse, individual
602 ecosystem types. At a higher level, synthesis of this site-
603 based knowledge across the network provides the
604 broader scientific understanding from which new the-
605 ory is derived and general applications can be
606 developed.

Information Dissemination: Creating well-designed, 607
608 documented databases that are accessible to the
609 broader scientific community.

610 Long-term research demands long-term data. The
611 creation, curation, and dissemination of long-term
612 databases are needed to assure that the data resources
613 needed by researchers will continue to be available.
614 These databases must include the additional informa-
615 tion required to interpret data (i.e., metadata) as well as
616 the data themselves. By adopting policies that promote
617 the timely sharing of data (both inside and outside the
618 LTER Network), the data can be used in a variety of
619 ways not anticipated by the original collector such as
620 regional, national, and global syntheses, thus providing
621 a resource for the broader scientific community.

622 *Legacies:* Creating a legacy of well-designed and
623 documented long-term observations, experiments,
624 and archives of samples and specimens.

625 Many ecological phenomena change at decadal to
626 century and longer time scales, and it is essential to
627 maintain experiments and observations across periods
628 appropriate to the questions addressed. The orderly
629 transfer of experiments and interim results from one
630 generation of scientists to the next requires a research
631 design and setting that allows for multiple samplings
632 (some unanticipated), long-term protection from
633 competing uses, and meticulous documentation of
634 experimental protocols. Also essential is a means to
635 store protocols and observations in a manner that is
636 secure and consistently accessible to the scientific com-
637 munity for use in syntheses and cross-site comparisons
638 (both inside and outside the LTER Network).

639 *Training:* Developing a cadre of scientists who are
640 equipped to conduct long-term, collaborative research
641 to address complex ecological problems.

642 One of the major lessons from the first 30 years of
643 LTER has been that success both within sites and within
644 the network requires a nontraditional approach to eco-
645 logical research. This approach is characterized by
646 a commitment to long-term measurements that may
647 yield only a few useful initial results but that are essen-
648 tial to understanding long-term change, by
649 a willingness to work as part of large teams that may
650 have priorities that are different than one's own, by
651 a desire to interact closely with others in order to
652 share ideas and data, and by the need to develop
653 a broad interdisciplinary perspective. Disseminating

654 this approach through the involvement of graduate and
655 undergraduate students, postdoctoral and interna-
656 tional scientists, and K-12 educators, students, and
657 the general public can ensure the success of long-term
658 ecology in the future.

659 *Outreach:* Providing knowledge to the broader eco-
660 logical community, general public, resource managers,
661 and policy makers to address complex environmental
662 challenges.

663 Humanity faces increasingly numerous and serious
664 environmental problems that range from local to global
665 in extent, and that must be tackled by institutions at
666 local to international scales. The LTER Network and
667 emerging ILTER networks provide the most compre-
668 hensive and diverse system of sites for ecological obser-
669 vations on the globe, and research of the LTER Network
670 has repeatedly demonstrated the ability of long-term
671 ecological science to address these environmental chal-
672 lenges. Increasingly, LTER research is finding applica-
673 tions in the work of federal, state, and local agencies
674 that manage environmental resources. The synoptic
675 and detailed knowledge of individual LTER sites, and
676 the opportunities for multidimensional comparisons
677 among sites, also represents significant opportunities
678 for other disciplines including social sciences, earth
679 sciences, and basic biological sciences that must be
680 pursued. Finally, knowledge from this breadth of
681 views permits us to identify and anticipate new issues
682 and challenges, test existing ideas about causation, and
683 help provide the science that underpins the processes of
684 open, participatory, and forward-looking decision
685 making.

686 **Achievements of the LTER Network**

687 ► “At each of the Network’s 26 sites we know an extraor-
688 dinary amount about organisms and processes impor-
689 tant at the site, about the way the site’s ecosystems
690 respond to disturbance, and about long-term environ-
691 mental change. A growing number of cross-site obser-
692 vations and experiments is also revealing much about
693 the way that key processes, organisms, and ecological
694 attributes are organized and behave across major envi-
695 ronmental gradients. In total, research in the LTER port-
696 folio is contributing substantially to both our basic
697 knowledge of ecological interactions and our ability

to forecast change and to test ecological theory.” 698
(p(i), [34]) 699

LTER’s long-term research and monitoring has led 700
to important new discoveries and had a transformative 701
effect on science and society. Hobbie [35] listed the 702
benefits resulting from the existence of the network: 703
value added to research sites in the network because of 704
long-term stability; value added to ecological science 705
because long-term sites provide ecology with sustained 706
intellectual attention to fundamental ecological issues; 707
LTER data bases, which are important resources for the 708
broader scientific community; cross-site synthesis, 709
enabling hundreds of scientists to ask similar questions 710
in a wide variety of habitats and increasing the possi- 711
bilities for creative breakthroughs from interdisciplin- 712
ary collaboration; education and training of teachers 713
and students as an integral part of research programs; 714
cooperative research with government agencies (e.g., in 715
national parks, wildlife refuges and reserves, and exper- 716
imental forests); contributions to society through 717
advice on public policy and environmental manage- 718
ment; and the establishment of an international LTER 719
Network that now numbers 40 countries, facilitating 720
collaboration in addressing environmental challenges 721
in different parts of the world. 722

In 2010, the LTER Network received the Distin- 723
guished Scientist award from the American Institute 724
of Biological Sciences for its contributions to the bio- 725
logical sciences. LTER research is featured in two of 726
NSF’s “Sensational 60” transformative scientific dis- 727
coveries or advances [36]. Results from LTER research 728
are embodied in over 10,000 peer-reviewed publica- 729
tions [35], a book series from Oxford University 730
Press, and summaries on network (www.lternet.edu) 731
and site web sites. Since 1993, the LTER research model 732
has been adopted by 40 other member countries of the 733
International Long Term Ecological Research Network. 734

Research Progress in achieving the LTER Mission 735
begins with the work of individual scientists, students, 736
and educators at the 26 LTER sites. It is their work at 737
the site level that forms the foundation of knowledge, 738
data, observational and experimental legacies, and 739
training that will ensure a lasting impact of the overall 740
LTER program. Data and knowledge gained from 741
intensive field experience are also key to development 742

743 of syntheses of site-level information into models that
 744 allow prediction of long-term change and responses to
 745 human and other disturbances. Site-level synthesis
 746 activities often lead to new insights that feed back to
 747 affect the future course and evolution of site-level
 748 research.

749 Network infrastructure also promotes and facili-
 750 tates cross-site and regional analyses, leading to
 751 larger-scale syntheses and to development and testing
 752 of ecological theory. In this work, the maintenance of
 753 a network database and protocols for data discovery
 754 and acquisition are particularly important. These
 755 efforts add to the basic body of scientific knowledge
 756 of long-term, large-scale ecological phenomena and,
 757 because students are deeply involved both at the site
 758 level and in intersite and network-level syntheses, they
 759 help to increase the numbers of people with appropri-
 760 ate expertise in both research and environmental prob-
 761 lem solving.

762 Ultimately, both site and network-level activities
 763 feed back to the development of scientific capital,
 764 which includes well-trained scientists, a well-informed
 765 citizenry, and the basic data and understanding that
 766 underpin them. This accumulation of scientific capital
 767 also leads to new research and new applications of
 768 LTER research, including new forms of support for
 769 both research and education. Growth of scientific cap-
 770 ital also includes interactions with new scientific disci-
 771 plines, leading to expansion of the scope and
 772 applications of LTER research.

773 *Research at LTER Sites* The LTER Network comprises
 774 sites chosen competitively on the basis of research
 775 excellence, quality and duration of existing data sets,
 776 and strength of the commitment to long-term research
 777 and site security. The 26 sites that constitute the
 778 network at present represent a wide variety of
 779 research emphases and approaches. As part of their
 780 commitment to the LTER program, each site
 781 conducts a series of measurements and experiments
 782 directed toward the understanding of the five core
 783 areas as well as studies addressing ecological issues
 784 specific to the site. The most common scientific
 785 approaches include observation, experimentation,
 786 comparative analysis, retrospective study, and
 787 modeling, although emphases differ among sites.
 788 A sampling of key research results from LTER sites

provides an idea of the potential impact of LTER 789
 research. 790

The Ecosystem Value Of Dead Wood – H. J. Andrews 791
 LTER scientists revealed the importance of dead trees to 792
 diversifying animal habitat and sustaining the flow of 793
 vital nutrients in forests and streams by tracking how 794
 fallen and standing deadwood changes as forests age. 795
 These studies profoundly influenced forest manage- 796
 ment by prioritizing the retention of dead wood in 797
 forests and streams. 798

Arctic Warming – Arctic LTER scientists discovered 799
 how Arctic warming is increasingly thawing frozen 800
 ground (permafrost), creating hot spots of erosion, 801
 nutrient release into rivers, and decomposition of 802
 ancient organic carbon. This information is essential 803
 for managers and policymakers grappling with how to 804
 mitigate and adapt to future climate change. 805

Fire and Climate – Through long-term studies of 806
 fire cycles and their links to climate, Bonanza Creek 807
 scientists have documented an increase in fire severity 808
 brought on by climate warming that will likely shift the 809
 Alaskan boreal forest from a spruce- to a broadleaf- 810
 dominated landscape. 811

New Climate Pattern – Long-term observations 812
 allowed California Current Ecosystem scientists to 813
 define a new climate pattern called the North Pacific 814
 Gyre Oscillation (NPGO), which links physical ocean 815
 changes, such as fluctuations in salinity and nutrients, 816
 with biodiversity and ecosystem processes in the east- 817
 ern North Pacific. This climate pattern may affect 818
 marine ecosystems around the world. 819

Biodiversity Matters – Cedar Creek scientists dis- 820
 covered that the number of plant species in an 821
 ecosystem – its biodiversity – has a profound and sur- 822
 prisingly strong effect on ecosystem function. Long-term 823
 experiments have shown that ecosystems with greater 824
 plant species diversity are more productive and stable. 825

Integrative Research – Central Arizona-Phoenix sci- 826
 entists spearheaded efforts to integrate ecological and 827
 social research in urban ecosystems. Such interdis- 828
 ciplinary research has changed the way scientists and 829
 citizens perceive the natural environment in cities, 830
 transformed environmental education at all levels, 831
 and informed problem solving in cities. 832

Future Nitrogen Cycling – Drawing on two decades 833
 of research, Coweeta researchers discovered that 834
 warmer temperatures increase peak nitrate loading to 835

836 forest streams during the growing season. These find- 883
837 ings suggest that climate warming will triple the nitro- 884
838 gen export from forests, reducing water quality and 885
839 long-term forest productivity. 886

840 *Productivity Paradox* – Florida Coastal Everglades 887
841 scientists revealed how human-induced nutrient 888
842 enrichment in the Everglade and Caribbean wetlands 889
843 affect the “productivity paradox” in which an extraor- 890
844 dinarily high level of algal growth supports far fewer 891
845 aquatic animal consumers than expected. Understand- 892
846 ing this dynamic is critical to the restoration of the 893
847 Everglade ecosystems.

848 *Sea-Level Rise* – Georgia Coastal Ecosystem scien- 894
849 tists predicted how rising sea levels will impact coastal 895
850 marshes and reduce the benefits they provide society, 896
851 such as clean water and fish habitat. Analyses have 897
852 shown that new marshes created by rising waters do 898
853 not fully offset the loss of existing marshes. 899

854 *Legacies Shape Ecosystems* – Using its century-long 900
855 studies, Harvard Forest scientists have documented the 901
856 persistent influence of human and natural history in 902
857 shaping modern forest ecosystems. Ancient land use 903
858 practices and prior forest conditions continue to influ- 904
859 ence a forest’s potential to grow trees, respond to dis- 905
860 turbance and stress, and support diverse plants and 906
861 animals.

862 *Shifting Songbirds* – Hubbard Brook scientists have 907
863 produced the longest continuous songbird record in 908
864 North America and discovered that changing habitat, 909
865 land use practices, and climate in eastern forests, trop- 910
866 ical forests, and migratory routes drive the abundance 911
867 of these beloved forest musicians. 912

868 *Grassland Tipping Points* – Jornada LTER scientists 913
869 discovered that grasslands, shrublands, and other eco- 914
870 systems have “tipping points,” where dramatic and 915
871 rapid changes can occur once certain thresholds are 916
872 reached. A better understanding of these thresholds is 917
873 paramount to management and protection of grass- 918
874 lands and other ecosystems. 919

875 *Agriculture and Climate Change* – Kellogg Biologi- 920
876 cal Station researchers discovered and quantified how 921
877 different crop management practices can interact to 922
878 provide novel opportunities for greenhouse gas miti- 923
879 gation by agriculture. These discoveries inform agricul- 924
880 tural greenhouse gas policies worldwide. 925

881 *Sensitive to Change* – Using long-term data on plant 926
882 productivity and novel experiments to manipulate 927

rainfall, Konza Prairie scientists demonstrated that 883
grasslands are among the most sensitive ecosystems to 884
changes in the water cycle. This research helps forecast 885
the impact of climate change on the carbon balance of 886
individual plants to whole ecosystems. 887

888 *Tropical Carbon Cycling* – Luquillo Experimental 889
889 Forest scientists discovered that carbon cycling in trop- 890
ical forests is highly sensitive to climate. Relatively 891
small increases in temperature can decrease the ability 892
of tropical forests to store carbon recently captured by 893
photosynthesis, thus accelerating climate change. 894

895 *Chain Reaction* – McMurdo Dry Valleys scientists 896
896 documented how even small variations in climate can 897
drive major changes in polar ecosystems: Seemingly 898
slight changes in temperature can set off a cascade of 899
magnified responses that affect stream flow, nutrient 900
cycling, and biodiversity. 901

902 *Diversity Matters* – Coral reef ecosystems are highly 903
903 sensitive to disturbances and climate change. Moorea 904
904 Coral Reef research documented how genetic and spe- 905
cies diversity among corals and their symbionts helps 906
corals to rapidly adapt to changing environmental con- 907
ditions such as warming seawater and ocean 908
acidification. 909

910 *Early Warning Signs* – Niwot Ridge research indi- 911
911 cates that alpine ecosystems provide important early 912
warning signs of global climate change. Alpine plants 913
and animals survive on the razor’s edge of environmen- 914
tal tolerances, making them more sensitive to changes 915
in climate than downstream ecosystems. 916

917 *Tracking Ice Cover* – By synthesizing long-term 918
918 records of lake and river ice cover throughout the 919
Northern Hemisphere, North Temperate Lake scien- 920
tists discovered long-term climate-induced reductions 921
in ice cover on freshwater ecosystems over the past 150 922
years. 923

924 *Penguins and Climate Change* – Palmer Station sci- 925
925 entists have documented a 75% reduction in Adélie 926
penguin populations since 1980 and determined the 927
cause to be altered cloud cover, winds, snowfall, sea ice 928
cover, and other climate changes. 929

930 *Tipping Points* – Plum Island Ecosystem scientists 931
931 discovered regionally specific “tipping points” beyond 932
932 which marshes can no longer keep up with rising sea 933
levels, and that human alteration of watersheds can 934
either enhance or compromise a marsh’s ability to 935
survive in the face of rising sea levels. 936

930 *Underwater Forests* – Giant kelp provides critical
931 food and shelter for a wide diversity of economically
932 important organisms. An interdisciplinary team of
933 Santa Barbara Coastal scientists discovered that kelp
934 plants disperse their reproductive spores over surpris-
935 ingly great distances, furthering our understanding of
936 how these important ecosystems establish and survive.

937 *Climate and Disease* – Long-term observations and
938 experiments by Sevilleta LTER scientists revealed an
939 important link between human hanta virus outbreaks
940 and the population dynamics of small mammals in the
941 southwestern United States as affected by changes in
942 climate systems such as El Niño. The discipline of the
943 ecology of infectious diseases that this research helped
944 to establish is now a transformative area of ecological
945 research.

946 *Plague and Prairie Dogs* – For over two decades,
947 Short Grass Steppe scientists have observed black
948 plague spreading through populations of the black-
949 tailed prairie dog, an endangered species candidate.
950 The effects of the resulting die-offs ripple through
951 other populations including other rodents, flowering
952 plants, pollinators, and large herbivores.

953 *Dynamic Coastal Landscapes* – By tracking long-
954 term shifts in land cover on undeveloped coastal barrier
955 ecosystems, Virginia Coast LTER scientists have learned
956 how sea-level rise and storms interact to create a highly
957 dynamic landscape. While the locations of lagoons,
958 marshes, and other coastal ecosystems have changed
959 over time, they have not experienced a net reduction in
960 the area they cover.

961 *Cross-Site Research and Synthesis* In addition to
962 transformative site-based research, LTER scientists
963 conduct synthetic studies focused on general
964 ecological principles underlying diverse ecosystems
965 [22, 26, 35, 37–47]. Johnson et al. [21] demonstrated
966 the evolution of the LTER program from a collection of
967 research sites with common goals to a highly connected
968 research network. A few examples illustrate the breadth
969 of LTER cross-site research.

970 *EcoTrends* – The EcoTrends Project [47] is a collab-
971 orative effort among state and federal agencies and
972 institutions in the United States to make long-term
973 ecological data easy to access, analyze, and compare
974 within and across sites (see <http://www.ecotrends.info>).
975 The project is designed to promote and enable

the use and synthesis of long-term data to examine 976
critical trends (e.g., climate, land cover, and habitat 977
availability) in the Earth’s ecosystems. In addition to 978
ecological data collected by participating sites, the 979
EcoTrends database includes ancillary data from other 980
sources. For example, LTER investigators obtained 981
human population and economic data from 1790 to 982
2000, which was one of the four types of data being 983
synthesized in the EcoTrends Project. The “Human 984
Population and Economy” dataset contains over 200 985
separate variables suitable for describing changes in 986
population and economic structure since the end of 987
the eighteenth century. The dataset was collected for 988
each of the more than 250 counties associated with the 989
21 continental North American LTER sites plus the 990
Luquillo site in Puerto Rico. These datasets, tools, and 991
information are available to anyone who would like to 992
view trends in ecological variables for one or multiple 993
sites or pursue additional statistical analyses of within- 994
site and cross-site comparisons. 995

Climate Database (CLIMDB) and Hydrology Data-
base (HYDRODB) – LTER sites have generally followed 996
established LTER Climate Committee guidelines 997
(see [29]) for collecting baseline meteorological data. 998
Standardized measurements provided a basis for coord- 999
inating meteorological measurements at two or more 1000
sites and enabled intersite comparisons, but access to 1001
comparable datasets from multiple sites was often 1002
problematic because most sites, while making climate 1003
data accessible online, displayed them in different for- 1004
mats and aggregated them using different methods. 1005
Similarly, sites that conducted long-term hydrologic 1006
measurements needed to establish access to their 1007
long-term datasets for streamflow, precipitation, and 1008
ambient air temperature, in addition to the hydrologic 1009
data. LTER developed ClimDB and HydroDB in 1010
response to the science-based need for standardized 1011
measurements, format, and aggregation of these data. 1012
LTER sites, along with USGS, and USDA Forest Service 1013
sites, contribute climate (<http://www.fsl.orst.edu/limhy/>) and hydrological (<http://www.fsl.orst.edu/hydrodb/>) data, which are stored in centralized servers 1014
that provide open access to long-term meteorological 1015
and stream flow records from these research sites. 1016
1017
1018
1019

Long-Term Intersite Decomposition Experiment
Team (LIDET) – Sixteen LTER sites participated in 1020
a 10-year, 28-site experiment to test the effect of 1021
1022

1023 substrate quality and macroclimate on long-term
1024 decomposition and nutrient dynamics – particularly
1025 the degree to which these two factors control the for-
1026 mation of stable organic matter and nitrogen after
1027 extensive decay. Reciprocal litter transplants of 27 spe-
1028 cies were conducted at sites in North and Central
1029 America. Decomposition rates were strongly affected
1030 by substrate quality, but climate also resulted in strong
1031 and consistent effects [25]. Large-scale patterns were
1032 better explained by variables including both moisture
1033 availability and temperature. In general, roots
1034 decomposed more slowly than leaves, but ratios of
1035 aboveground to belowground decomposition rates varied
1036 across ecosystem types. Predictions of decomposi-
1037 tion rates were possible using uncomplicated models
1038 based on litter quality and climate, but ecosystem-
1039 specific factors also contributed to observed differences
1040 (see [http://andrewsforest.oregonstate.edu/research/
1041 intersite/lidet.htm](http://andrewsforest.oregonstate.edu/research/intersite/lidet.htm) for more information).

1042 *Lotic Intersite Nitrogen Experiment (LINX)* – The
1043 Lotic Intersite Nitrogen Experiment was a collaborative
1044 study of nitrogen cycling in streams involving simula-
1045 tion modeling, field tracer (^{15}N) additions, and
1046 intersite comparison. The central hypothesis was that
1047 the considerable variability among streams in uptake,
1048 retention, and cycling of nitrogen is controlled by key
1049 hydrodynamic, chemical, and metabolic characteristics
1050 that determine water retention, degree of nitrogen
1051 deficiency, and energy flow through food webs in
1052 stream ecosystems. LINX I ran from September 1996
1053 through August 2001 and resulted in 26 publications, 7
1054 theses and dissertations, and 69 presentations. The
1055 study demonstrated that the smallest streams had the
1056 highest uptake of inorganic nitrogen, and that small
1057 streams were potentially significant sources of atmo-
1058 spheric nitrogen via nitrification.

1059 LINX II was a 5-year project that began in Septem-
1060 ber 2001 and ended in 2006. Data from tracer experi-
1061 ments across 72 streams and eight regions representing
1062 several biomes showed that biotic uptake and denitri-
1063 fication were less efficient at removing stream nitrate in
1064 streams with high nitrate concentrations. As a result,
1065 high nitrate streams export a disproportionate amount
1066 of nitrate to receiving waters. In addition, these pat-
1067 terns suggest that small streams become less important
1068 as nitrate sinks as nitrate concentration increases [48].

In addition to the specific cross-site and intersite 1069
research mentioned above, LTER sites also participate 1070
in numerous long-term interdisciplinary and 1071
multi-site syntheses with both LTER and non-LTER 1072
organizations. These include studies of above- and 1073
belowground productivity, carbon dioxide (CO_2) and 1074
climate change, biodiversity, disease control, microbial 1075
ecology, remote sensing, and geographical information 1076
systems, the adsorption of trifluoroacetate (TFA) in 1077
soils, among others. 1078

National and International Networking – As a global 1079
leader in long-term and broad-scale ecological 1080
research, the LTER Network establishes linkages with 1081
existing and developing long-term ecological research 1082
programs in the United States and abroad. These rela- 1083
tionships range from exchanges at the individual sci- 1084
entist and site research program levels, to participation 1085
in national and international meetings, to global-scale 1086
research planning and collaboration. 1087

Nationally, LTER develops innovative partnerships 1088
with leading ecological research organizations and syn- 1089
thesis centers; facilitates the advancement of current 1090
ecological science and innovative research technolo- 1091
gies; develops strong multidisciplinary science and 1092
public education programs; and pursues a multi- 1093
agency approach to develop databases of long-term 1094
research in key biomes and along major gradients. 1095

Internationally, LTER assists in the establishment of 1096
networks for long-term ecological research worldwide; 1097
creates opportunities for collaboration between US and 1098
International LTER sites and networks; develops and 1099
operates a communication and data-sharing system 1100
among an international network of sites; facilitates 1101
the establishment of a global network of environmental 1102
research sites; and participates in other international 1103
scientific efforts. 1104

Education Education and outreach efforts are inte- 1105
gral aspects of the LTER program. As a network of sites 1106
with a preponderance of academic scientists, graduate 1107
and undergraduate education is central to the goals of 1108
the network. Students at both graduate and undergrad- 1109
uate levels are routinely engaged in collecting LTER 1110
data, performing experiments, and analyzing results. 1111
This participation forms an important part of their 1112
educational experience, and hence education and 1113
research are highly integrated in most LTER programs. 1114

1115 The network has many examples of former undergrad-
1116 uate students that have become research scientists in
1117 the LTER program.

1118 In addition, LTER provides a unique opportunity
1119 to address the educational needs of teachers and stu-
1120 dents from grades K-12. As a long-term program, LTER
1121 has the potential to provide continuous opportunities
1122 for students to participate and learn throughout their
1123 entire academic life.

1124 The LTER Network has adopted a strategic vision
1125 for education and outreach with three components.
1126 The first component addresses the structure needed
1127 to enable LTER research to have a public impact. This
1128 structure includes leadership within the network,
1129 a distributed organization that provides resources for
1130 sites to implement education programs at the local
1131 level, and cyberinfrastructure that enables broad col-
1132 laboration among local education projects and between
1133 researchers and educators. The second element of the
1134 LTER vision for education establishes the goal of
1135 conducting programs in research and development
1136 that address environmental science literacy by respect-
1137 ing and including the diverse perspectives that exist
1138 within the LTER Network. The final aspect of the
1139 LTER vision addresses inclusion of key constituent
1140 groups, including K-12 teachers and administrators,
1141 undergraduate and graduate students and professors,
1142 and end citizens active in LTER communities.

1143 *K-12 Schoolyard LTER Program* In 1998, LTER
1144 formally expanded its education efforts to include K-
1145 12 students and teachers, mainly through the
1146 Schoolyard LTER (SLTER – <http://schoolyard.lternet.edu/>
1147 [edu/](http://schoolyard.lternet.edu/)) program, which is funded through supplements
1148 by NSF’s Division of Environmental Biology (DEB).
1149 The SLTER approach emphasizes the connection to
1150 local communities, for which an LTER site can serve
1151 as a “schoolyard” for understanding ecology and
1152 environmental science. The sites design their own
1153 programs in relation to the ecological research
1154 conducted at the site and the particular needs and
1155 resources of the local school district and community
1156 ([49], [http://schoolyard.lternet.edu/](http://schoolyard.lternet.edu/LTEReduHandbook.pdf)
1157 [LTEReduHandbook.pdf](http://schoolyard.lternet.edu/LTEReduHandbook.pdf)). SLTER funds support
1158 a wide range of education activities, including field
1159 trips and lab work for students, teacher professional
1160 development workshops, teaching supplies,

community outreach, and program and research 1161
coordination. The schoolyard approach is particularly 1162
consistent with the development of empathy for their 1163
local environment (“Environmental Empathy”) as 1164
discussed by Sobel [50] as a basis for teaching 1165
elementary age students. All the 26 LTER sites 1166
participate in the SLTER program. 1167

As the SLTER program matured, LTER scientists 1168
devised the idea for a Children’s Book Series to supple- 1169
ment SLTER activities – thus using children’s science 1170
literature to overcome “ecophobia” while fostering 1171
environmental empathy [51]. The series currently 1172
includes three titles: “My Water Comes From The 1173
Mountains” by Tiffany Fourment (Note: the title has 1174
since been modified to reference specific mountains, 1175
e.g., “My Water Comes From The Rocky Mountains” 1176
and “My Water Comes From The San Juan Moun- 1177
tains”), “The Lost Seal” by Diane McKnight; and “Sea 1178
Secrets” by Mary M. Cerullo and Beth E. Simmons. 1179
Each book is richly illustrated with scenes derived from 1180
the story, with many artworks and sidebar comments 1181
by elementary school children. 1182

Graduate and Undergraduate Education The LTER 1183
science community includes academic and 1184
government scientists and educators, graduate and 1185
undergraduate students, and professional staff. The 1186
research conducted at the sites is diverse, 1187
encompassing all aspects of ecology and ecosystem 1188
science, as well as investigations in atmospheric 1189
science, hydrology, and geomorphology. As centers of 1190
excellence in ecological research, LTER sites hosted by 1191
universities, government agencies, and nonprofit 1192
research institutions also provide important training 1193
grounds for the next generation of scientists and 1194
leaders. LTER offers opportunities for graduate and 1195
undergraduate training and education. Many 1196
undergraduate and graduate students are supported 1197
directly from LTER awards each year and others use 1198
LTER facilities and equipment in support of their 1199
research programs. In addition, the LTER Network, 1200
through its association with other networks 1201
worldwide, provides opportunities for the 1202
international interchange of students and faculty. 1203

In addition to typical university-based training, 1204
many LTER sites are involved in NSF-funded Integra- 1205
tive Graduate Education and Research Traineeship 1206



1207 (IGERT) programs, and serve as hosts for Undergrad-
 1208 uate Mentoring in Environmental Biology (UMEB)
 1209 and Research Experience for Undergraduates (REU)
 1210 site activities. The programs integrate field and labora-
 1211 tory techniques with education, providing the students
 1212 with deeper understanding of the scientific process in
 1213 ecology.

1214 Most LTER sites or their home institutions partic-
 1215 ipate in the REU and UMEB programs, which offer
 1216 opportunities for students at both LTER and non-LTER
 1217 institutions to work with LTER scientists. Participating
 1218 sites fund REU students through separate grants and
 1219 supplements or out of project funds. REU students
 1220 receive stipends and course credit and work closely
 1221 with scientist mentors on ongoing site research pro-
 1222 grams or specially designed projects. The UMEB pro-
 1223 gram provides stipends to minority students during the
 1224 summer and academic year to undertake independent
 1225 research projects in environmental biology under the
 1226 direction of departmental faculty. Students in the pro-
 1227 gram come from a wide variety of disciplines including
 1228 chemistry, geophysics, and biology. Some sites provide
 1229 similar opportunities through private foundations and
 1230 other sources.

1231 *LTER Education in the Future* The LTER Network has
 1232 adopted the goal of advancing the theory and practice
 1233 of ecological and environmental education at all levels
 1234 and in all areas of LTER expertise. The LTER sites and
 1235 network are uniquely poised to promote education at
 1236 the program, institution, state, and national levels. This
 1237 work builds on, and is linked closely to, LTER scientific
 1238 expertise in its five core research areas and its long-
 1239 term, comparative approach. LTER education
 1240 addresses some of the most important but vexing
 1241 objectives for ecological and environmental
 1242 education; that is, it uses outdoor, inquiry-based
 1243 teaching and learning to build ecological literacy; it
 1244 creates effective strategies for interdisciplinary and
 1245 collaborative learning about ecology and it teaches
 1246 about local ecosystems while fostering an
 1247 understanding of distant ones as well. Strategic
 1248 objectives for future LTER education programs [2]
 1249 include:

1250 1. Expanded resources for education and outreach at
 1251 both site and network levels by developing new

- 1252 funding sources and improving coordination with 1252
- 1253 existing education and outreach programs 1253
- 1254 2. Increased participation by LTER sites in education 1254
- 1255 and outreach through collaboration, coordination, 1255
- 1256 training, and exchange of best practices among sites 1256
- 1257 3. Preparation and dissemination of new instructional 1257
- 1258 materials designed and developed through strategic 1258
- 1259 partnerships with constituent organizations, with 1259
- 1260 particular attention to the needs of traditionally 1260
- 1261 underrepresented groups 1261
- 1262 4. Development of metrics to evaluate and guide edu- 1262
- 1263 cation and outreach activities at site and network 1263
- 1264 levels 1264
- 1265 5. Increased use of appropriate cyber technologies to 1265
- 1266 improve indication among partners and to dissem- 1266
- 1267 inate educational and outreach materials more 1267
- 1268 effectively 1268
- 1269 6. Regular adaptive assessment by external evaluators 1269
- 1270 to monitor progress of LTER education and out- 1270
- 1271 reach programs and to design new approaches 1271
- 1272 when necessary 1272

1273 **Data and Information** Long-term research and syn- 1273

1274 thesis demands the long-term stewardship and ready 1274

1275 accessibility of data. The creation, curation, and dis- 1275

1276 semination of long-term databases are needed to assure 1276

1277 that the data resources needed by researchers will con- 1277

1278 tinue to be available. In addition, by adopting policies 1278

1279 that promote the timely sharing of data (both inside 1279

1280 and outside the LTER Network), scientists can use the 1280

1281 data in a variety of ways not anticipated by the original 1281

1282 collector, including for regional, national, and global 1282

1283 syntheses, thus providing a rich resource for the 1283

1284 broader scientific community [2]. 1284

1285 LTER has led the ecological community in develop- 1285

1286 ing protocols and practices for documenting, curating, 1286

1287 and sharing data. The strategic goals for LTER infor- 1287

1288 mation management are (1) to provide sources of high- 1288

1289 quality, well-documented, and error-checked data at 1289

1290 each site that support local science, stimulate synthesis 1290

1291 and the creation of new knowledge, and facilitate trans- 1291

1292 formative network-wide research at broad scales; (2) to 1292

1293 improve existing data practices and information man- 1293

1294 agement systems at sites to make them uniformly easy 1294

1295 to use, sustainable, and consistent with LTER proto- 1295

1296 cols; (3) to develop a central network-level data 1296

1297 discovery and integration platform comprising data-
1298 bases and servers connected through web services for
1299 single-portal data publication, discovery, and access;
1300 (4) to improve information flow between LTER and
1301 other networks; and (5) to evaluate recent develop-
1302 ments in computer science, information technology
1303 and design, cybersecurity, community standards, and
1304 communication and collaboration technology for
1305 potential application in LTER Network and site infor-
1306 mation management.

1307 The recent proliferation of long-term collaborative
1308 research programs has created a parallel need for sci-
1309 entific information systems that allow data, informa-
1310 tion, and knowledge to flow across disciplinary and
1311 cultural boundaries [52]. Scientific information sys-
1312 tems expand the potential for scientific inquiry and
1313 are leading to a paradigm shift in biology [53] most
1314 evident to date in the genomic community [54]. Other
1315 disciplines, including ecology, are primed for similar
1316 dramatic changes driven in part by new tools and
1317 approaches to managing data. The success of long-
1318 term studies is measured both on the generation of
1319 new knowledge and the creation of data and informa-
1320 tion that will facilitate subsequent studies.

1321 **Future Directions**

1322 LTER is moving increasingly toward research that inte-
1323 grates ecological and social sciences (Fig. 7), having
1324 realized that fundamental questions related to the ser-
1325 vices that society receives from ecosystems, how these
1326 services are perceived, how perceptions affect behavior,
1327 and how behavioral changes affect ecosystem form and
1328 function are central to understanding the sustainability
1329 of ecosystems on which society depends. By blending
1330 ecological and social science theories, methods, and
1331 interpretations, LTER is better able to understand and
1332 forecast environmental changes at a time when no
1333 ecosystem on Earth is free from human influence. The
1334 *Decadal Plan for LTER* [34] laid out a plan for inte-
1335 grated, network-level research to address crucial long
1336 term social-ecological questions in three thematic
1337 areas: (1) land and water use change – the dynamics
1338 of urban, exurban, and working systems; (2) climate
1339 change, variability, and extreme events; and (3) nutrient
1340 mobilization and species introductions. These ques-
1341 tions are interdisciplinary in nature, and were

developed after extensive discussions and consultations
among teams of biophysical and social scientists, edu-
cators, and information managers. The questions are
also multi-scale, and require observations and experi-
ments at multiple sites to test hypotheses at scales
ranging from regional to continental.

In fact, LTER is uniquely positioned to address
these questions for a variety of reasons related to their
long-term nature, the geographic distribution of net-
work sites, the core strength of the network's biophys-
ical science, its considerable and growing strength in
the area of coupled human-natural systems, and its
commitment to K-12 education and leadership in envi-
ronmental cyberinfrastructure. Nevertheless, LTER
recognized that it will require new long-term social-
ecological observations, experiments, and modeling to
address these questions effectively; advanced environ-
mental cyberinfrastructure to collect, store, retrieve,
visualize, and integrate the resulting complex data
streams; partnerships with other environmental obser-
vatory networks to achieve this integration and facili-
tate synthesis; and education initiatives to train the
next generation of environmental scientists to address
transdisciplinary issues, and to enhance environmental
literacy among the public.

Specific details of how the Decadal Plan's goals are
to be achieved are constantly being worked out by
Network science, education, and cyberinfrastructure
teams, who identify individual questions, design obser-
vations, experiments, and modeling activities to
address them, and the corresponding education and
cyberinfrastructure needs for the resulting transdisci-
plinary research initiative. Science teams are presently
developing four projects to advance the goals of the
LTER Decadal Plan. The first of these projects is an
effort to develop future scenarios to understand the
vulnerability and resilience of regional landscapes to
climate and land use change. Vulnerability to future
climate change is also the theme of a second working
group that will examine the affects of sea-level rise,
increased storm surge, ocean acidification, and
increases in water temperature, loss of sea ice, and
changes in fresh water inflows on coastal LTER sites.
Another working group is developing an experimental
approach to evaluate the sensitivities of inland social-
ecological systems to climate change to be conducted
on a continental scale. Finally, a fourth group will



1389 examine how changes in the global cryosphere will
 1390 affect ecosystem services such as planetary cooling,
 1391 sea-level regulation, carbon storage, soil insulation,
 1392 and water storage. Together, these four developing pro-
 1393 jects reflect the future direction of the LTER program.

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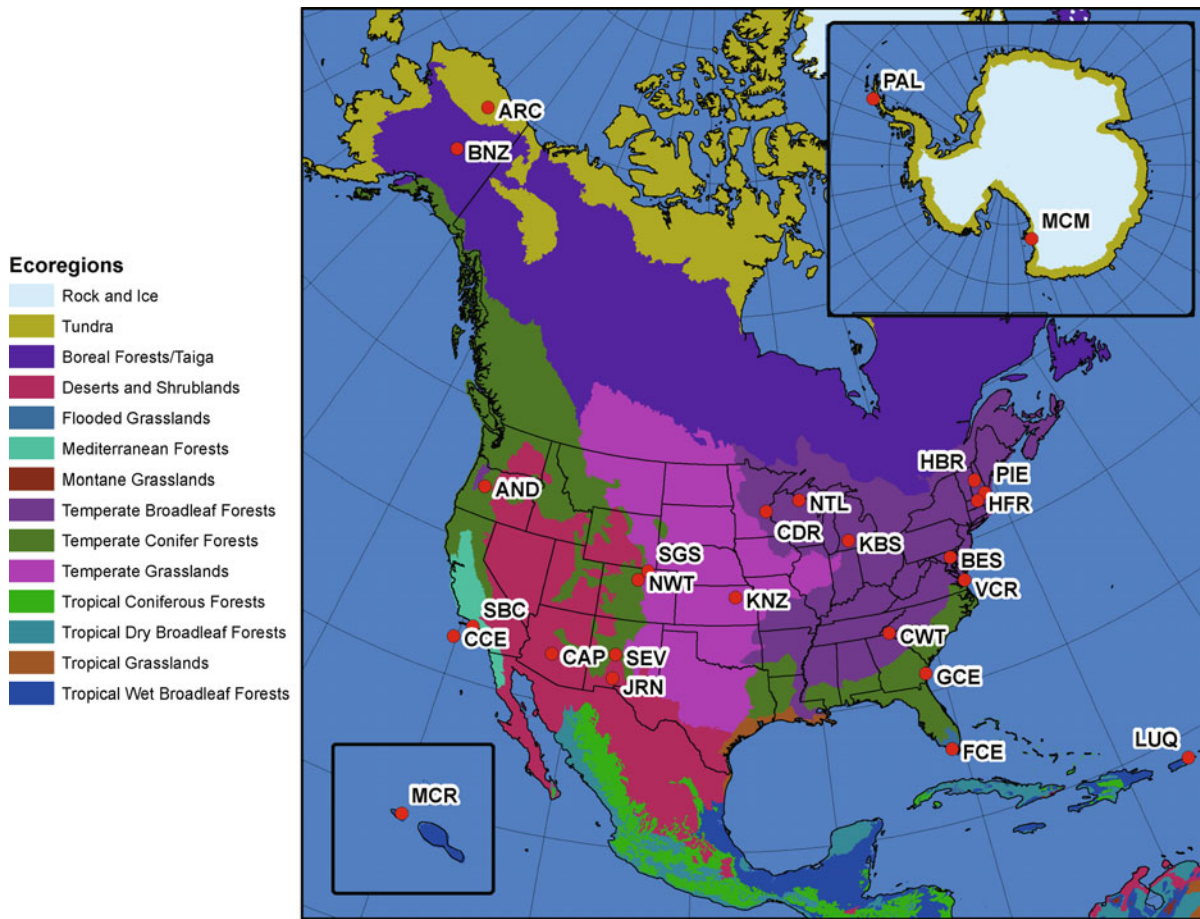
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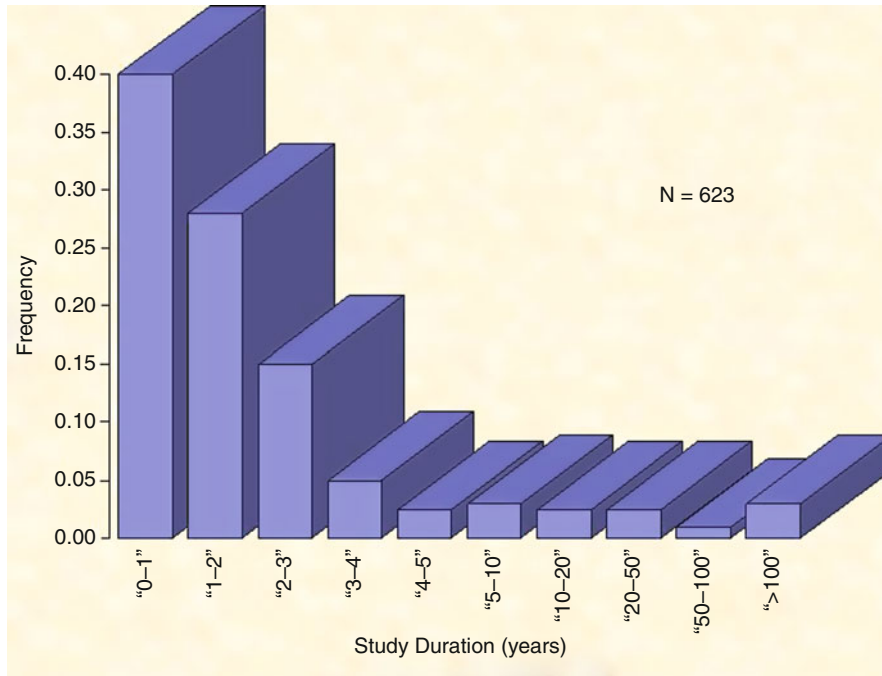
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Long-Term Ecological Research Network (LTER). Figure 1

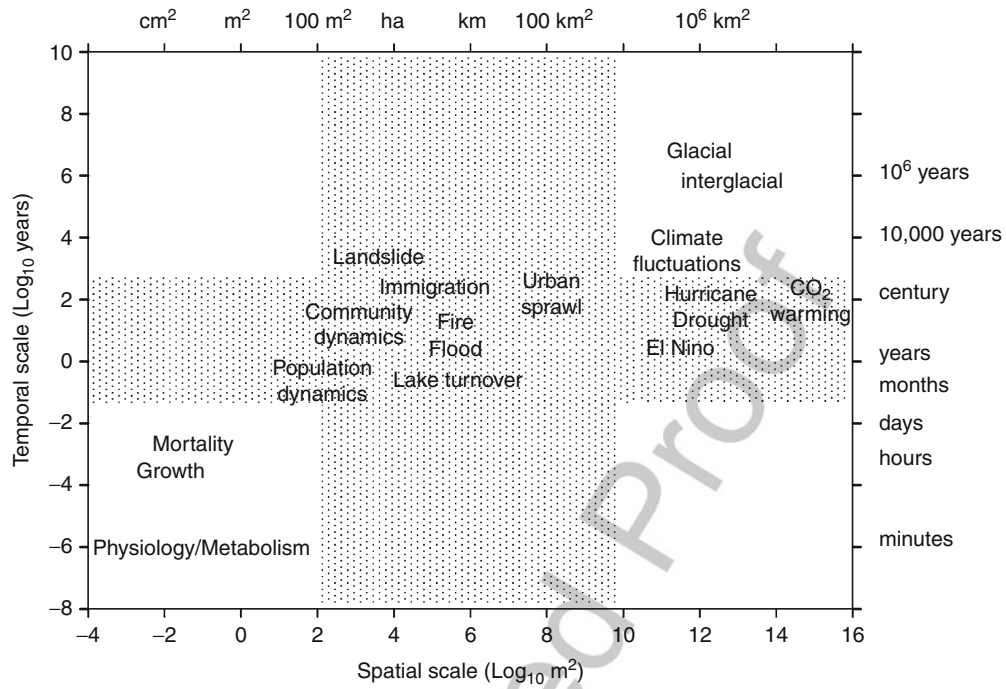
Locations of current LTER sites within global ecoregions. Site names, acronyms, and home institutions are as follows: Andrews Experimental Forest LTER (AND) – Oregon State University; Arctic LTER (ARC) – The Ecosystems Center, Marine Biological Laboratory; Baltimore Ecosystem Study (BES) – Cary Institute of Ecosystem Studies; Bonanza Creek LTER (BNZ) – University of Alaska – Fairbanks; California Current Ecosystem (CCE) – Scripps Institution of Oceanography; Cedar Creek Natural History Area LTER (CDR) – University of Minnesota; Central Arizona – Phoenix (CAP) – Arizona State University; Coweeta LTER (CWT) – University of Georgia; Florida Coastal Everglades (FCE) – Florida International University; Georgia Coastal Ecosystems (GCE) – University of Georgia; Harvard Forest (HFR) – Harvard University; Hubbard Brook Experimental Forest LTER (HBR) – Cornell University; Jornada Basin (JRN) – New Mexico State University; Kellogg Biological Station (KBS) – Michigan State University; Konza Prairie LTER (KNZ) – Kansas State University; Luquillo Experimental Forest LTER (LUQ) – University of Puerto Rico; McMurdo Dry Valleys (MCM) – Ohio State University; Moorea Coral Reef (MCR) – University of California-Santa Barbara; Niwot Ridge LTER (NWT) – University of Colorado; North Temperate Lakes (NTL) – University of Wisconsin-Madison; Palmer Station (PAL) – The Ecosystems Center, Marine Biological Laboratory; Plum Island Ecosystems (PIE) – The Ecosystems Center, Marine Biological Laboratory; Santa Barbara Coastal (SBC) – University of California-Santa Barbara; Sevilleta LTER (SEV) – University of New Mexico; Shortgrass Steppe (SGS) – Colorado State University; Virginia Coast Reserve (VCR) – University of Virginia (Courtesy of Jamie Hollingsworth; data from The Nature Conservancy [1])



Long-Term Ecological Research Network (LTER). Figure 2

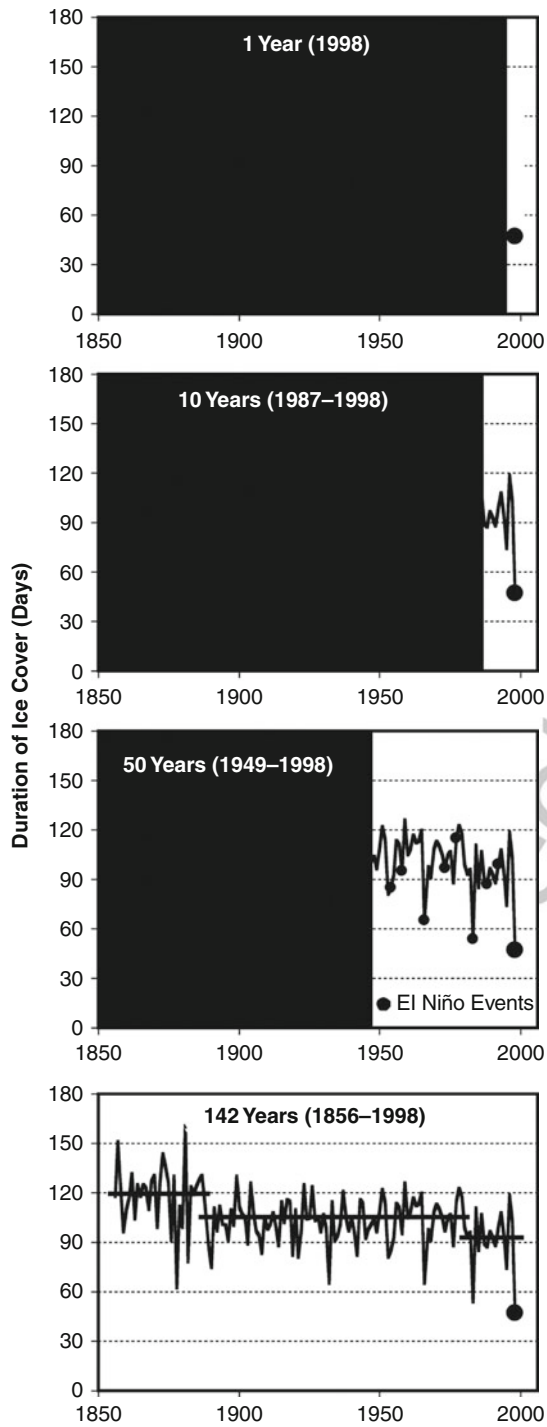
Frequency distribution of a random sample of observational and experimental studies published in the journal Ecology between 1977 and 1987 (From Gosz et al. [7]. Data from Tilman [8])

Uncorrected



Long-Term Ecological Research Network (LTER). Figure 3

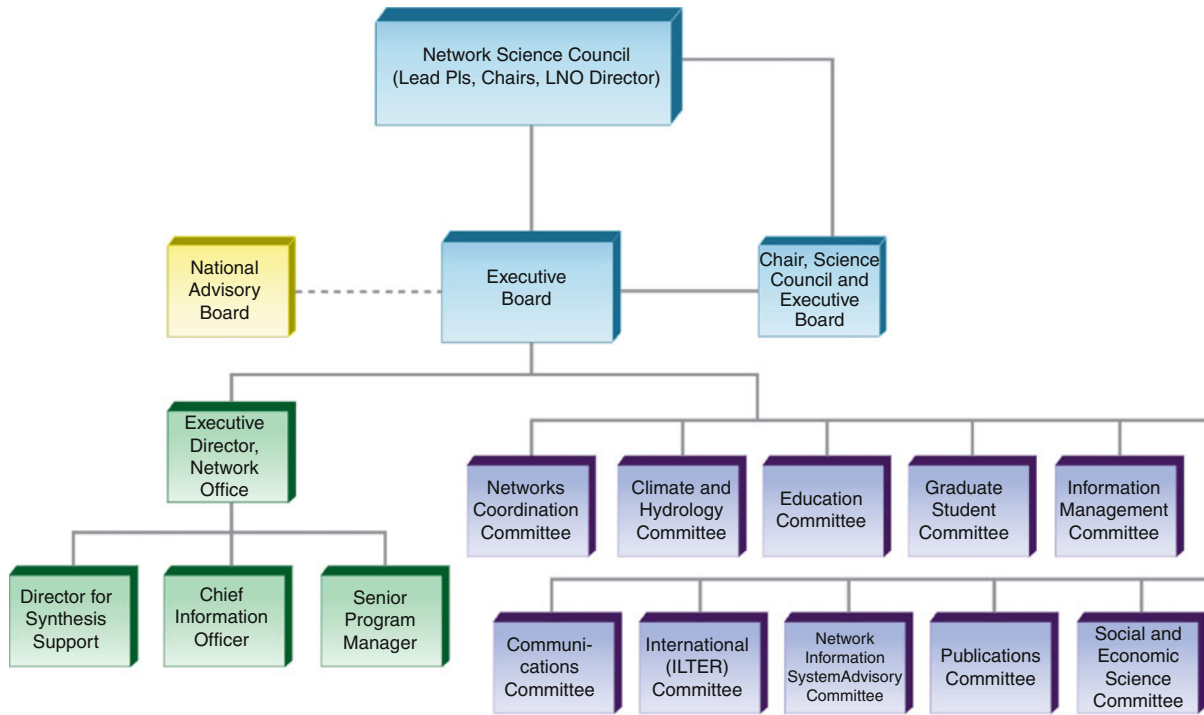
Temporal and spatial domains of the LTER program focus on biological phenomena and physical events that operate on year to century time scales and plot to regional spatial scales (Redrawn from Magnuson et al. [13], with permission)



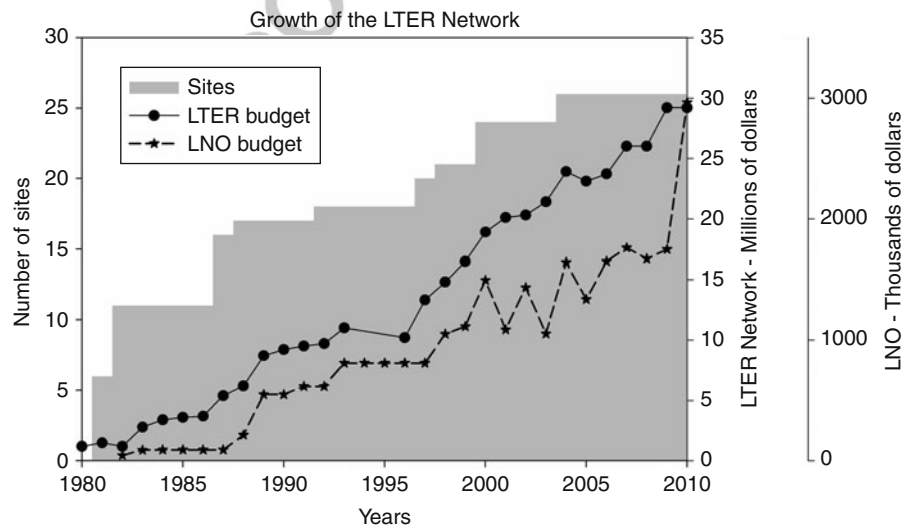
Long-Term Ecological Research Network (LTER).

Figure 4

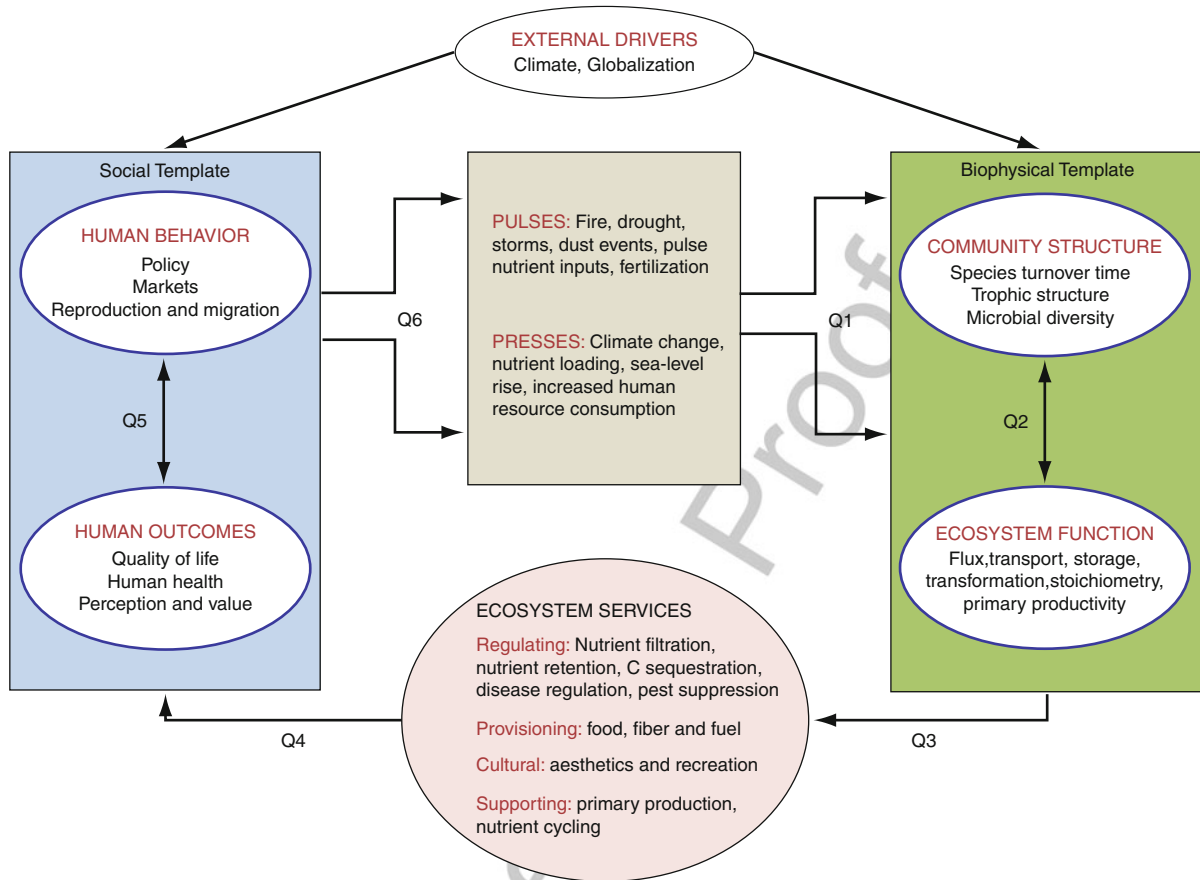
Observations of ice cover records of Lake Mendota demonstrate the importance of broad temporal scale in rendering the present visible (From Magnuson et al. [14])



Long-Term Ecological Research Network (LTER). Figure 5
 Organizational chart for the LTER Network (Courtesy of Phil Robertson)



Long-Term Ecological Research Network (LTER). Figure 6
 Growth of the LTER Network



Long-Term Ecological Research Network (LTER). Figure 7

Integrated science for society and the environment, a framework for future LTER research (From Collins et al. [55])