

Archimedes 59

New Studies in the History and Philosophy
of Science and Technology

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The Challenges of Long Term Ecological Research: A Historical Analysis

 Springer

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Chapter 3

Long-Term Dynamics of the LTER Program: Evolving Definitions and Composition



Julia Jones and Michael Paul Nelson

Abstract This chapter investigates how the National Science Foundation's (NSF) Long Term Ecological Research (LTER) Program has changed from 1980 to 2018. The LTER program is designed to balance persistence with response to change in science, society, and ecosystems through renewable 6-year grants subjected to peer review at the midterm and at renewal. The LTER program had an initial period of rapid growth with some terminations (1980s), a middle period of slower growth with no terminations (1990–2010), and a third period of no net growth, with added and terminated sites and an accelerated rate of site probations (2010s). Changes in the character and composition of the LTER program are associated with changes in leadership and research directions within individual LTER sites, as well as changes in the sources of funding for the LTER program within NSF, turnover in NSF program officers, and changes in review criteria used to renew LTER site funding. In the past decade, a focus on conceptual frameworks as a tool for integrating LTER research emerged from the LTER renewal review process. Given the accelerated pace of environmental change, the need for long-term ecological research is even more urgent today than when NSF established the pioneering LTER program. The LTER Program history reveals important lessons for how to structure and manage long-term ecological research.

Keywords LTER program · Long-term ecological research · National Science Foundation · NSF funding, Ecological networks · Network management · Site termination · Site probation · Conceptual frameworks

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R. B. Waide, S. E. Kingsland (eds.), *The Challenges of Long Term Ecological Research: A Historical Analysis*, Archimedes 59,

https://doi.org/10.1007/978-3-030-66933-1_3

3.1 Introduction

Long-term ecological research is overwhelmingly valued by the scientific community for its capacity to provide ecological understanding (Kuebbing et al. 2018) and contribute to policy (Hughes et al. 2017). Yet large programs that fund long-term ecological research are difficult to establish and sustain. In the 1980s, Callahan (1984) captured the essence of the challenge involved in making long-term ecological research a reality when he wrote:

There is a serious contradiction between the time scales of many ecological phenomena and the support to finance their study. The problem is a difficult one. Funding cannot be guaranteed to any research undertaking for even tens of years, let alone for centuries or more. How can this pattern be broken, a pattern that acts against the consistent and reliable accumulation of sets of long-term synoptic data?

To address the problems that Callahan noted, the US National Science Foundation (NSF), founded in 1950, has funded the US Long Term Ecological Research (LTER) program since 1980 (i.e., for more than half the lifespan of the agency).

For 40 years, the LTER program has supported a changing number of sites through a competitive process. The NSF LTER program has expanded over time, and new sites have been added. LTERs develop understanding of how ecosystem processes respond to long-term environmental change in the past and the future. LTER site-based research programs design and implement experiments and studies that will outlive any given grant period and even the researchers themselves. LTER sites operate as a network, with offices (the LTER Network Office and Network Communications Office) and regular meetings to promote network interactions and synthetic research.

The NSF LTER renewal process attempts to strike a balance between providing funding for periods long enough to embark on, and continue, “consistent and reliable” (sensu Callahan 1984) long-term ecological research, without guaranteeing funding to any particular LTER site. Each site is funded for periods of 6 years (5 years in the 1980s) and must submit a renewal proposal to NSF every 6 years. Some LTER sites have obtained renewal funding for as many as seven periods, while other sites have been terminated after as little as one to as many as six funding periods. Some LTER sites have been placed on “probation” at the time of renewal; these sites must submit a 4-year renewal proposal 2 years later. As of 2020, currently funded LTER sites vary from as little as 3 years to 40 years of continuous funding.

A number of publications have described research and other accomplishments of the LTER program (e.g., Kratz et al. 2003; Gosz et al. 2010; Foster 2012). However, no publications have addressed the funding and evaluation process of the LTER program. Here we examine the review criteria, the evolving composition of sites resulting from establishment and renewal decisions, and factors influencing these changes over the history of the NSF LTER program. The following questions are examined:

1. Over the history of the LTER program (1980–2018), how many sites have been funded, and what types of ecosystems have been studied?
2. What have been the review criteria for LTER sites? How have they changed?
3. What have been the rates of funding, renewal, probation, and termination of sites?

This analysis of program history and administration may be helpful for those seeking context for the development and management of long-term ecological research programs globally.

3.2 Methods

3.2.1 Data

Analyses were based on information provided by the LTER Network Office (LNO), LTER Network Communications Office (NCO), NSF, and LTER principal investigators (PIs). The LNO provided historical information on dates of site funding, renewal, probation, termination, and wind-down funding. NSF documents included requests for proposals (RFPs, now called solicitations at NSF, and hereafter collectively referred to as RFPs); invitations for renewal; proposal reviews and panel summaries; and program officer comments. RFPs and letters for renewal were obtained from archives compiled by the LNO, NCO, and individual LTER sites. Reviews, panel summaries, and program officer comments were provided with permission to use by current LTER principal investigators.

3.2.2 Analyses

Our analysis has three main components: (1) inventory of LTER sites and their funding status over the history of the program, (2) analysis of historical NSF requests for proposals (RFPs), and (3) analysis of the outcome of the renewal review process resulting in probation and termination decisions since 2010, a period in which 11 sites were placed on probation and four were terminated.

We compiled an inventory of LTER sites funded over the history of the program. A table of LTER site names, acronyms, funding periods, and ecosystem type was assembled from data provided by the LNO and NCO (Table 3.1). A master database was created including the dates of each event (funding, renewal, probation, termination, end of post-termination wind-down funding) throughout the funded period for each LTER site (Fig. 3.1). Data in the master database were grouped by type of event (i.e., funding, probation, termination) to show the growth and change in numbers of LTER sites (Fig. 3.2). These data were also grouped by decade and ecosystem type in order to show how the composition of the LTER network changed over

Table 3.1 Names, funded periods, and ecosystem types of LTER sites examined in this study

Name and abbreviation	Type of ecosystem	Period
<u>Continued long-term funding</u>		
Andrews Forest (AND)	Conifer forest and streams	1980–
Arctic (ARC)	Tundra, lakes, rivers	1986–
Beaufort Lagoon Ecosystem (BLE)	Coastal ocean	2017–
Bonanza Creek ^a (BNZ)	Boreal forest	1986–
California Current Ecosystem (CCE)	Coastal upwelling biome	2004–
Cedar Creek Ecosystem Science Reserve ^a (CDR)	Savanna/tallgrass prairie	1982–
Central Arizona – Phoenix ^b (CAP)	Urban	1997–
Florida Coastal Everglades ^b (FCE)	Freshwater marsh, mangroves, seagrass	2000–
Georgia Coastal Ecosystems (GCE)	Coastal rivers, marsh, barrier islands	2000–
Harvard Forest (HFR)	Temperate forest and wetlands	1988–
Hubbard Brook (HBR)	Temperate forest and streams	1986–
Jornada Basin ^{ab} (JRN)	Chihuahuan desert grassland, shrubland	1982–
Kellogg Biological Station ^b (KBS)	Row-crop agriculture	1986–
Konza Prairie (KNZ)	Native tallgrass prairie	1980–
Luquillo ^{ab} (LUQ)	Tropical forest and streams	1988–
McMurdo Dry Valleys (MCM)	Ice-covered lakes, streams, ice-free soil	1991–
Mo'orea Coral Reef ^b (MCR)	Coral reef and lagoon	2004–
Niwot Ridge ^a (NWT)	Alpine glacier and tundra	1980–
North Temperate Lakes (NTL)	Lakes in a forested landscape	1980–
Northeast US Shelf (NES)	Coastal ocean	2017–
Northern Gulf of Alaska (NGA)	Coastal ocean	2017–
Palmer Antarctica (PAL)	Pelagic marine	1990–
Plum Island Ecosystems ^b (PIE)	Coastal rivers, estuaries and marshes	1998–
Santa Barbara Coastal (SBC)	Coastal rivers, kelp forests	2000–
Virginia Coast Reserve ^a (VCR)	Coastal marsh, estuary, barrier islands	1986–
<u>Terminated^d</u>		
Baltimore Ecosystem Study ^b (BES)	Urban	1997–2018
Coweeta ^b (CWT)	Temperate forest	1980–2018
Illinois Rivers	River, riverine marsh, floodplain forest	1982–1988
North Inlet	Coastal rivers, estuaries and marshes	1980–1993
Okefenokee	Freshwater wetland	1982–1988
Shortgrass Steppe ^a (SGS)	Semi-arid grassland	1982–2012

(continued)

Table 3.1 (continued)

Name and abbreviation	Type of ecosystem	Period
<u>Terminated and re-funded</u>		
Sevilleta ^{abc} (SEV)	Desert grassland, shrubland, woodland	1988–

^aSite experienced probation before 2010

^bSite experienced probation between 2010 and 2018

^cTerminated and then re-funded

^dTerminated sites receive “wind-down” funding for several years after termination. This study uses the date when termination decision was made

Sources: <https://lternet.edu/site/> and archives of the LTER Network Office, <https://lternet.edu/?taxonomy=document-types&term=lter-network-office>

time relative to type of ecosystem and source of funding (i.e., Directorates and Divisions) within NSF (Fig. 3.3).

Analysis of Historical NSF RFPs, 1980–2020 All RFPs from 1980 to 2020 were collected and placed in an electronic archive in the following locations.

New site solicitations:

<https://lternet.edu/?taxonomy=document-types&term=new-site-solicitations>

Renewal solicitations and guidance:

<https://lternet.edu/?taxonomy=document-types&term=renewal-solicitations>

Planning documents:

<https://lternet.edu/?taxonomy=document-types&term=planning-documents>

All three categories are posted on the LTER Network archive, under the heading

LTER Organization:

<https://lternet.edu/intranet/>

The dates, titles, and names of program officers listed in each RFP from 1980 to 2020 were tabulated in order to determine the Directorates and Divisions of NSF and the numbers and turnover of program officers involved over the course of the program (Table 3.2). Each RFP was read, and six review criteria were identified from the original RFP in 1980, as well as six additional review criteria that appeared later and persisted in renewal RFPs. Each RFP was searched for each combination of these twelve sets of review criteria keywords/key phrases, and sentences containing these keywords or key phrases were excerpted, tabulated, and compared over time (Table 3.3). The dates of first appearance and revisions of review criteria were assembled into a timeline for the history of the LTER program (Fig. 3.4). The numbers of words in each RFP was counted (Fig. 3.5), and the turnover in the wording of review criteria in each successive RFP from 1980 to 2018 was calculated (Table 3.3).

An analysis was conducted of the outcome of the renewal review process in the fourth decade. A schematic diagram was developed to show the process for renewal of LTER sites (Fig. 3.6). The reviews, panel summaries, and program officer comments for 12 cases of probation or termination that occurred between 2010 and 2018 were read and searched for the key words/key phrases of review criteria identified

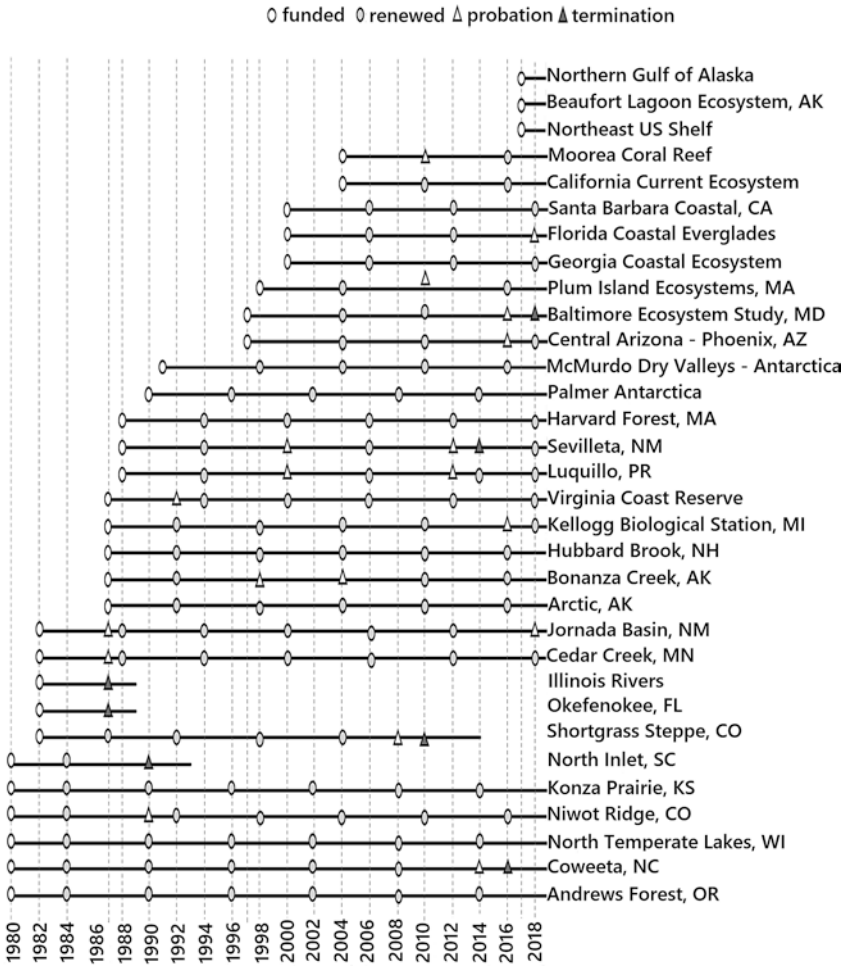


Fig. 3.1 Timelines of initial funding, renewal, probation, and termination of LTER sites, 1980–2018. Length of each line indicated the total funding period for that site, including wind-down funding after termination, and renewal funding to 2020, 2022, and 2024

from the analysis of historical RFPs. Sentences containing these keywords/key phrases were excerpted and grouped by review criterion and site. The frequency of use of these keywords in probation and termination decisions was tabulated by year from 2010 to 2018 (Table 3.4). The outcomes of LTER site renewals (shown in Fig. 3.1) were tabulated by decade and used to calculate the proportion of probations and terminations relative to numbers of proposals reviewed (Table 3.5). The outcomes of LTER site renewals (from Fig. 3.1) also were tabulated to determine the proportion of probations and terminations relative to the numbers of renewal proposals each site had submitted (Table 3.6).

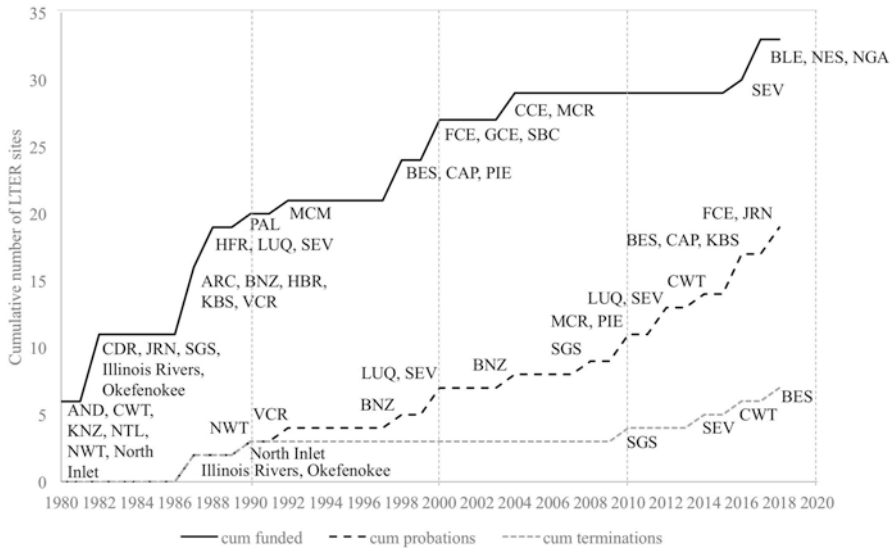


Fig. 3.2 Cumulative numbers of sites funded, on probation, and terminated in the NSF LTER Program. LTER site abbreviations are from Table 3.1

3.3 Results

3.3.1 Overview of LTER Program Sites by Ecosystem Type Over Time

Thirty-three awards were made to initiate funding to 32 LTER sites from 1980 to 2018 (one site was funded twice) (Table 3.1). Funding periods of individual LTER sites ranged from one to 38 years as of 2018 (Fig. 3.1). Overall, 133 renewal proposals have been reviewed. Nineteen of these proposals (14.3%) resulted in probation and seven proposals (5.3%) resulted in termination of an LTER site. Three sites were terminated in the first decade of the program after 5–10 years of funding. The first instance of probation was in 1990. Four sites were terminated in the most recent decade (2010–2018) after 20–38 years of funding.

The number of LTER sites increased rapidly in the first decade and more slowly in the second decade, and then leveled off (Fig. 3.2). In the first decade, twenty sites were funded, and three sites were terminated, leaving a net of 17 sites as of 1990 (Table 3.5). By 2000, including terminations and new sites, 24 LTER sites were funded. Since 2000 there has been little net change in numbers of funded LTER sites: four sites have been terminated, and six new sites were added, including one which had been terminated but was re-initialized. Four sites were placed on probation in each of the second and third decades (1990s and 2000s), and one of these eight sites was terminated in 2010. Seven sites were placed on probation in the

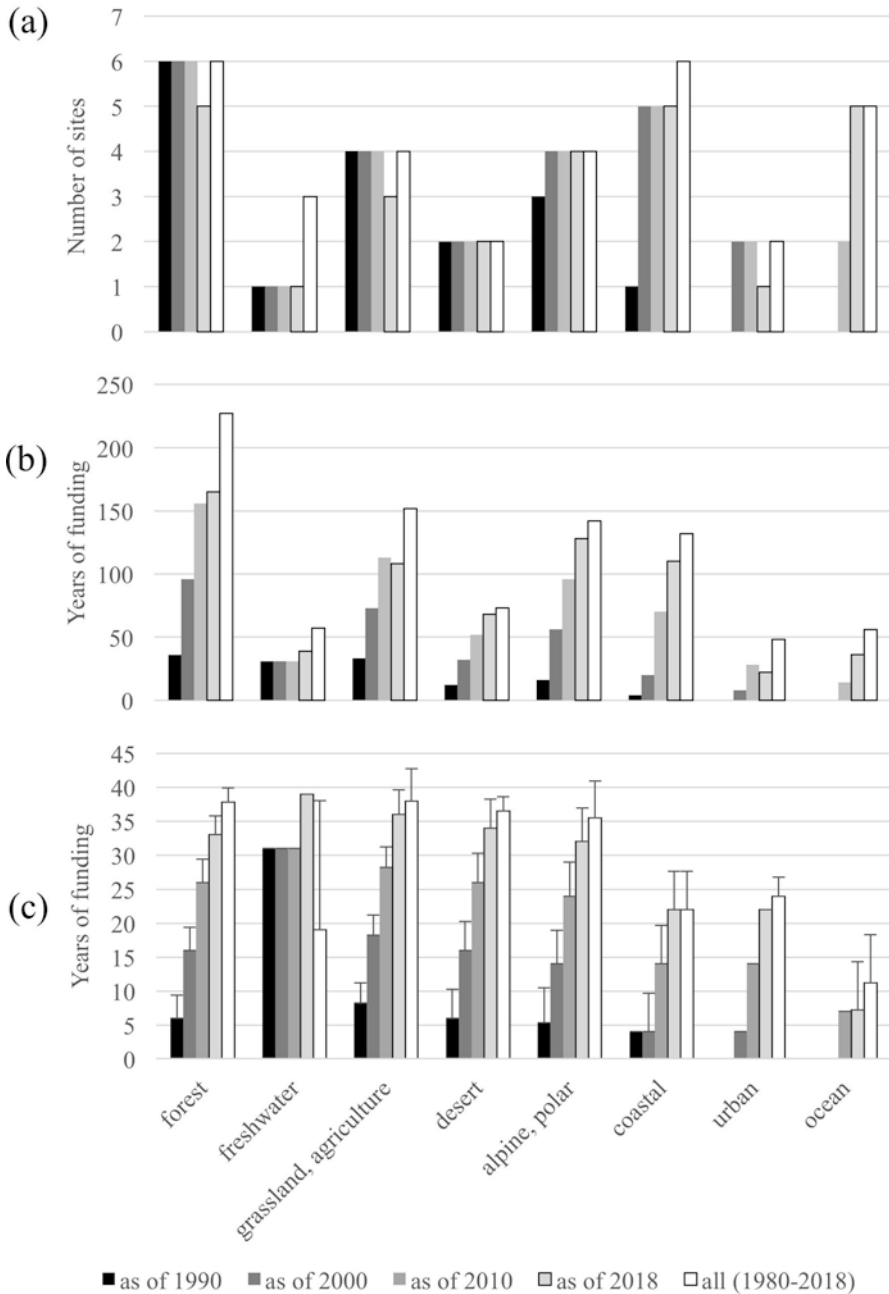


Fig. 3.3 Composition of LTER sites and funded period by ecosystem type and decade. **(a)** Number of sites funded, **(b)** total years of funding, and **(c)** average funded period. A total of 32 sites have been funded since 1980 (Table 3.1), broken into eight categories: Forest ($n = 6$): AND, BNZ, CWT, HBR, HFR, LUQ; freshwater ($n = 3$): Illinois Rivers, Okefenokee, NTL; Grassland, agriculture ($n = 4$): KNZ, SGS, CDR, KBS; desert ($n = 2$): JRN, SEV; alpine and polar ($n = 4$): NWT, ARC, MCM, PAL; coastal ($n = 6$): North Inlet, PIE, FCE, GCE, SBC, VCR; Urban ($n = 2$): BES, CAP; ocean ($n = 5$): CCE, MCR, BLE, NES, NGA

Table 3.2 Sources of information for analysis of NSF requests for proposals (RFPs) involving the LTER program. Site abbreviations are explained in Table 3.1

Date	Name of competition	Outcome	NSF Directorate/ Division	Program officers
1980	NSF 79–64 A new emphasis in long-term research (first competition)	AND, CWT, KNZ, NTL, NWT, North Inlet	BIO/DEB	J.T. Callahan
1981	NSF long-term ecological research (LTER)	CDR, JRN, SGS, Big Rivers, Okefenokee	BIO/DEB	J.T. Callahan
1986	n/a (renewal)		BIO/DEB	J.T. Callahan
1987	NSF 86–16 third competition for long-term ecological research (LTER)	ARC, BNZ, HBR, KBS, VCR	BIO/DEB	J.T. Callahan
1988	NSF 87–41 fourth competition for long-term ecological research (LTER)	HFR, LUQ, SEV	BIO/DEB	J.T. Callahan
1990,1991	n/a	MCM, PAL	GEO/OPP, BIO/DEB	n/a
1994	NSF 94–60 LTER project augmentation for regionalization, comprehensive site histories, and increased disciplinary scope	Augmented CWT, NTL	BIO/DEB	J.T. Callahan
1997	NSF 97–53 fifth competition for long-term ecological research (LTER): Urban LTER	BES, CAP	BIO/DEB, EHR, SBE	S.L. Collins, E. Hamilton, J.W. Harrington
1999	NSF 99–89 long-term ecological research (LTER) in land/ocean margin ecosystems	PIE, FCE, GCE, SBC	BIO/DEB, GEO/OCE	S.L. Collins, P. Taylor
2002	Guidelines for LTER 2002 renewal proposals	Renewal	BIO/DEB	H.L. Gholz
2004	NSF 03–599 long-term ecological research (LTER) in Coastal Ocean ecosystems	CCE, MCR	BIO/DEB, GEO/OCE	D.L. Garrison, G. Pugh
2006	Preparation Guidelines for LTER 2006 Renewal Proposals	Renewal	BIO/DEB, GEO/OCE	H.L. Gholz, P. Taylor

(continued)

Table 3.2 (continued)

Date	Name of competition	Outcome	NSF Directorate/ Division	Program officers
2008	Preparation Guidelines for LTER 2009 Renewal Proposals	Renewal	BIO/DEB, GEO/OCE, GEO/OPP, SBE	H.L. Gholz, M. Caldwell, P. Taylor, R. Marinelli, T. Baerwald
2010	Preparation Guidelines for LTER 2011 Renewal Proposals	Renewal, SGS	BIO/DEB, GEO/OCE, GEO/OPP, SBE	T. Crowl, H.L. Gholz, D. Garrison, R. Marinelli, T. Baerwald
2012	NSF 12–524 long-term ecological research (LTER)	Renewal	BIO/DEB, GEO/OCE, GEO/OPP, SBE	S. Twombly, T. Baerwald, D.L. Garrison, P. Milne
2014	NSF 13–588 long-term ecological research (LTER)	Renewal, SEV	BIO/DEB, GEO/OCE, GEO/OPP	S. Twombly, D.L. Garrison, L. Clough
2016a	NSF 16–509 long-term ecological research (LTER) new site competition	BLE, NES, NGA, SEV	BIO/DEB, GEO/OCE	S. Twombly, D.L. Garrison
2016b	NSF 15–596 long-term ecological research (LTER) renewal	Renewal	BIO/DEB, GEO/OCE, GEO/OPP	J. Schade, L. Kaplan, D.L. Garrison, L. Clough
2018	NSF 17–593 long-term ecological research (LTER) renewal	Renewal	BIO/DEB, GEO/OCE, GEO/OPP, SBE	D. Garrison, J. Schade, D. Levey, L. Kaplan
2020	NSF 19–593 long-term ecological research (LTER) renewal	Renewal	BIO/DEB, GEO/OCE, GEO/OPP, SBE	J. Burns, R. Delgado, D. Levey, C. St. Mary, J. Schade, D. Thornhill, J. Yellen

Program officers are those listed in the RFP. *BIO/DEB* Directorate for Biological Sciences/Division of Environmental Biology, *SBE* Directorate of Social, Behavioral and Economic Sciences, *GEO/OCE* Directorate for Geological Sciences/Division of Ocean Sciences, *GEO/OPP* Directorate for Geological Sciences/Office of Polar Programs. Original funding to a site is shown in regular font and terminated sites are struck out, e.g. Data on funding outcomes is from records maintained by the LTER Network Office, 2015 onward

fourth decade (2010s) and three of these have been terminated (Figs. 3.1 and 3.2, Table 3.5).

The composition of LTER sites varies by ecosystem type and decade. Funding for LTER sites has been provided from several of the Directorates of NSF, but principally from the Biological Sciences Directorate (BIO) and the Geosciences Directorate (GEO). In the first decade, LTER funding was exclusively from the NSF Division of Environmental Biology in the Biological Sciences Directorate (BIO/

Table 3.3 Changes in frequency of LTER review criteria in NSF rfps, 2010–2020

	2010	2012	2014	2016	2018	2020
<u>Original criteria in 1980</u>						
Information (data) management	3	13	14	8	9	9
Site (project) management, diversity	2	3	3	3	3	2
Long-term	3	15	18	17	17	5
Cross-site, network	10	28	7	8	8	2
Goal	0	8	5	5	5	1
Core area	0	3	2	2	7	6
<u>Criteria added in 1997 or later</u>						
Integrate, -s, -d, -ing	1	15	11	17	17	2
Conceptual framework	3	6	5	7	7	7
Social, socio-, human	0	12	6	13	11	2
Theory, -ies	0	3	1	2	2	2
Model, -ing	2	4	8	6	5	4
Publications	4	0	1	1	7	6
Predict	0	1	1	7	3	3
Total words in instructions	1230	2205	2546	2664	3034	3186
Turnover in instructions (%)	1	100	37	30	26	31

Total words and turnover were calculated for Section V of the RFP: proposal preparation
 Turnover = (number of words in in year t that do not appear in year t–1 + number of words in year t–1 that do not appear in year t)/(total words in year t and year t–1). Turnover from 1980 to 2010 was <21%

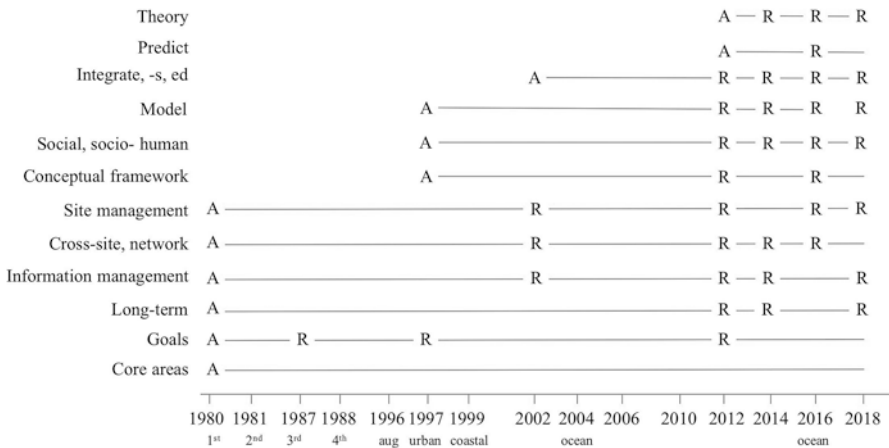


Fig. 3.4 First appearance (A) and subsequent revisions (R) of key terms and concepts in NSF LTER review criteria in NSF solicitations (RFPs) issued on dates shown on x-axis. NSF competitions for new or augmented (“aug”) LTER sites (from Table 3.2) are shown below the dates

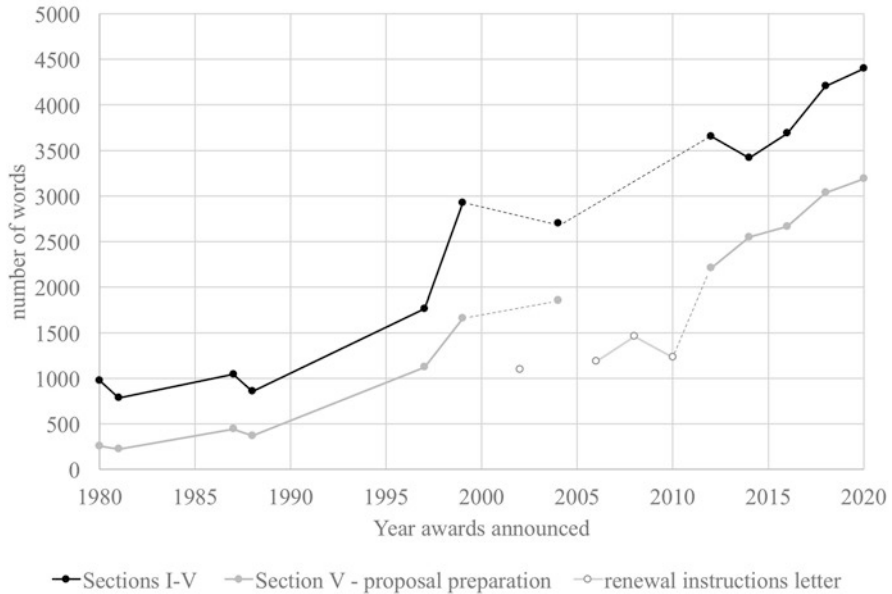


Fig. 3.5 Trends in numbers of words in NSF RFPs and renewal instruction letters for the LTER program. Section V is guidelines for proposal submission, including review criteria. Numbers for 2012–2018 refer to renewal RFPs only (see Table 3.2)

DEB), and focused on terrestrial sites, such as forest, grassland (including agricultural), and desert (Table 3.2, Fig. 3.3a). Two of three freshwater sites were terminated by 1990.

In the second decade, ecosystem types of LTER sites expanded to include polar, urban, and coastal/land margin ecosystems. Polar sites were funded by the Office of Polar Programs of the Geosciences Directorate (GEO/OPP). Urban sites were funded by BIO/DEB with contributions for the first few years from the Directorate of Social, Behavioral, and Economic Sciences (SBE), Education and Human Resources (EHR), and the Engineering Directorates (S.L. Collins, personal communication). Coastal/land margin sites were funded by the Division of Ocean Sciences of the Geosciences Directorate (GEO/OCE) (Table 3.2, Fig. 3.3a).

In the third and fourth decades, ecosystem types of LTER sites expanded to include coastal ocean ecosystems (funded by GEO/OCE and GEO/OPP). No new terrestrial sites have been initiated with BIO/DEB funding since 1988. BIO/DEB provides all the funding for the urban sites, which began in the 1990s (S.L. Collins, personal communication). All new LTER sites since 1988 have involved funding from the GEO (and briefly, from the SBE) Directorates of NSF. All seven of the sites that have been terminated were funded by BIO/DEB at the time of termination. Thus, as of 2018, 13 of the 26 sites that retain funding are funded by BIO/DEB, and 13 sites are funded by GEO/OPP or GEO/OCE, with a few sites receiving co-funding from two or more directorates (Table 3.2, Fig. 3.3a).

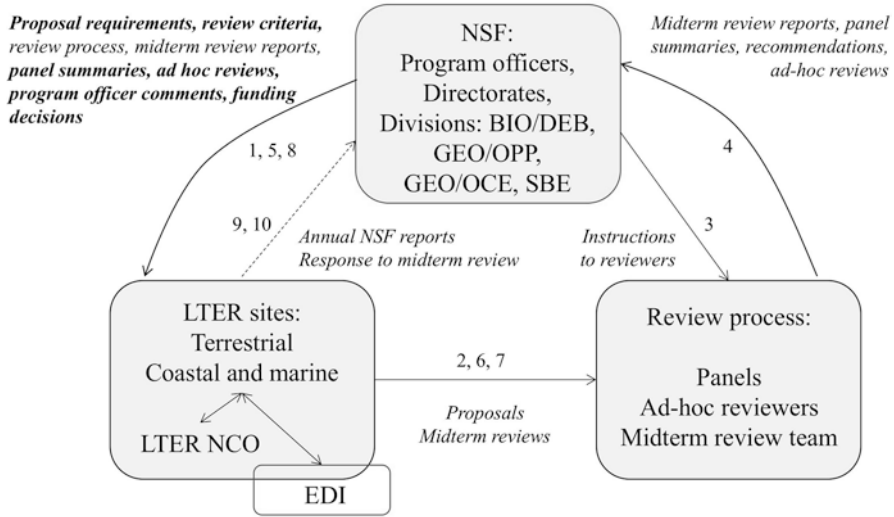


Fig. 3.6 Structure of the LTER community, and information and communication flows that influence binding decisions on the structure and composition of the LTER program over time. This study analyzed the items in bold font. *NCO* LTER Network Communication Office, *EDI* Environmental Data Initiative. NSF Directorates and Divisions are defined in Table 3.2. Numbers are explained in the text

As a result of these funding patterns, the total years of LTER funding also vary by ecosystem type and decade (Fig. 3.3b). Years of funding (and associated data and long-term analyses) are dominated by forest sites, then grassland, alpine/polar, and coastal sites. Desert, freshwater, ocean, and urban sites have the least total years of funding. The average years of funding per site (which are a measure of the expected length of longest records) also vary by ecosystem type and decade (Fig. 3.3c). Average funding periods of forest, grassland, and desert exceed 35 years for the entire program history, as does the funding period for the single freshwater lake site. Average funded periods for coastal and urban sites exceed 20 years. The average funding period is shortest for ocean sites (Table 3.2, Fig. 3.3c).

3.3.2 LTER Site Renewal Process and Review Criteria

The review process for LTER site renewal involves multiple participants, and is directed by NSF. The renewal process includes institutions (NSF, LTER sites) and individuals (program officers, PIs, reviewers, and panelists) (Fig. 3.6). The principal flows of information that control decision-making are: (1) requests for proposals issued by NSF, (2) submission of research proposals from LTER sites, (3) instructions to reviewers from NSF, (4) reviews, summaries and panel recommendations to NSF, and (5) funding decisions from NSF to LTER sites (Fig. 3.6). Proposals are

Table 3.4 Frequency of use of key phrases in decisions on probation and termination from 2010 to 2018 (n = 12)

Review criteria	2010	2012	2014	2016	2018	Total	%
<u>Original criteria</u>							
Information (data) management	1	2	0	3	1	7	58
Site (project) management	2	2	1	1	0	6	50
Long-term	1	1	1	1	1	5	42
Cross-site, network	2	1	0	0	0	3	25
Goal	0	1	0	1	0	2	17
Core area	0	0	0	0	1	1	8
<u>Added or changed criteria</u>							
Integration, integrated, integrating	2	2	1	3	2	10	83
Conceptual framework	1	2	0	4	2	9	75
Social, socio-, human	1	0	0	4	2	7	58
Theory	1	2	0	2	0	5	42
Model	1	1	0	2	0	4	33
Publications	1	1	0	0	1	3	25
Predict	0	0	0	1	0	1	8
Total decisions	2	2	1	4	3	12	
Total criteria used	13	15	4	22	12	66	
Average no. criteria used per decision	6.5	7.5	4	5.5	4	5.5	46

Analysis included documents from 12 of 14 panel reviews affecting 11 sites; 11 were probation decisions and 3 were termination decisions. % = percent of times used in probation or termination

Table 3.5 Cumulative numbers of LTER site proposals by outcome and proportions of proposals leading to probation and termination, at the end of each of four decades of the NSF LTER program

	1990	2000	2010	2018
Cumulative sites funded	20	27	29	33
Net sites with continued long-term funding	17	24	25	26
Cumulative renewal proposals reviewed	20	50	92	133
Cumulative renewal proposals funded	14	40	77	107
Cumulative renewal proposals leading to probation	3	7	11	19
Cumulative site terminations	3	3	4	7
Cumulative terminations/cumulative funded	0.15	0.11	0.14	0.21
Cumulative probations/renewal proposals	— ^a	0.14	0.12	0.14
Terminations/probations in that decade	— ^a	0	0.25	0.38

A total of 33 funding decisions has been made to fund a total of 32 LTER sites from 1980 to 2018 (Sevilleta was funded twice)

^aThere are no records of probation before 1990

reviewed by the panelists, and (since 2012) additional ad-hoc reviews are solicited from other scientists prior to the meeting of the panel; often one or more of the ad-hoc or panel reviewers are drawn from within the LTER network. Supplemental flows of information include (6) midterm site reviews by NSF, (7) midterm review reports by review teams to NSF, (8) NSF midterm review evaluation sent to LTER

Table 3.6 Numbers and fates of LTER renewal proposals submitted by each site over its entire funded period, and effects on site-level probation and termination

	Numbers of renewal proposals submitted								All
	0	1	2	3	4	5	6	7	
N of sites	3	2	3	3	5	4	8	4	32
N of proposals reviewed	–	2	6	9	20	20	48	28	133
N of proposals leading to probation or termination	–	2	2	1	4	2	9	6	26
N of proposals leading to probation	–	0	1	1	3	2	7	5	19
N of sites on probation	–	0	1	1	3	1	5	4	15
N of sites terminated	–	2	<i>1</i>	0	1	0	2	1	7
Proposals leading to probation or termination (%)	–	<i>100</i>	33	11	20	10	19	21	31
Sites on probation or termination (%)	–	0	33	33	60	25	63	100	45
Sites terminated (%)	–	<i>100</i>	33	0	20	0	25	25	29
Sites terminated given probation (%)	–	–	<i>100</i>	0	33	0	40	25	33

Italics indicates this figure includes termination of three sites in the first decade of the program, 1980–1990, before the first documented instance of probation identified in this study

sites, and (9) response to midterm review from LTER sites. Finally, (10) LTER sites submit annual reports to NSF.

From 1980 to 2020, there has been expansion and turnover of program officers and directorates involved in LTER (Table 3.2). In the 1980s, the LTER program was initiated by a single program officer in one NSF directorate/division (BIO/DEB). In the 1990s, LTER had expanded to at least three directorates (BIO, GEO, SBE), and four new program officers were added. In the 2000s (2002 to 2010), eight program officers from three NSF directorates and four NSF divisions were listed on LTER RFPs. Of these eight program officers, seven were new, and one (Taylor) had been listed on an LTER RFP in 1999. In the 2010s (2012 to 2020), thirteen program officers from three NSF directorates and four NSF divisions were listed on LTER RFPs. Of these, twelve were new, and one (Garrison) had been listed on an LTER RFP in the previous decade. Over the history of the program, some LTER program officers had prior experience as LTER researchers, and others did not.

The length of RFPs and number of review criteria have increased steadily since 1980. From 1980 to 2020, the total length of the RFP increased by four times, and the length of Section V (instructions for proposal submission) increased by more than ten times (Fig. 3.5, Table 3.3).

The original RFPs (issued in 1980 and 1981) established the main goals and essential features of LTER: core areas, long-term questions, cross-site research and network participation, information management/data availability, and continuity of leadership (Table 3.2, Fig. 3.4). Criteria involving “conceptual framework,” modeling, and social factors (for urban sites) were added in the late 1990s. In the 2012 RFP, the language changed for solicitation-specific review criteria including integration, conceptual frameworks, modeling, social science, and the terms “theory,” and “predict” were added. The 2012 RFP changed the language regarding cross-site research and network participation, information management, and site

management. From 2012 to 2018 there were a number of important changes in the wording of these new criteria (Fig. 3.4). Over the period 2012–2018, all but two of the criteria used in the early decades of the LTER program decreased in frequency, while terms involving integration (“integrate, -ed, -ing”) and social processes (“social, socio-ecological, social-ecological, human”) increased in frequency. In 2020, these latter terms decreased in frequency (Table 3.3, NSF announcement for 2020).

3.3.3 *Changes Over Time in the Wording of Original Review Criteria for LTER*

This section summarizes major changes from 1980 to 2020 in the wording used to describe the original LTER review criteria. NSF’s program announcements and calls for proposals are listed in Table 3.2: references in brackets in this and subsequent sections are abbreviated as “NSF” and year, and refer to the announcement in Table 3.2.

Overall Goals and Mission The overall goals of LTER were defined in the 1980 RFP and have not changed. In 1980, program goals were to “(1) *initiate the collection of comparative data at a network of sites representing major biotic regions of North America and (2) evaluate the scientific, technical and managerial problems associated with such long-term comparative research*” (NSF 1980). Key phrases were added to the goals in 2012 to 2014; these include “*mechanistic understanding,*” “*multiple scales,*” “*predict ... responses to future environmental change,*” and “*social responses*” (NSF 2012, 2014).

Core Areas The core areas first appeared in the 1980 RFP: “*Investigators must focus on a series of core research topics, coordinate their studies across sites, utilize documented and comparable methods, and be committed to continuation of work for the required time. The core research areas are: (1) pattern and control of primary production, (2) dynamics of populations of organisms selected to represent trophic structure, (3) pattern and control of organic matter accumulation in surface layers and sediments, (4) patterns of inorganic inputs and movement of nutrients through soils, groundwater, and surface waters, and (5) patterns and frequency of disturbances*” (NSF 1980). The description of the core areas has not changed since 1980, although the 2018 RFP added core areas to the review criteria (Fig. 3.4, Table 3.3).

Long-Term Data and Long-Term Research In 1980, the RFP had no specific wording about long-term data and research, although emphasis was placed on the need for a long-term commitment by the investigators. From 2012 to 2018, “long-term” appeared frequently in the RFP (Table 3.3), and the wording was changed in each successive RFP (Fig. 3.4), including “*questions that uniquely demand study on*

decadal time scales,” “justify the need for long-term support,” “questions that arise from the analysis of long-term data,” “questions that ... require uninterrupted, long-term collection, analysis, and interpretation of environmental data” (NSF 2012, 2014, 2016b, 2018). The frequency of “long-term” increased sharply from 2012 to 2018, but decreased in the 2020 RFP (Table 3.3, NSF 2020).

Information Management and Data Availability Information management and data availability have been a hallmark of LTER since its inception, and requirements have become more numerous and specific over time. *“Data storage and retrieval”* was required in the 1980 RFP (NSF 1980). Starting in 1997, the RFP required proposals to explain data accessibility, data completeness, and how data from LTER research were provided to LTER information managers (NSF 1997). In 2012, the RFP required reporting of specific timelines for data release for “core” datasets, and documentation of data use, but the latter requirement was dropped in 2014 (NSF 2012, 2014). Starting in 2012, the RFP required sites to comply with *“LTER Network Access goals,”* and in 2018 the RFP required sites to comply with the *“LTER Network’s Information Management Policy.”* The 2018 RFP also lists specific requirements for depositing data in public data repositories and reporting on the data deposited at these sites. In addition, in 2018, the solicitation-specific review criteria require *“comprehensive availability of data previously collected by the site”* (NSF 2018), which might refer to data collected with NSF LTER funding, as well as other funding.

Site Management and Leadership, Including Diversity Continuity of leadership has been a key component of LTER since it began. In 1980, the RFP stated *“The principal investigators must be prepared to make long-term time commitments and should consider ... continuity of site leadership”* (NSF 1980), and continuity of site leadership remains a criterion in the 2020 RFP (NSF 2020). Originally the emphasis was on continuity of leadership within a single LTER award (5 or 6 years). However, many sites were led by their founding PI for several grant cycles, and therefore, starting in 2012, the RFP specifically requires a description of how site leadership transitions are planned and managed (NSF 2012, 2014, 2016b, 2018, 2020). Starting in 2002, the RFP also required sites to explain how they encourage participation in LTER by *“non LTER scientists”* and how site management *“enhance[s] ... diversity of scientists”* (NSF 2002). In 2018, wording was added, *“New participants bring new ideas and fresh perspectives, which are likely to enrich the development of research at the site”* (NSF 2018).

Cross-Site Research and Network Participation The early phases of LTER strongly emphasized cross-site research and network participation, but RFPs have de-emphasized it since 2012. In 1980, the RFP stated, *“Investigators must ... coordinate their studies across sites”* (NSF 1980). Cross-site analysis and network coordination was specified in all RFPs and included as a specific review criterion until 2014, when it was made optional. In the 2012 and 2014 RFPs, *“sites are encouraged to develop network-level interactions”*, and *“proposals are encouraged to*

broaden the spatial scale ... through comparative research with other LTER sites or studies outside of the LTER network" (NSF 2012, 2014). However, in 2016, cross-site work became optional: *"where appropriate, projects among sites or with collaborators outside of the LTER network may be included"* (NSF 2016b).

3.3.4 Additional Review Criteria Added Starting in the Mid-1990s

This section describes additional solicitation-specific review criteria that were included starting in the mid-1990s, and changes in these criteria to 2018.

Integration The first appearance of "integration" in instructions for LTER proposal preparation was in the renewal guidelines in 2002: *"describe the methods and planned analyses in detail and ... conceptually integrate these efforts to your long-term studies ... [C]lose ... with a synthesis that shows how your major activities will be integrated"* (NSF 2002). Starting in 2012, the term "integrate, -ed, -ive" appeared frequently in the RFP linked to many different review criteria, and wording using this term was expanded or modified in each successive RFP through 2020 (Table 3.3, Fig. 3.4). Lack of integration was cited as a reason for 83% of probation and termination decisions from 2010 to 2018 (Table 3.4). In 2020, the term had largely disappeared from the RFP (Table 3.3, NSF 2020).

Conceptual Framework Conceptual frameworks were added to NSF RFPs for LTER in 1997: *"LTER research should be developed around a site-specific conceptual framework that generates questions requiring experiments and observations over long time frames and broad spatial scales"* (NSF 1997). This definition was omitted starting with the renewal instructions in 2002, which merely stated, *"Develop and explain the conceptual framework that provides the unifying ecological theme for your site"* (NSF 2002). The 2012 RFP refers to, but does not define, conceptual frameworks (NSF 2012). In 2014, sites were required to *"extend"* or develop *"new"* conceptual frameworks (NSF 2014). In 2016, key new phrases were added requiring a conceptual framework that *"examines and predicts," "produce[s] a comprehensive understanding," "integrates across populations, communities, and ecosystems,"* and *"develop[s] predictions"* (NSF 2016b). Issues with the conceptual framework were cited as a reason for 75% of probation and termination decisions from 2010 to 2018 (Table 3.4). The 2020 RFP re-defined the conceptual framework as something that, *"motivates questions requiring experiments and observations over long time frames. The conceptual framework should explicitly justify the long-term question(s) posited by the research and it should identify how data in LTER core areas and any experimental work contribute to an understanding of the question(s) while testing major ecological theories or concepts. The framework should provide the justification for all studies outlined in the proposal and should be informed by ongoing analyses of long-term data"* (NSF 2020).

Social Science (Social, Socio-, Human) The term “social” did not appear in LTER RFPs until 2012, with two exceptions. In 1994, the term “social” was introduced into LTER RFPs in a supplemental competition for expanded research (NSF 1994, Table 3.1). In 1997, a competition for urban LTER sites brought social factors to prominence and added them as a required review criterion for urban sites (NSF 1997). The word “social” was absent from subsequent RFPs and renewal guidelines until 2012. In 2012, the RFP added references to “*social scientists*,” “*socio-ecological connections*,” “*social responses*,” and “*social strategies*” (NSF 2012). In the 2012 RFP, if social science was proposed, it was to be evaluated based on “*the extent to which the research draws from and contributes to social science theory and understanding*.” The 2012 RFP stated that all LTER sites “may elect to” include social science “*if there are key, conceptually motivated social science questions*.” In 2014, the RFP language was qualified by the addition of “*if appropriate*” preceding “*social factors*,” and the recommendation was qualified as “[*sites*] may elect to include social science research” ... “*if it helps to advance or to understand key, conceptually motivated ecological questions*” (NSF 2014). In 2018, this wording was changed to simply, “*The disciplinary breadth of LTER research includes ... in some cases, social and economic science*” (NSF 2018). The terms “social, socio-, human” etc. appeared frequently in the RFP from 2012 to 2018 (Table 3.3), and the wording associated with these terms was modified in each successive RFP through 2020. Issues with these concepts were cited as reasons for probation and termination in 58% of cases from 2010 to 2018 (Table 3.4). In the 2020 RFP these terms rarely appeared (Table 3.3).

Models The word “model” or “modeling” did not appear in RFPs from 1980 to 1996. From 1997 to 2012, RFPs noted that modeling was important and required modeling efforts to be “*discussed in detail as appropriate*” (NSF 1997, 2010). In 2012, the RFP included new wording that required use of models, or development of models, and mentioned specific categories of models. In 2014, this wording was modified to include “*refinement*” of models to “*incorporate sources of uncertainty*” and “*model-data assimilation*” (NSF 2014); this wording was dropped in the 2016 RFP. The 2018 RFP stated that proposals must include “*development, refinement, and testing of quantitative models that provide a mechanistic understanding of ecological processes fundamental to the conceptual framework and inform future work*” (NSF 2016b, 2018). The term “model, -ing” increased in frequency in RFPs starting in 2012 (Table 3.3), and wording was modified in each successive RFP (Fig. 3.4). Issues with models were cited in 33% of decisions for probation and termination from 2010 to 2018 (Table 3.4).

Theory The term “theory” was absent from RFPs until 2012 although “*general systems theory*” appeared in RFPs of 1987 and 1988; and “*theoretical efforts*” appeared in the RFP of 1997 (NSF 1980, 1981, 1987, 1988, 1997). In 2012, new wording and solicitation-specific review criteria were added requiring “*test[ing] of ecological or ecosystem theories*” (NSF 2012). Wording associated with the term “theory” was modified in each of the successive RFPs (Fig. 3.4, NSF 2014, 2016b,

2018, 2020). Issues with theory were cited in 42% of decisions for probation or termination from 2010 to 2018 (Table 3.4).

Predict From 1980 to 2011 the word “predict” was not mentioned in the RFPs. Starting in 2012, the RFP required research to “*predict ecological, evolutionary, and social responses*” (NSF 2012). In 2016, revised wording requires “*a conceptual framework that describes or predicts*” and “*testing of predictive models*” (NSF 2016b). The 2018 RFP includes the evaluation criterion, “*develop predictions that link processes and observations across levels of organization or across temporal or spatial scales*” and “[*predict*] *how populations, communities, and other ecosystem components interact*” (NSF 2018). The 2020 RFP includes the evaluation criterion, “*Conceptually-based predictions that link processes and observations across levels of organization (population, community, and ecosystem) or across temporal or spatial scales*” (NSF 2020).

3.3.5 Outcomes of LTER Site Renewal

The outcomes of the LTER renewal process vary by decade. Three of the first eleven sites were terminated in first decade of the program. The fraction of renewal proposals that led to probation increased in the fourth decade. Four sites were terminated in the fourth decade after a period of two decades with no terminations (Table 3.5, Fig. 3.2).

During the fourth decade of the LTER program, review criteria that had been added or changed since the mid-1990s were identified as the basis for decisions for probation and termination more frequently than the original review criteria for the LTER program (Table 3.4). Integration and conceptual framework were the most commonly cited review criteria for decisions for probation and termination in the fourth decade.

The number of renewal proposals a site has submitted is associated with the outcome of renewal decisions. There is an increased likelihood of probation with an increased number of renewal proposals submitted (Table 3.6). Four sites that were terminated in the fourth decade had submitted 4 to 7 renewal proposals. Of the 21 sites submitting their 4th to 7th renewal proposal, 11 have been placed on probation and 4 have been terminated in the 4th decade.

3.4 Discussion

The LTER program has transitioned from 1980 to 2020. In the 1980s, twenty terrestrial and freshwater ecosystems received LTER funding from the BIO Directorate. As of 2018, there are 26 sites with continued funding, equally divided between the BIO and GEO Directorates. From 1980 to 2018, the LTER program had three

distinct periods: an initial period of rapid growth with some terminations (1980s), a middle period of slower growth with no terminations (1990s and 2000s), and a third period of no net growth, with added and terminated sites (2010s). As the result of new funding and terminations, the character and composition of LTER sites changed, especially in the 1980s and the most recent decade (2010–2018).

The early period (1980s) had a single NSF program officer and funding from one NSF directorate (BIO). LTER sites in terrestrial and aquatic ecosystems were funded in this first period. Three aquatic ecosystem sites were terminated. The second period (1990s and 2000s) had an increasing number and turnover of program officers. In this period, the original Directorate (BIO) funded no new sites, and at least three additional directorates in NSF (including GEO, SBE, and EHR) contributed funding for LTER sites. LTER funding was extended to include urban, polar, land margin, and coastal ocean ecosystems. In this second period, a number of sites were placed on probation, but none were terminated. The most recent decade (2010s) had very high turnover of program officers, a complete revision of review guidelines, additions and revisions of review criteria, shift in emphasis of review criteria in panel summaries, increased frequency of probation, and multiple terminations of sites. All new sites in this period were marine sites funded by the GEO Directorate, and all sites terminated in this period (grassland, desert, forest, urban) had been funded by the BIO Directorate for several decades.

Changes in the character and composition of LTER sites are associated with many factors, both at LTER sites and in the review process. LTER sites and the review process are simultaneously attempting to respond to changes in the science community and society. LTER sites face both scientific and social challenges in maintaining a long-term research program. A number of factors associated with individual LTER sites may be responsible for their ability to achieve continued funding in successive renewal proposals. These include: (1) ongoing changes in science and the expectations of the science community, (2) changes in site leadership, coordination, and communication, and (3) changing relationships with host institutions and partner institutions. These are described below.

Over time, as science and the scientific community change, LTER site research programs experience an evolution of scientific understanding and priorities. There is a simultaneous evolution in LTER research as expressed in renewal proposals, the renewal criteria, and the scientific community which provides panelists and reviewers. Thus, one explanation for the increased frequency of probation and termination in the 2010s is that sites are unable to adapt to the changing expectations of the RFPs and reviewers. Alternatively, it may become increasingly difficult to propose novel and innovative research at the same site after several decades of continued funding.

Site leadership, coordination, and communication are also important. Creating and maintaining an “integrated conceptual framework” in an LTER project requires prolonged intensive communication and coordination among a large set of project elements and participants. Changes within individual LTER sites may weaken communication and coordination. Changing leadership and composition of researchers within an LTER site, including loss of experienced leaders, varying availability of

interested researchers within participating institutions, and lack of budget incentives or effective mentoring of researchers new to LTER may all contribute to an apparent lack of integration, or a conceptual framework which reviewers perceive as inadequate. Such changes may explain why some LTER sites, despite two or more decades of success in long-term research, were perceived as lacking integration or having inadequate conceptual frameworks, leading to probation and termination over the past decade.

Changing institutional understanding and support likely also affect the ability of sites to meet LTER review criteria for renewal. For example, partner or lead institutions may be essential to making key data available. Lead and partner institutions also may provide administrative assistance, cost-sharing or PI salaries, and reduced overhead, all of which may effectively expand the LTER budget and the corresponding scope of the LTER project. Changes in these relationships may undermine the ability of an LTER site to sustain an innovative program.

A number of factors associated with the review and funding process at NSF may also be responsible for the changes in the LTER program. These include: (1) changes in review criteria, (2) continuity of leadership within NSF, (3) experience and expertise of LTER program officers, (4) changes in NSF procedures for managing the renewal process, and (5) continuity and commitment to funding.

Changes in review criteria for LTER site establishment and renewal, and changes in reviewer attention to these criteria, have shaped the LTER program over time. In the early years of the program, LTER review criteria focused on program goals and core areas, establishing and maintaining long-term research, and making data available. However, in the fourth decade, RFPs, reviewers and panelists focused increasingly on conceptual frameworks and integration in renewal decisions, especially for long-running LTER sites. The requirement for a “conceptual framework,” introduced in the 1990s, was initially a request for some kind of depiction of how things fit together in an LTER program (S.L. Collins, personal communication). Initially, sites had considerable latitude in how they chose to present the conceptual framework motivating their LTER research, but the conceptual framework has attracted increasing attention from reviewers in the past decade.

Another example is the increased attention to the concept of “integration,” since its first appearance in the 2002 RFP, in renewal decisions for LTER sites. The LTER program has always emphasized integration of studies under a common overarching research theme or question(s). Nevertheless, in the past decade the term “integrate” proliferated in successive versions of the RFP, and lack of integration perceived by reviewers was a criterion in almost all (83%) of probation and termination decisions. Although the term “integrate” was largely erased from the 2020 RFP, increased attention of reviewers to conceptual frameworks and integration in the past decade is associated with declining use of the original review criteria for LTER sites in renewal decisions.

Continuity of leadership at NSF also appears to be an important factor influencing the evolution of the LTER program. During periods of sustained leadership lasting more than a decade, individual program officers in BIO/DEB (Tom Callahan, program officer from 1980–1994) and GEO/OCE (Dave Garrison, program officer

from 2004--2019) were associated with expanded numbers of LTER sites in these directorates. In contrast, a period of leadership transition with high turnover and multiple, short-term program officers in the past decade (2010--2018) coincided with multiple site probations and terminations of sites, all funded by BIO/DEB. The roles of NSF Division Directors may also have been crucial, but no data on this was available for this study. The LTER experience since 1990 suggests that sustained leadership of LTER programs within NSF is associated with continuity and expansion of the LTER program and LTER sites, while turnover is associated with site probations, terminations, and no net growth.

The research experiences and areas of expertise of individual LTER program officers may also have affected how the LTER program has changed over time. Program officers are responsible for establishing the wording of the RFPs, organizing review panels, evaluating panel summaries and midterm reviews, and ultimately making funding and renewal decisions (Fig. 3.6). Modification and updating of review criteria is part of due diligence on the part of program officers in response to evolving science or societal needs. Program officers' experience in, and attitudes toward, long-term ecological research influence their interpretation of the evolution of scientific understanding and priorities for the LTER program.

Changes in NSF procedures for the LTER renewal process also may have played a role in how the LTER program has evolved. In the first decade of the program, three sites were terminated without probation. The probation process was instituted in the second decade of the program as a means of protecting NSF's investment in long-term research. In multiple instances, sites corrected perceived problems and were renewed after probation, thus preserving and extending the long-term research at these sites. However, the probationary process requires submission of a second renewal proposal 2 years later to a new panel (and in recent years, responding to a significantly revised RFP). Data presented above demonstrate that the more renewal proposals a site submits, the higher is the chance of probation and termination. At some times in the past, when renewal proposals had minor deficiencies, NSF program officers have requested "addenda" (explanatory documents submitted by LTER PIs to program officers) as a means of clarifying issues with renewal proposals rather than placing the site on probation. However, this process has been little used in the past decade, when the rate of probation was higher than in previous decades.

Continuity and commitment to funding is an obvious factor influencing the changes over time in the LTER program. Decisions to allocate funding to long-term ecological research made at the level of NSF Directorates clearly influenced the composition of the LTER program over time. No data were available to explain why LTER funding expanded in the GEO Directorate after 1990, why funded LTER sites in the BIO Directorate decreased from 18 in the late 1980s to 13 as of 2018, or whether funding issues affected LTER sites (i.e., urban sites) with shared funding from several Directorates.

3.5 Conclusions and Implications for the Future of LTER

The history of the LTER program suggests that programs to support long-term ecological research must strike a balance between continuity and change. Continuity in science leadership, administration, and expectations is important, and at the same time research and administration must respond to ongoing changes in science, in ecosystems, and in the long-term study sites. Long-term ecological research spans periods of evolving scientific understanding and priorities. As long-term ecological research matures, the expectations for that research will also grow. If LTER continues into the future, there will continue to be turnover of LTER researchers and NSF personnel as well as evolution of research topics, conceptual frameworks, research methods, and information management technologies. In this changing environment, continuity in administration and expectations can be fostered through communication at four scales: long-term leadership and mentoring of leadership transitions within each LTER site; communication, collective memory, and mentoring within the LTER network; open discussion of LTER program history and management between LTER sites and NSF; and attention by NSF to continuity and experience of LTER program officers, LTER review criteria, and review processes.

At current (4th decade) rates of termination, especially of sites with long-term funding, the LTER program is on a path to lose many of its longest terrestrial ecosystem sites in the next few funding cycles. How will this affect the future of the LTER program and long-term ecological research in general? Alternatively, might NSF and LTER sites make adjustments that could protect the science community's investment in long-term research, at a time of heightened awareness of its value (Kuebbing et al. 2018) and influence (Hughes et al. 2017)?

Given the accelerated pace of environmental change, the need for long-term ecological research is even more urgent today than when NSF established the pioneering LTER program in 1980. LTER sites are valued not only for their novel research, which is critically evaluated in every proposal, but also for their long-term data on core research topics. Both are essential for documenting ecosystem responses to environmental change, for providing a means of predicting responses to future change, and as a basis for environmental policy. The context for, and lessons from, long-term ecological research continue to shift in response to environmental, social, and technological change. The NSF LTER program is designed to be able to respond to all of these drivers of change, through a process of 6-year grants that are renewed based on peer review. The LTER Program history reveals important lessons for how to structure and manage long-term ecological research.

Acknowledgements This work was supported by funding to the Andrews Forest LTER program (NSF 1440409). We thank J. Blair, S.L. Collins, L. M. DiGregorio, C.T. Driscoll, D.R. Foster, S.K. Hamilton, D. Reed, G.P. Robertson, E. Seabloom, F.J. Swanson, J. Van de Castle, and R.B. Waide for information and helpful comments on earlier drafts of this manuscript.

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