



United States Department of Agriculture

Agricultural  
Research  
Service

Technical  
Bulletin  
Number 1931

September 2013

# Long-Term Trends in Ecological Systems: A Basis for Understanding Responses to Global Change



## **Contents**

Contributors .....	VIII
Technical Consultants .....	X

### ***Introduction to Cross-Site Comparisons and History and Organization of the EcoTrends Project***

Chapter 1: Long-Term Trends in Ecological Systems: An Introduction to Cross-Site Comparisons and Relevance to Global Change Studies .....	1
Chapter 2: History and Organization of the EcoTrends Project .....	21

### ***Cross-Site Comparisons of Ecological Responses to Global Change Drivers***

Chapter 3: Cross-Site Comparisons of Ecological Responses to Climate and Climate-Related Drivers .....	28
Chapter 4: Cross-Site Comparisons of State-Change Dynamics .....	36
Chapter 5: Patterns of Net Primary Production Across Sites .....	42
Chapter 6: Cross-Site Comparisons of Precipitation and Surface Water Chemistry .....	46
Chapter 7: Cross-Site Comparisons of Ecological Responses to Long-Term Nitrogen Fertilization .....	51
Chapter 8: Long-Term Trends in Human Population Growth and Economy Across Sites .....	54
Chapter 9: Disturbance Regimes and Ecological Responses Across Sites .....	58
Chapter 10: Cross-Site Studies “By Design”: Experiments and Observations That Provide New Insights .....	72

### ***Long-Term Trends in Global Change Drivers and Responses at Site and Continental Scales***

Chapter 11: Long-Term Trends in Climate and Climate-Related Drivers .....	81
Chapter 12: Long-Term Trends in Precipitation and Surface Water Chemistry .....	115
Chapter 13: Long-Term Trends in Human Demography and Economy Across Sites .....	162
Chapter 14: Long-Term Trends in Production, Abundance, and Richness of Plants and Animals .....	191
Chapter 15: Management and Policy Implications of Cross- and Within-Site Long-Term Studies .....	206
Chapter 16: Recommendations for Data Accessibility .....	216
Chapter 17: Long-Term Research Across Sites, Ecosystems, and Disciplines: Synthesis and Research Needs .....	226

### ***Appendices***

Appendix 1: Site Descriptions .....	234
Appendix 2: Average (Standard Error) Maximum, Mean, and Minimum Air Temperature and Annual Precipitation at Each Site .....	312

Appendix 3: Average (Standard Error) Ice Duration, Sea Level, Streamflow, Water Clarity, and Water Temperature for Sites With Data .....	314
Appendix 4: Regression Coefficients and R <sup>2</sup> Values for Nine Climatic Variables for Which Linear Regression Against Time Is Significant ( $p < 0.05$ ) .....	316
Appendix 5: Annual Average (Standard Error) Nitrogen (as Nitrate) From Various Sources at Sites With Data .....	319
Appendix 6: Regression Coefficients and R <sup>2</sup> Values for Nitrogen (as Nitrate) From Various Sources for Which Linear Regression Against Time Is Significant ( $p < 0.05$ ) .....	321
Appendix 7: Annual Average (Standard Error) Nitrogen (as Ammonium) From Various Sources at Sites With Data .....	323
Appendix 8: Regression Coefficients and R <sup>2</sup> Values for Nitrogen (as Ammonium) From Various Sources for Which Linear Regression Against Time Is Significant ( $p < 0.05$ ) .....	325
Appendix 9: Annual Average (Standard Error) Sulfur (as Sulfate) From Various Sources at Sites With Data .....	326
Appendix 10: Regression Coefficients and R <sup>2</sup> Values for Sulfur (Sulfate) From Various Sources for Which Linear Regression Against Time Is Significant ( $p < 0.05$ ) .....	328
Appendix 11: Annual Average (Standard Error) Chloride From Various Sources at Sites With Data ..	330
Appendix 12: Regression Coefficients and R <sup>2</sup> Values for Chloride From Various Sources for Which Linear Regression Against Time Is Significant ( $p < 0.05$ ) .....	332
Appendix 13: Annual Average (Standard Error) Calcium From Various Sources at Sites With Data ...	334
Appendix 14: Regression Coefficients and R <sup>2</sup> Values for Calcium From Various Sources for Which Linear Regression Against Time Is Significant ( $p < 0.05$ ) .....	336
Appendix 15: Human Population and Economy Variables in 2000 for the Focal County of Each Site, as Grouped by Ecosystem Type .....	338
Appendix 16: Annual Average (Standard Error) Aboveground Net Primary Production (ANPP) at Sites With Data .....	341
Appendix 17: Other Measures of Average (Standard Error) Terrestrial Production at Sites With Data..	343
Appendix 18: Average (Standard Error) Aquatic Production at Sites With Data .....	344
Appendix 19: Average (Standard Error) Biomass of Primary Producers (Plants, Algae) for Sites With Data .....	345
Appendix 20: Average (Standard Error) Plant Species Richness for Sites With Data .....	347
Appendix 21: Average (Standard Error) Animal Abundance for Sites With Data .....	349
Appendix 22: Average (Standard Error) Animal Species Richness for Sites With Data .....	352
Appendix 23: Regression Coefficients and R <sup>2</sup> Values for Plant and Animal Variables for Which Linear Regression of Each Variable Against Time Is Significant ( $p < 0.05$ ) and the Trend Appears Linear .....	353
Appendix 24: Lead Principal Investigator(s) (PI), Information Managers (IM), and Administrative Program of the LTER Programs .....	355
Appendix 25: Researchers Involved in the EcoTrends Project at Non-LTER Sites .....	359

Appendix 26: List of Stations and Length of Record for Each Climate Variable by Site .....	362
Appendix 27: List of Stations and Length of Record for Each Precipitation or Surface Water Chemistry Variable by Site .....	367
Appendix 28: List of Stations and Length of Record for Each Plant and Animal Variable by Site, as Grouped by Ecosystem Type .....	371
Index .....	i

Appendix 15. Human population and economy variables in 2000 for the focal county of each site, as grouped by ecosystem type

Site code	Focal county	Total population	Population density	Urban population	Employment by sector							
					Commercial <sup>1</sup>	Farming <sup>2</sup>	Manufacturing <sup>3</sup>	Service <sup>4</sup>				
#/km <sup>2</sup>												
% total population												
<b>Alpine and arctic</b>												
ARC	North Slope, AK	7,385	0	59	4.6	0.0	-	7.3				
GLA	Albany, WY	32,014	3	88	5.7	0.5 <sup>2</sup>	1.3	6.1 <sup>4</sup>				
LWV	Larimer, CO	251,494	37	86	7.1	0.3 <sup>2</sup>	3.6	4.7 <sup>4</sup>				
MCM	-	-	-	-	-	-	-	-				
NWT	Boulder, CO	291,288	152	91	8.4	0.1	5.6	6.7				
<b>Aridlands</b>												
EOA	Haney, OR	7,609	0	57	4.4	3.8 <sup>2</sup>	4.2 <sup>3</sup>	2.3 <sup>4</sup>				
JRN	Dona Ana, NM	174,682	18	80	4.4	0.4	1.1	7.1				
RCE	Owyhee, ID	10,644	1	26	3.6	4.6 <sup>2</sup>	5.6	1.1 <sup>4</sup>				
SEV	Socorro, NM	18,078	1	47	2.9	0.8	0.6 <sup>3</sup>	7.0				
SRE	Pima, AZ	843,746	36	92	6.1	0.1	1.9	4.1 <sup>4</sup>				
WGE	Santa Cruz, AZ	38,381	12	68	11.3	0.3 <sup>2</sup>	1.9 <sup>3</sup>	3.8 <sup>4</sup>				
<b>Coastal</b>												
CCE	San Diego, CA	2,813,833	259	96	6.3	0.1	2.7	7.1				
FCE	Miami-Dade, FL	2,253,362	447	99	8.4	0.1	2.3	6.9				
GCE	McIntosh, GA	10,847	10	26	7.2	0.1	3.3 <sup>3</sup>	7.2				
MCR	-	-	-	-	-	-	-	-				
PAL	-	-	-	-	-	-	-	-				
PIE	Essex, MA	723,419	558	95	7.0	0.0	5.1	6.6				
SBC	Santa Barbara, CA	399,347	56	95	6.0	0.3	2.1	7.7				
VCR	Northampton, VA	13,093	24	-	4.5	0.7	10.7 <sup>3</sup>	7.9				

## Long-Term Trends in Ecological Systems:

**Appendix 15. Human population and economy variables in 2000 for the focal county of each site, as grouped by ecosystem type—  
*Continued***

A Basis for Understanding Responses to Global Change

Site code	Focal county	Total population	Population density	Urban population	Employment by sector							
					Commercial <sup>1</sup>	Farming <sup>2</sup>	Manufacturing <sup>3</sup>	Service <sup>4</sup>				
#/km <sup>2</sup>												
% total population												
<b>Eastern forests</b>												
BEN	Buncombe, NC	206,330	122	71	6.7	0.1	7.8 <sup>3</sup>	7.6				
CRO	Ashley, AR	24,209	10	49	4.0	0.7 <sup>2</sup>	13.4	1.2 <sup>4</sup>				
CWT	Macon, NC	29,811	22	19	6.6	0.2	4.1	6.7				
FER	Tucker, WV	7,321	7	—	3.6	0.4	5.2 <sup>3</sup>	9.1				
HAR	Harrison, MS	189,601	126	79	6.9	0.1 <sup>2</sup>	1.9	5.3 <sup>4</sup>				
HBR	Grafton, NH	81,743	18	35	8.9	0.2	6.4	8.3				
HFR	Worcester, MA	750,963	192	81	6.5	0.1	5.3	6.8				
LUQ	Rio Grande, PR	52,362	333	96	1.7	—	2.8	4.6				
MAR	Itasca, MN	43,992	6	19	6.4	0.4 <sup>2</sup>	4.5	3.2 <sup>4</sup>				
NTL	Dane, WI	426,526	137	85	9.8	0.4	4.6	7.4				
SAN	Berkeley, SC	142,651	50	66	3.1	0.1 <sup>2</sup>	3.3	1.7 <sup>4</sup>				
TAL	Lafayette, MS	38,744	24	50	6.0	0.4 <sup>2</sup>	4.5	4.5 <sup>4</sup>				
WBW	Roane, TN	51,910	56	51	4.3	0.4 <sup>2</sup>	3.2	2.1 <sup>4</sup>				
<b>Temperate grasslands and savannas</b>												
CDR	Anoka, MN	298,084	271	86	6.4	0.1	6.0	6.6				
FTK	Custer, MT	11,696	1	83	7.8	2.2 <sup>2</sup>	0.9 <sup>3</sup>	5.4 <sup>4</sup>				
GRL	Grady, OK	45,516	16	34	4.7	1.8 <sup>2</sup>	5.4	2.2 <sup>4</sup>				
GSW	Bell, TX	237,974	87	82	4.6	0.3 <sup>2</sup>	2.6	3.0 <sup>4</sup>				
KBS	Kalamazoo, MI	238,603	164	80	9.3	0.1	6.7	7.9				
KNZ	Riley, KS	62,843	40	85	6.0	0.6	0.7	8.8				
SGS	Weld, CO	180,936	18	72	5.4	0.9	4.7	7.1				
SPR	Woodward, OK	18,486	6	60	7.6	2.1 <sup>2</sup>	2.1	3.3 <sup>4</sup>				
<b>Urban</b>												
BES	Baltimore City, MD <sup>5</sup>	651,154	3,104	100	5.5	0.0	3.2	7.9				
CAP	Maricopa, AZ	3,072,149	129	97	7.4	0.1	3.2	6.8				

**Appendix 15. Human population and economy variables in 2000 for the focal county of each site, as grouped by ecosystem type—Continued**

Site code	Focal county	Total population	Population density	Urban population	Employment by sector		
					Commercial <sup>1</sup>	Farming <sup>2</sup>	Manufacturing <sup>3</sup>
<i>Western forests</i>							
AND	Lane, OR	322,959	27	81	7.8	0.2	4.6
BLA	Lassen, CA	33,828	3	41	3.2	0.6 <sup>2</sup>	2.1 <sup>3</sup>
BNZ	Fairbanks North Star, AK	82,840	4	70	6.4	0.1	0.4 <sup>3</sup>
CHE	Tillamook, OR	24,262	9	24	4.9	1.2 <sup>2</sup>	4.5
CSP	Mendocino, CA	86,265	10	54	6.7	0.7 <sup>2</sup>	3.8
FRA	Grand, CO	12,442	3	0	6.8	1.1 <sup>2</sup>	1.1 <sup>3</sup>
PRI	Bonner, ID	36,835	8	23	7.6	0.8 <sup>2</sup>	4.6
WIN	Skamania, WA	9,872	2	0 <sup>6</sup>	1.5	0.3 <sup>2</sup>	4.6 <sup>3</sup>
<i>% total population</i>							
							2.4 <sup>4</sup>

<sup>1</sup> Data from 1997. The 1997 total population size is interpolated from long-term data for the county.<sup>2</sup> With footnote, data are from 1992; without footnote, data are from 2000. The 1992 total population size is interpolated from long-term data for the county.<sup>3</sup> With footnote, data are from 1992; without footnote, data are from 1997. The 1992 and 1997 total population sizes are interpolated from long-term data for the county.<sup>4</sup> With footnote, data are from 1997; without footnote, data are from 2000. The 1997 total population size is interpolated from long-term data for the county.<sup>5</sup> The focal county is Baltimore City, not Baltimore County.<sup>6</sup> Percentage of urban population in 1990, not 2000.

- No available data.